

NM1-62

**Permit
Application**

**Volume 3
Part 2 of 3**

**APPLICATION FOR PERMIT
SUNDANCE WEST**

**VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 4: HELP MODEL**

ATTACHMENT III.4.D

HELP MODEL INPUT AND OUTPUT FILES: CD-ROM

**APPLICATION FOR PERMIT
SUNDANCE WEST**

**VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 5: PIPE LOADING CALCULATIONS**

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LIST OF ATTACHMENTS

Attachment No.	Title
III.5.A	QIAN, XUEDE; KOERNER, ROBERT M.; AND GRAY, DONALD H. 2002. <i>GEOTECHNICAL ASPECTS OF LANDFILL DESIGN AND CONSTRUCTION</i> . NEW YORK: PRENTICE HALL
III.5.B	SHARMA, HARI .D. AND SANGEETA P. LEWIS. 1994. <i>WASTE CONTAINMENT SYSTEMS, WASTE STABILIZATION AND LANDFILLS: DESIGN AND EVALUATION</i> . NEW YORK: JOHN WILEY AND SONS
III.5.C	WASHINGTON STATE DEPARTMENT OF ECOLOGY. 1987. <i>SOLID WASTE LANDFILL DESIGN MANUAL</i> . WASHINGTON: WDOE
III.5.D	POLY PIPE INDUSTRIES, INC. 2008. <i>DESIGN AND ENGINEERING GUIDE FOR POLYETHYLENE PIPING</i> . WWW.PLASTICPIPE.ORG
III.5.E	DRISCOPIPE, INC. 2008. <i>POLYETHYLENE PIPING SYSTEMS MANUAL</i>
III.5.F	CHEVRON PHILLIPS CHEMICAL COMPANY, LP. 2003. <i>PERFORMANCE PIPE ENGINEERING MANUAL</i> . BULLETIN: PP 900

**APPLICATION FOR PERMIT
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SECTION 5: PIPE LOADING CALCULATIONS**

1.0 INTRODUCTION

Sundance West (Sundance West Facility) is a proposed Surface Waste Management Facility for oil field waste processing and disposal services. The proposed Sundance West Facility is subject to regulation under the New Mexico Oil and Gas Rules, specifically 19.15.36 NMAC, administered by the Oil Conservation Division (OCD). The Facility has been designed in compliance with 19.15.36 NMAC, and will be constructed and operated in compliance with a Surface Waste Management Facility Permit issued by the OCD. The Facility is owned by, and will be constructed and operated by, Sundance West, Inc.

1.1 Description

The Sundance West site is comprised of a 320-acre \pm tract of land located approximately 3 miles east of Eunice, 18 miles south of Hobbs, and approximately 1.5 miles west of the Texas/New Mexico state line in the South $\frac{1}{2}$ of Section 30, Township 21 South, Range 38 East, Lea County, New Mexico (NM). Site access will be provided via NM 18 and Wallach Lane. The Sundance West Facility will include two main components; a liquid oil field waste Processing Area (80 acres \pm), and an oil field waste Landfill (120 acres \pm). Oil field wastes are anticipated to be delivered to the Sundance West Facility from oil and gas exploration and production operations in southeastern NM and west Texas. The Site Development Plan provided in the **Permit Plans, Volume III.1**, identifies the locations of the Processing Area and Landfill facilities.

2.0 DESIGN CRITERIA

The leachate collection system piping for the Sundance West Facility is designed to meet the requirements of the regulatory standards identified in the New Mexico Oil Conservation Division (OCD) Rules 19.15.36 NMAC. More specifically, 19.15.36.14.C.(3) NMAC requires that the leachate collection pipe be able to:

“...[withstand] structural loading and other stresses and disturbances from overlying oil field waste, cover materials, equipment operation, expansion or contraction...”

The purpose of these calculations is to confirm that high-density polyethylene (HDPE) standard dimension ration (SDR) 11.0 solid and perforated piping incorporated into the landfill design will remain intact after placement of waste fill and retain its required characteristics after exposure to operating equipment and long term stresses (see **Figure III.5.1**). The basic design approach consists of calculating the deflection on the leachate collection pipe, which cannot exceed its allowable value, with a minimum factor of safety against failure of 1.0.

**TABLE III.5.1
HDPE Pipe Specification
Sundance West**

Characteristic	6” Diameter Leachate Collection Pipes
	HDPE
Dimension Ratio	11.0
Method of Joining	Welded
Manning’s Number (n)	0.010
Outside Diameter (in)	6.625
Min. Wall Thickness (in)	0.602
Nominal Weight/ft (lb/ft)	4.971
Tensile Strength (psi)	5,000
Modulus of Elasticity (psi)	35,000
Flexural Strength (psi)	135,000

Information listed in **Table III.5.1** is provided in **Attachment III.5.E**.

3.0 PIPE STRENGTH CALCULATIONS

3.1 6-Inch SDR 11.0 HDPE Pipe

In order to determine the capability of 6-inch HDPE SDR 11.0 perforated collection pipes to withstand maximum stresses from the overlying soil profile, the pipes were analyzed for adequate protection against ring deflection and wall buckling using **Attachment III.5.E**, Driscopipe, Inc., Polyethylene Piping Systems Manual.

Wall buckling occurs if the total external soil pressure exceeds the pipe-soil system’s critical buckling pressure; and excessive ring deflection occurs if the vertical strain in the surrounding soil envelope is greater than the allowable ring deflection of the pipe. SDR 11.0 HDPE pipe has been found to be equivalent or better than PVC piping in landfill leachate pipe

applications (i.e., greater resistance to buckling and crushing) and therefore was selected for this design. SDR stands for standard dimension ratio which is the ratio of the outside pipe diameter to the pipe wall thickness $SDR = OD/t$. As the SDR gets smaller the thickness of the pipe wall is increased. Characteristics of the SDR 11.0 pipe is made in **Table III.5.1**.

3.1.1 6-Inch Diameter SDR 11.0 HDPE Pipe Dimensions (Attachment III.5.D):

- Pipe nominal diameter: 6-inches
- Pipe Outside Diameter (OD): 6.625-inches
- Pipe Wall Thickness (t): 0.602 inches
- Pipe Inner Diameter (ID): 5.421 inches
- SDR : 11.0
- Perforation/ft: 9 perforation holes
- Perforation Hole Diameter (in) 0.5 inch

3.1.2 Loads Acting on the Leachate Collection Pipe

To calculate the total vertical load on the pipes, P_T , the pressure from each overlying layer was calculated and summed. The greatest waste depth occurs in Unit 2 at station 10+60 on cross section A-A' (**Figure III.5.1**). There will be five layers: a 3 foot final cover, 1 foot thick intermediate cover, 159.69 feet of waste, 2 feet of protective soil layer, and a leachate collection gravel layer that is 1 ft thick. Based on the known thickness of each layer and assigned unit weights, the pressure that will be exerted by each layer was calculated. The results for P_T are presented in **Table III.5.2**.

**TABLE III.5.2
Pipe Loading Parameters
Sundance West**

Layer	Thickness (feet)	Unit Weight (pcf)	Actual Load (psf)
Final Cover Soil	3.0	105	315.0
Intermediate Cover Soils	1.0	105	105.0
Waste	159.69	74	11,817.06
Protective Soil Layer	2.0	105	210.0
Drainage Rock above Pipe	1.0	130	130.00
		TOTAL:	12,577.06 psf (87.34 psi)

3.1.3 Correction of Load on Pipe with Perforations (HDPE SDR 11.0)

Perforating pipes reduces the effective length of pipe available to carry loads and resist deflection. The effect of perforations can be taken into account by using an increased load per nominal unit length of the pipe, the increased vertical load per unit length of pipe.

Vertical Load per Unit Length of Pipe:

$$W_C = (P_T)(D_o) / (1 - ((n)(d)/12)) \quad (\text{Attachment III.5.A, p. 306})$$

Where: P_T = Design load (psi)
 D_o = Outside Diameter of the Pipe (inches)
 n = number of perforated holes per foot of pipe
 d = diameter of perforated hole on the pipe (inches)

$$W_C = [(87.34 \text{ psi})(6.625)] / [1 - ((12)(0.5 \text{ in}) / 12)]$$

$$W_C = [(87.34 \text{ psi})(6.625)] / 0.5$$

$$W_C = 1,157.26 \text{ lbs/in} = 13,887.12 \text{ lbs/ft}$$

The design value in psi is found by dividing the design load in lbs/in by the diameter of pipe.
 $P_D = 1,157.26 / 6 = 192.88 \text{ psi}$.

3.1.4 Deflection

The ring deflection of the pipe can be calculated from the following:

$$\Delta X = \left(\frac{(D_L)(K)(W_c)(r^3)}{(E)(I) + 0.061(E')(r^3)} \right)$$

Where: W_C = Vertical load per unit length of pipe, lb/in = 1,157.26 ppi
 ΔX = Ring deflection (in.)
 D_L = Deflection lagging factor = 1.0 for Prism Loads (**Attachment III.5.A, Page 307**)
 E = Modulus of elasticity = 35,000 psi (**Attachment III.5.E, Page 43**)
 E' = Soil modulus = 3,000 psi (**Attachment III.5.A, Page 307**)
 K = Bedding factor = 0.083 (**Attachment III.5.A, Page 306**)
 r = Pipe Radius = 3.01 in
 I = Moment of Inertia = $t^3/12$ (in⁴/in) where t = wall thickness = 0.602 inches

Ultimate degree of compaction and E' will increase as waste is placed over the leachate trench resulting in at least 3,000 psi for the modulus of passive soil resistance.

$$\Delta X = \left(\frac{(1.0)(0.083)(1,157.26)(3.01^3)}{(35,000)(0.0182) + 0.061(3,000)(3.01^3)} \right) = 0.465in$$

The ring deflection is then used to determine the ring bending strain using the equation:

$$\varepsilon = f_D \left(\frac{\Delta x}{D_M} \right) \left(\frac{2C}{D_M} \right)$$

Where: ε = Wall strain
 f_D = deformation shape factor = 6.0 (**Attachment III.5.F, page 112**)
 Δx = Deflection From previous calculation
 D_M = Mean Diameter, in
 C = Distance from outer fiber to wall centroid, in

$C = 0.5(1.06t)$, where t = wall thickness

$C = 0.5 \times 1.06 \times 0.602 = 0.3191$ in

$$\varepsilon = (6.0) \left(\frac{0.465}{6} \right) \left(\frac{2(0.3191)}{6} \right) = 0.050 = 5.0\%$$

The wall strain of 5.0% is less than 8%, which has an acceptable factor of safety of $8\%/5.0\% = 1.60$ (**Attachment III.5.F, page 112**).

3.1.5 Wall Buckling

Wall buckling may govern design of flexible pipes under conditions of loose soil burial, if the external load exceeds the compressive strength of the pipe material. To determine a factor of safety for wall buckling the pipe critical-collapse differential pressure P_c must be calculated using the following formula (**Attachment III.5.E, p. 43**):

$$P_c = \frac{2.32(E)}{SDR^3} \text{ where } E \text{ is the modulus of elasticity, approximately } 35,000 \text{ psi}$$

$$P_c = \frac{2.32(35,000)}{11.0^3} = 61.01psi$$

The critical-collapse pressure can then be used to determine the critical buckling pressure from the following relation:

$$P_{cb} = 0.8\sqrt{(E')(P_c)} \quad \text{where } P_{cb} = \text{Critical buckling pressure, } E' = \text{Long term degree of compaction of bedding} = 3,000 \text{ psi (Attachment III.5.E, p. 43)}$$

$$P_{cb} = 0.8\sqrt{(3,000)(61.01)} = 342.26 \text{ psi}$$

The factor of safety is then determined:

$$FS = \frac{P_{cb}}{P_D} = \frac{342.26}{192.88} = 1.77$$

3.1.6 Wall Crushing

To determine a factor of safety for wall crushing the following equations were used (Attachment III.5.E, p. 42):

$$S_A = \frac{(SDR - 1)}{2} \times P_D$$

Where: S_A = Actual compressive stress, psi
 P_D = Total external pressure on the top of the pipe, psi
 $P_D = W_c/D = 1,157.26/6 = 192.88$ psi

For a SDR of 11.0 the actual compressive stress is:

$$S_A = \frac{(11.0 - 1)}{2} \times 192.88 = 964.40 \text{ psi}$$

The factor of safety can then be found using the compressive yield strength of HDPE pipe of 1,500 psi:

$$FS = \frac{1,500 \text{ psi}}{964.40 \text{ psi}} = 1.56$$

3.1.7 Equipment Loading

Worst-case conditions would include a piece of equipment operating over the leachate collection pipe after 2 feet of protective soil layer has been placed. A loaded CAT 627 Scraper was used conservatively as the piece of equipment operating on top of the leachate collection

pipe. The CAT 627 Scraper has the following specifications (Reference Caterpillar Performance Handbook, Edition 29):

- Tractor Weight = 48,061 lbs
- Scraper Weight = 33,399 lbs
- Soil Load (20 cy) = 48,000 lbs
- Total weight = 129,460 lbs
- Max weight per tire = 33,012 lbs (assumes 49% of the total weight acts on the rear tires and 51% of the weight acts on the front tires).
- Tire width = approximately 18 inches = 1.5 feet
- Tire contact length = approximately 4 inches = 0.33 feet
- Tire contact area = (18 inches)(4 inches) = 72 in² = 0.50 ft²

Superimposed loads distributed over an area during equipment operations are determined from the following equation (ASCE, 1982):

$$W_{SD} = (C_s)(p)(F)(B_c)$$

Where: W_{SD} = Load on pipe (lbs/ft)
 p = Intensity of distributed load (lbs/ft²)
 F = Impact factor
 B_c = Outside diameter of pipe (ft)
 C_s = Load coefficient

The load coefficient is a function of $D/2H$ and $M/2H$, in which H is the height from the top of the pipe to the ground surface (3 feet) and D and M are the width and length, respectively, or the area over which the distributed load acts. Table 4C.3, **Attachment III.5.E, p. 4C-16**, lists values of the load coefficients for loads centered over the pipe.

Determining the required parameters:

$$\begin{aligned} H &= 3 \text{ feet} \\ D &= 1.5 \text{ feet} \\ M &= 0.33 \text{ feet} \\ F &= 1.0 \text{ (Table 4C.4, Attachment III.5.E, p. 4C-17)} \\ B_c &= 6.625 \text{ inches} = 0.55 \text{ feet} \\ D/2H &= 1.5 \text{ feet} / (2(3 \text{ feet})) = 0.25 \\ M/2H &= 0.33 \text{ feet} / (2(3 \text{ feet})) = 0.055 \\ p &= 33,012 \text{ lbs} / (1.5 \text{ feet})(0.33 \text{ feet}) = 66,691 \text{ lbs/ft}^2 \\ C_s &\sim 0.053 \text{ per Table 4C.3, Attachment III.5.E, p. 4C-16} \end{aligned}$$

Therefore:

$$W_{SD} = (0.053)(66,691 \text{ lbs/ft}^2)(1.0)(0.55 \text{ feet})$$

$$W_{SD} = 1,944.0 \text{ lbs/ft} = 162.0 \text{ lbs/in}$$

The superimposed load due to equipment loading is less than static loading conditions (W_C); therefore the static loading conditions govern.

3.1.8 HDPE Pipe Loading Results

Calculations for ring deflection, wall crushing, wall buckling, due to dead and live loading stresses for the proposed 6-inch laterals were completed and the following table summarizes the results.

Table III.5.3
SDR 11.0 HDPE Pipe Results
Sundance West

DESIGN CRITERIA	CRITICAL VALUE	ACTUAL VALUE	FACTOR OF SAFETY
Dead Load Only			
Ring Deflection	8.0 %	5.0 %	1.60
Wall Buckling	342.26 psi	192.88 psi	1.77
Wall Crushing	1500 psi	964.40 psi	1.56

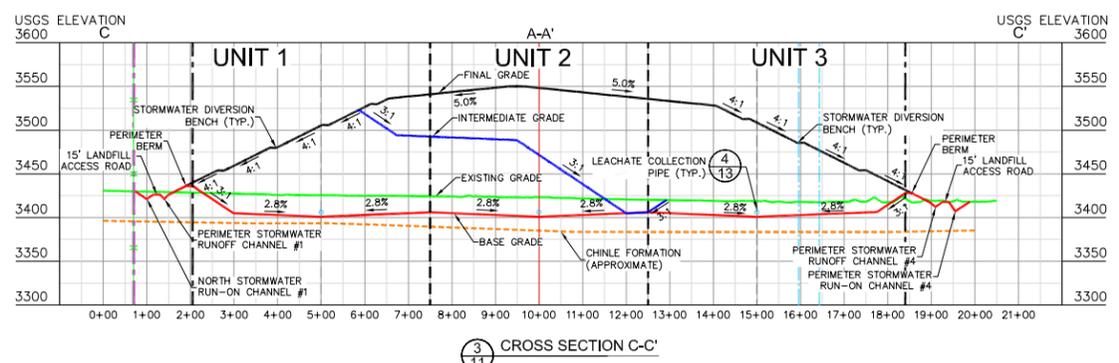
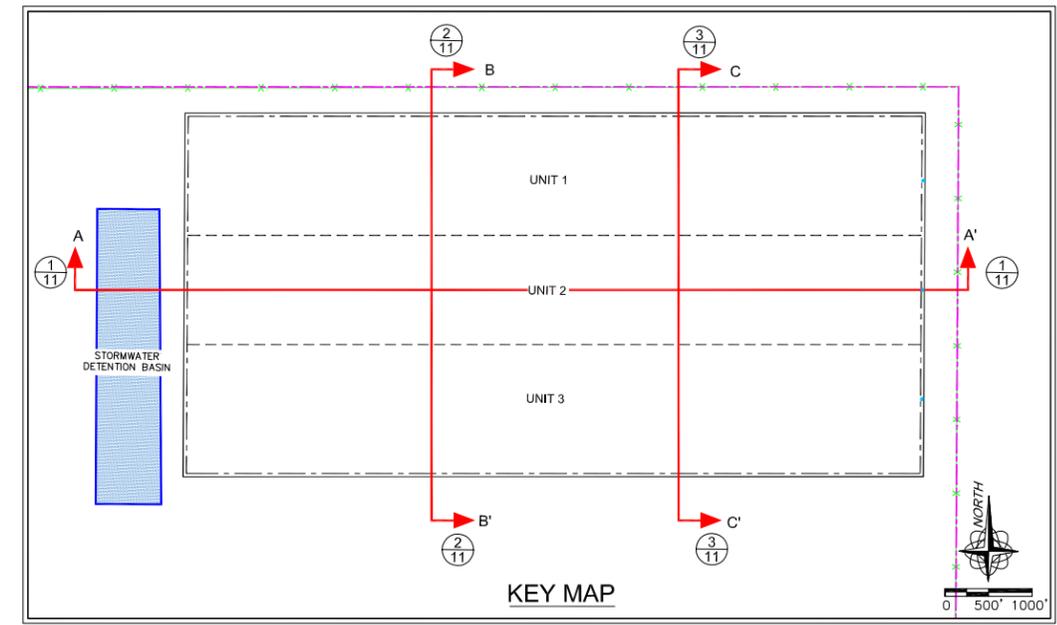
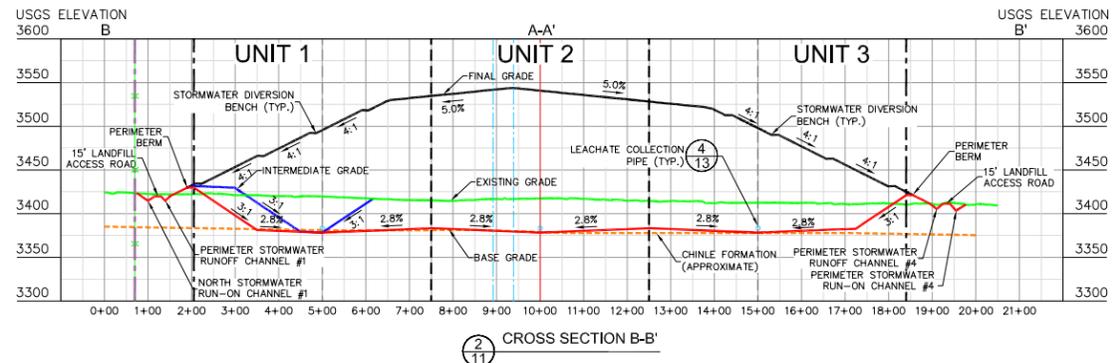
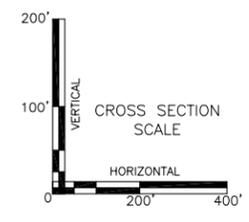
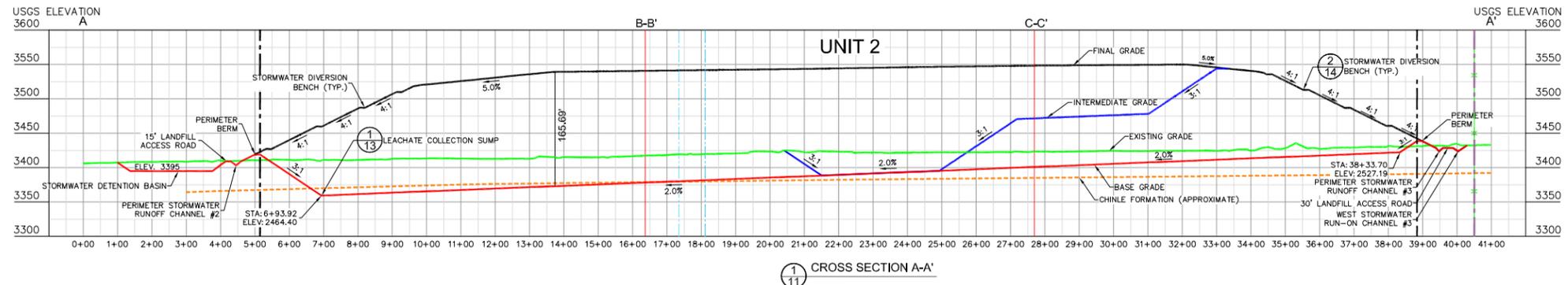
As shown, for each limiting design criterion, the factor of safety is greater than design criteria, thus the performance standard for the HDPE pipes is more than adequate.

4.0 REFERENCES

Leachate pipe strength calculations were completed using guidelines provided on **Table III.5.4**.

TABLE III.5.4
Leachate Pipe Strength References
Sundance West

- A. “Geotechnical Aspects of Landfill Design and Construction”, Xuede Qian, Robert M. Koerner, Donald H. Gray, Prentice Hall, 2002.
- B. “Waste Containment Systems, Waste Stabilization, and Landfills” Hari D. Sharma and Sangeeta P. Lewis. John Wiley & Sons, 1994.
- C. WDOE Landfill Design Manual, 1987
- D. “Design and Engineering Guide for Polyethylene Piping”, Poly Pipe Industries, Inc, 2008
- E. “Polyethylene Piping Systems Manual”, Driscopipe, Inc., 2008
- F. Chevron Phillips, “Bulletin: PP 900”, Book 2 – Chapter 7, p. 112, 2003



- LEGEND**
- FACILITY BOUNDARY
 - FENCE
 - UNIT BOUNDARY
 - LIMIT OF WASTE
 - FINAL GRADE
 - INTERMEDIATE GRADE (EAST PHASE DEVELOPMENT)
 - EXISTING GRADE
 - BASE GRADE
 - CHINLE FORMATION (APPROXIMATE)
 - EXISTING WATER SERVICE PIPELINE
 - PIPELINE EASEMENT
 - LEACHATE COLLECTION PIPE
 - DETAIL NUMBER
DETAIL LOCATED ON SHEET NUMBER
 - CROSS SECTION LOCATION
 - STORMWATER DETENTION BASIN

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UPDATED: AUGUST, 2016

LANDFILL CROSS SECTIONS

SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

Gordon Environmental, Inc.
Consulting Engineers

213 S. Camino del Pueblo
Bernalillo, New Mexico, USA
Phone: 505-867-6990
Fax: 505-867-6991

DATE: 08/02/2016
DRAWN BY: DMI
APPROVED BY: IKG

CAD: 11 X SECTIONS.dwg
REVIEWED BY: CWF
get@gordonenvironmental.com

PROJECT #: 530,06,01
FIGURE III.5.1

**APPLICATION FOR PERMIT
SUNDANCE WEST**

**VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 5: PIPE LOADING CALCULATIONS**

ATTACHMENT III.5.A

**QIAN, XUEDE; KOERNER, ROBERT M.; AND GRAY, DONALD H. 2002.
GEOTECHNICAL ASPECTS OF LANDFILL DESIGN AND CONSTRUCTION.
NEW YORK: PRENTICE HALL**

GEOTECHNICAL ASPECTS OF LANDFILL DESIGN AND CONSTRUCTION

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Number of Perforation Holes:

$$\begin{aligned}
 N &= Q_{in}/Q_b & (9.12) \\
 &= 0.0002184/0.00002114 \\
 &= 10.35 \text{ holes/ft (34 holes/m)}
 \end{aligned}$$

So, use 12 holes/ft (40 holes/m); that is 6 holes per foot (20 holes per meter) each side as shown in Figure 9.3.

9.4 DEFORMATION AND STABILITY OF LEACHATE COLLECTION PIPE

All components of the leachate collection and removal system must have sufficient strength to support the weight of the overlying waste, cover system, and post-closure loadings, as well as the stresses from operating equipment. The component that is perhaps the most vulnerable to compressive strength failure is the drainage layer piping. Leachate collection and removal system piping can fail by excessive deflection, which may lead to buckling or collapsing. Pipe strength calculations should include resistance to pipe deflection and critical buckling pressure. This situation is heightened by the current tendency to create extremely large landfills, sometimes called “megafills.”

9.4.1 Pipe Deflection

Leachate collection pipes may excessively deform during construction, during the active life of the landfill or under the post-closure loading. This deformation may lead to buckling and eventual collapse. Thus, leachate pipes should be handled carefully and brought on site only when the trench is ready. Passage of heavy equipment directly over a pipe must be avoided. A pipe can be installed in either a positive or negative projection mode. However, every effort should be made to install it in a negative projection mode (Figure 9.2), although at times it may be necessary to install a pipe in a positive projecting mode (Figure 9.5). The essential difference between these two con-

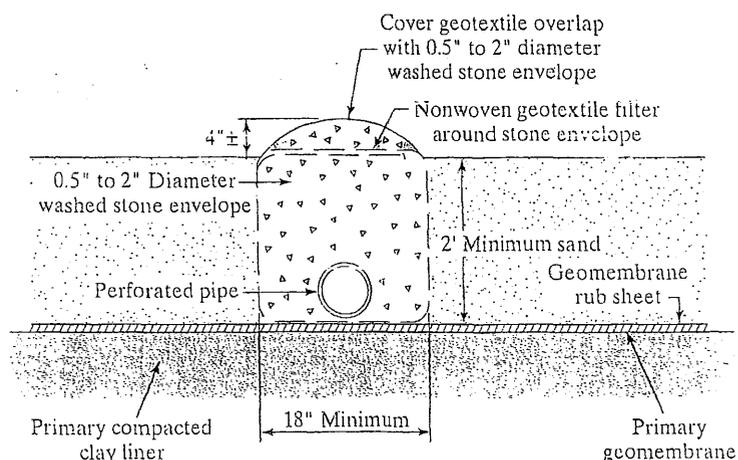


FIGURE 9.5 Leachate Collection Pipe in a Positive Projection Mode

cepts is that a negative projection allows for soil arching which limits the load on the pipe. Conversely, positive projection can actually add load to the pipe. Spangler (1960), among others, explains these concepts for deeply buried pipelines. The design of a pipe must be checked to ascertain whether it will be able to withstand the load during both preconstruction and postconstruction periods. Usually one of two types of pipes are used, HDPE or PVC. These are considered as flexible type pipes. This infers that they do not rupture or break under excessive load, they deform, and if excessively, buckle and/or collapse. The basic design approach consists of calculating the deflection of the pipe, which should not exceed the allowable value. The following formula, commonly known as the Modified Iowa formula, can be used to estimate pipe deflection (Spangler and Handy, 1973; Moser, 1990).

Modified Iowa Formula:

$$\Delta X = \frac{D_L \cdot K \cdot W_c \cdot r^3}{E \cdot I + 0.061 E' \cdot r^3} \tag{9.16}$$

where ΔX = horizontal deflection, in or m (Figure 9.6);

K = bedding constant, its value depending on the bedding angle (see Table 9.1 and Figure 9.7); also, as a general rule, a value of $K = 0.1$ is assumed;

D_L = deflection lag factor (see Table 9.2);

W_c = vertical load per unit length of the pipe, lb/in or kN/m;

r = mean radius of the pipe, $r = (D_o - t)/2$, in or m;

E = elastic modulus of the pipe material, lb/in² or kN/m²;

I = moment of inertia of the pipe wall per unit length,

$$I = t^3/12, \text{ in}^4/\text{in} = \text{in}^3 \text{ or } \text{m}^4/\text{m} = \text{m}^3;$$

t = thickness of pipe, in or m; and

E' = soil reaction modulus, lb/in² or kN/m², see Table 9.3.

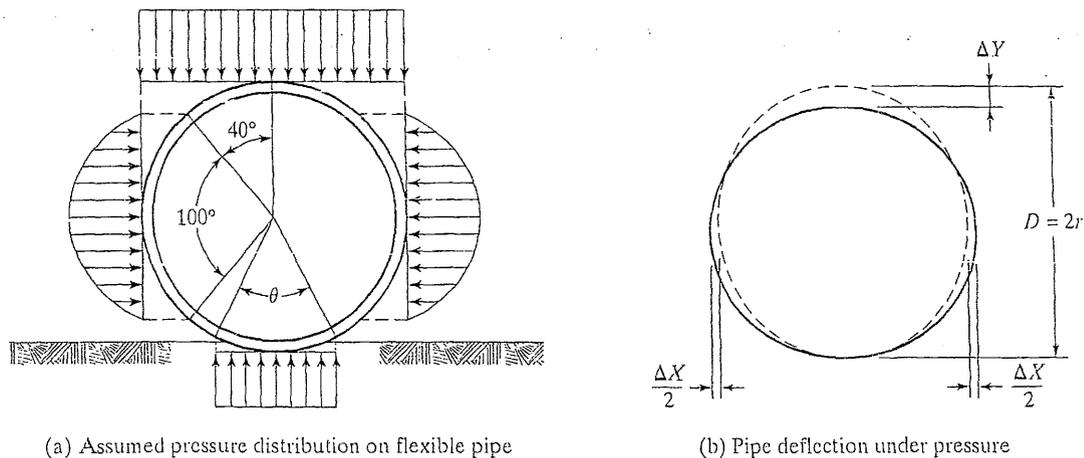


FIGURE 9.6 Buried Flexible Pipe

TABLE 9.1 Values of Bedding Constant, K

Bedding Angle, θ (degree)	Bedding Constant, K
0	0.110
30	0.108
45	0.105
60	0.102
90	0.096
120	0.090
180	0.083

The deflection of the pipe, ΔX , calculated from Equation 9.16 is the deflection in the horizontal direction, as shown in Figure 9.6. When the deflection of pipe is not large (e.g., less than 10%), the vertical deflection of pipe, ΔY , is usually assumed to be approximately equal to the horizontal deflection of pipe, ΔX .

Vertical Load per Unit Length of Pipe:

For Solid Pipe,

$$W_c = (\sum \gamma_i \cdot H_i) \cdot D_o \quad (9.17)$$

where W_c = vertical load per unit length of the pipe, lb/in or kN/m;
 γ_i = unit weight of material i on the pipe (sand, clay or solid waste),
 lb/in³ or kN/m³;
 H_i = thickness of material i , in or m; and
 D_o = outside diameter of the pipe, in or m.

For Perforated Pipe,

$$W_c = \frac{(\sum \gamma_i \cdot H_i) \cdot D_o}{(1 - n \cdot d/12)} \quad (9.18)$$

where W_c = vertical load per unit length of the pipe, lb/in or kN/m;
 γ_i = unit weight of material i (soils or solid waste), lb/in³ or
 kN/m³;
 H_i = thickness of material i , in or m;
 D_o = outside diameter of the pipe, in or m;
 d = diameter of perforated hole or width of perforated slot on the pipe, in
 or m; and
 n = number of perforated holes or slots per row per foot of pipe.

FIGURE 9.7 Pipe Bedding Angle

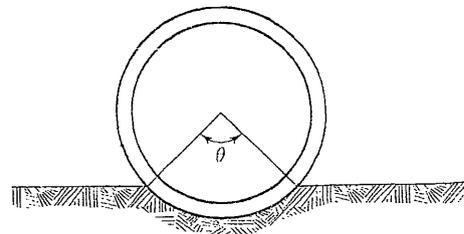


TABLE 9.2 Approximate Range of Values of D_L

Variable	Range	Remarks
D_L	1.5 to 2.5	If the soil in the trench is not compacted, then the higher value of D_L should be used.
	1.0	When deflection calculations are based on prism loads.

 TABLE 9.3 Average Values of Soil Reaction Modulus, E' (for Short Term Flexible Pipe Deflection) (Howard, 1977)

Soil type-pipe bedding material (United Classification System) ^a	E' for degree of compaction of bedding			
	Dumped	Slight, < 85% Proctor, < 40% relative density	Moderate, 85%–95% Proctor, 40%–70% relative density	High, > 95% Proctor, > 70% relative density
Fine-grained soils (LL > 50) ^b Soils with medium to high plasticity CH, MH, CH-MH	No data available; consult a competent soils engineer; Otherwise use $E' = 0$			
Fine-grained soils (LL < 50) Soils with medium to no plasticity CL, ML, ML-CL, with less than 25% coarse-grained particles	50 lb/in ² (345 kN/m ²)	200 lb/in ² (1,380 kN/m ²)	400 lb/in ² (2,760 kN/m ²)	1,000 lb/in ² (6,900 kN/m ²)
Fine-grained soils (LL < 50) Soils with medium to no plasticity CL, ML, ML-CL, with more than 25% coarse-grained particles	100 lb/in ² (690 kN/m ²)	400 lb/in ² (2,760 kN/m ²)	1,000 lb/in ² (6,900 kN/m ²)	2,000 lb/in ² (13,800 kN/m ²)
Coarse-grained soils with fines GM, GC, SM, SC contains more than 12% fines	200 lb/in ² (1,380 kN/m ²)	1,000 lb/in ² (6,900 kN/m ²)	2,000 lb/in ² (13,800 kN/m ²)	3,000 lb/in ² (20,700 kN/m ²)
Coarse-grained soils with little or no fines GW, GP, SW, SP ^c contains less than 12% fines	1,000 lb/in ² (6,900 kN/m ²)	3,000 lb/in ² (20,700 kN/m ²)	3,000 lb/in ² (20,700 kN/m ²)	3,000 lb/in ² (20,700 kN/m ²)
Crushed rock	1,000 lb/in ² (6,900 kN/m ²)	3,000 lb/in ² (20,700 kN/m ²)	3,000 lb/in ² (20,700 kN/m ²)	3,000 lb/in ² (20,700 kN/m ²)
Accuracy in term of percentage deflection ^d	± 2	± 2	± 1	± 0.5

^a ASTM Designation D2487, USBR Designation E-3

^b LL = Liquid Limit

^c or any borderline soil beginning with one of these symbols (i.e., GM-GC, GC-SC)

^d for ± 1% accuracy and predicted deflection of 3%, actual deflection would be between 2% and 4%

Note: Values applicable only for soil fills less than 50 ft (15 m). Table does not include any safety factor. For use in predicting initial deflections only—appropriate deflection lag factor must be applied for long-term deflections. If bedding falls on the borderline between two compaction categories, select lower E' value or average the two values. Percentage Proctor based on laboratory maximum dry density from test standards using about 12,500 ft-lb/ft³ (600 m-kN/m³) (ASTM D698, AASHTO T-99, USBR Designation E-11).

Used with permission of ASCE.

The parameter that controls the pipe deformation is known as the deflection ratio. The deflection ratio of a pipe is defined as the ratio of the vertical deflection of pipe and the mean diameter of the pipe.

Deflection Ratio:

$$\text{Deflection Ratio (\%)} = (\Delta Y/D) \times 100\% \quad (9.19)$$

where ΔY = vertical deflection of pipe, $\Delta Y \approx \Delta X$ when the deflection is less than 10%, in or m; and
 D = mean diameter of pipe, in or m.

Mean Diameter of Pipe:

$$D = (D_o + D_i)/2 = D_o - t = D_i + t \quad (9.20)$$

where D = mean diameter of pipe, in or m;
 D_o = outside diameter of pipe, in or m;
 D_i = inside diameter of pipe, in or m; and
 t = thickness of pipe, in or m.

There is another formula that can be used to estimate the deflection of the pipe. It is essentially an alternative version of the Modified Iowa formula and has been widely used in the engineering field. This formula is

$$\Delta X = \frac{D_L \cdot K \cdot W_c}{0.149 \cdot PS + 0.061 \cdot E'} \quad (9.21)$$

where ΔX = horizontal deflection, in or m (Figure 9.6);
 K = bedding constant, its value depending on the bedding angle (see Table 9.1 and Figure 9.7); as a general rule, a value of $K = 0.1$ is assumed;
 D_L = deflection lag factor, see Table 9.2;
 W_c = vertical load per unit length of the pipe, lb/in or kN/m;
 PS = pipe stiffness, lb/in² or kN/m²; and
 E' = soil reaction modulus, lb/in² or kN/m².

The vertical pressure on solid pipe is given by

$$P_{tp} = \sum \gamma_i \cdot H_i \quad (9.22)$$

The vertical pressure on perforated pipe is given by

$$P_{tp} = \frac{\sum \gamma_i \cdot H_i}{(1 - n \cdot d/12)} \quad (9.23)$$

where P_{tp} = vertical pressure on the pipe, $P_{tp} = W_c/D_o$, lb/in² or kN/m²;
 γ_i = unit weight of material i on the pipe (sand, clay or solid waste), lb/in³ or kN/m³;
 H_i = thickness of material i , in or m;

d = diameter of perforated hole or width of perforated slot on the pipe, in or m; and
 n = number of perforated holes or slots per row per foot of pipe.

Pipe stiffness is measured according to ASTM D2412 (Standard Test Method for External Loading Properties of Plastic Pipe by Parallel-Plate Loading). The elastic modulus of the pipe material depends on the type of resin and formulation being used. Three formulas that can be used to calculate pipe stiffness are

$$PS = \frac{E \cdot I}{0.149 \cdot r^3} \quad (9.24)$$

$$PS = 0.559 \cdot E \cdot (t/r)^3 \quad (9.25)$$

and

$$PS = 4.47 \cdot \frac{E}{(SDR - 1)^3} \quad (9.26)$$

where PS = pipe stiffness, lb/in² or kN/m²;
 E = elastic modulus of the pipe material, lb/in² or kN/m²;
 I = moment of inertia of the pipe wall per unit length,
 $I = t^3/12$, in⁴/in = in³ or m⁴/m = m³;
 r = mean radius of pipe, in or m;
 t = wall thickness of pipe, in or m; and
 SDR = standard dimension ratio, the same as the dimension ratio.

The allowable deflection ratios for a typical commercial polyethylene pipe are listed in Table 9.4.

Deflections of buried flexible pipe are commonly calculated using Equation 9.16 or 9.21. These equations use the soil reaction modulus, E' , as a surrogate parameter for soil stiffness. It should be noted that the values of E' in Table 9.3 only apply for soil fills of less than 50 ft (15 m). However, megafills built over leachate collection pipes often exceed 150 ft (46 m) in height. The soil reaction modulus is not a directly measurable soil parameter; instead it must be determined by back-calculation using observed pipe deflections. Research by Selig (1990) showed that E' is a function of the bedding condition and overburden pressure. Selig's studies were carried out to seek a correlation between the soil reaction modulus and soil stiffness parameters such as

TABLE 9.4 Allowable Deflection Ratio of Polyethylene Pipe

SDR	Allowable Deflection Ratio
11	2.7%
13.5	3.4%
15.5	3.9%
17	4.2%
19	4.7%
21	5.2%
26	6.5%
32.5	8.1%

Young's modulus of soil, E_s , and the constrained modulus of soil, M_s , where E_s and D_s are related through Poisson's ratio of soil, ν_s , by

$$M_s = \frac{E_s \cdot (1 - \nu_s)}{(1 + \nu_s)(1 - 2 \cdot \nu_s)} \quad (9.27)$$

where M_s = constrained modulus of soil, lb/ft² or kN/m²;
 E_s = elastic modulus of soil, lb/ft² or kN/m²; and
 ν_s = Poisson's ratio of soil.

The studies and analyses by Neilson (1967), Allgood and Takahashi (1972), and Hartely and Duncan (1987) indicated that for

$$E' = k \cdot M_s \quad (9.28)$$

the value of k may vary from 0.7 to 2.3. Using $k = 1.5$ as a representative value and $\nu_s = 0.3$, in addition to combining Equations 9.27 and 9.28 yields the following relationship between the elastic modulus of the pipe and soil (Selig, 1990):

$$E' = 2 \cdot E_s \quad (9.29)$$

The values of elastic parameters, E_s and ν_s , can be found in Table 9.5 according to different percents of density from a standard Proctor compaction test (ASTM D698).

TABLE 9.5 Elastic Soil Parameters (Selig, 1990)

Soil Type	Stress Level		85% Standard Density			95% Standard Density		
			E_s		ν_s	E_s		ν_s
	psi	kPa	psi	MPa		psi	MPa	
SW, SP, GW, GP	1	7	1,300	9	0.26	1,600	11	0.40
	5	35	2,100	14	0.21	4,100	28	0.29
	10	70	2,600	18	0.19	6,000	41	0.24
	20	140	3,300	23	0.19	8,600	59	0.23
	40	280	4,100	28	0.23	13,000	90	0.25
	60	420	4,700	32	0.28	16,000	110	0.29
GM, SM, ML, and GC, SC with < 20% fines	1	7	600	4	0.25	1,800	12	0.34
	5	35	700	5	0.24	2,500	17	0.29
	10	70	800	6	0.23	2,900	20	0.27
	20	140	850	6	0.30	3,200	22	0.29
	40	280	900	6	0.38	3,700	25	0.32
	60	420	1,000	7	0.41	4,100	28	0.35
CL, MH, GC, SC	1	7	100	1	0.33	400	3	0.42
	5	35	250	2	0.29	800	6	0.35
	10	70	400	3	0.28	1,100	8	0.32
	20	140	600	4	0.25	1,300	9	0.30
	40	280	700	5	0.35	1,400	10	0.35
	60	420	800	6	0.40	1,500	10	0.38

9.4.2 Pipe Wall Buckling

Buckling can occur because of insufficient stiffness. Buckling may govern design of flexible pipes subjected to internal vacuum, external hydrostatic pressure, or high soil pressures in compacted soil (Figure 9.8). As Moser (1990) notes the more flexible the conduit (e.g., high values of SDR), the more unstable the wall structure will be in resisting buckling.

Most conduits are buried in a soil medium that does offer considerable shear resistance. An exact rigorous solution to the problem of buckling of a cylinder in an elastic medium entails some advanced mathematics (Moser, 1990). However, because of uncertainties in the behavior and performance of the surrounding soil, an exact solution is not necessary. Meyerhof and Baikal (1963) developed the following empirical formula for computing the critical buckling pressure in a buried circular conduit:

$$P_{cr} = 2 \cdot \{ [E' / (1 - \mu^2)] (E \cdot I / r^3) \}^{1/2} \quad (9.30)$$

Where,

- P_{cr} = critical buckling pressure, lb/in² or kN/m²;
- E' = modulus of soil reaction, lb/in² or kN/m², see Table 9.3;
- μ = Poisson's ratio of pipe material;
- E = modulus of elasticity of the pipe material, lb/in² or kN/m²;
- I = moment of inertia of the pipe wall per unit length,
in⁴/in = in³ or m⁴/m = m³, $I = t^3/12$; and
- r = mean radius of the pipe, in or m.

Because $I = t^3/12$ and $r = D/2$, Equation 9.30 can be rewritten as

$$P_{cr} = 2 \cdot (G_b \cdot E')^{1/2} \quad (9.31)$$

where

$$G_b = \frac{2 \cdot E}{3 \cdot (1 - \mu^2)} \cdot (t/D)^3 \quad (9.32)$$

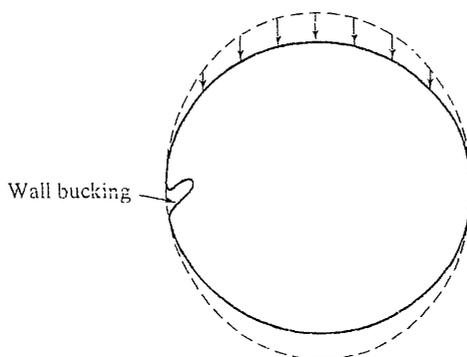


FIGURE 9.8 Localized Wall Buckling

in which

$$t = \text{thickness of pipe, in or m and}$$

$$D = \text{mean diameter of pipe, in or m}$$

The factor of safety for pipe wall buckling can be determined by

$$FS = P_{cr}/P_{ip} \quad (9.33)$$

where P_{ip} = actual vertical pressure at the top of the pipe, obtained from Equation 9.22 or 9.23, lb/in² or kN/m².

In both Equations 9.30 and 9.31 initial out-of-roundness is neglected but the reduction in P_{cr} because of this has been assumed to be no greater than 30% (Moser, 1990). As a result, a factor of safety ≥ 2 is recommended for use with Equation 9.33 in the design of a flexible conduit to resist buckling.

EXAMPLE 9.2

An 8-inch (200-mm) SDR 11 HDPE perforated pipe with 8, 0.25-inch (6-mm) holes per foot (i.e., 4 holes per side per foot) is selected as a primary leachate collection pipe. The maximum load acting on the pipe includes a 2-ft (0.6-m) protective sand layer ($\gamma_{\text{sand}} = 115 \text{ lb/ft}^3$ or 18 kN/m^3), 100-ft (30-m) solid waste ($\gamma_{\text{waste}} = 60 \text{ lb/ft}^3$ or 9.4 kN/m^3), 12-inch (0.3-m) gas venting layer ($\gamma_{\text{sand}} = 115 \text{ lb/ft}^3$ or 18 kN/m^3), 18-inch (0.45-m) compacted clay layer ($\gamma_{\text{clay}} = 110 \text{ lb/ft}^3$ or 17.3 kN/m^3), 24-inch (0.6-m) drainage and protective layer ($\gamma_{\text{silt}} = 110 \text{ lb/ft}^3$ or 17.3 kN/m^3), and 6-inch (0.15-m) topsoil ($\gamma_{\text{top}} = 90 \text{ lb/ft}^3$ or 14 kN/m^3). Assume bedding angle $\theta = 0^\circ$, deflection lag factor $D_L = 1.0$, elastic modulus of the pipe material for 50 years at 73°F (23°C) temperature $E = 28,200 \text{ lb/in}^2$, (194,000 kN/m²), Poisson's ratio of pipe material $\mu = 0.3$. The bedding material of the pipe is poorly graded gravel (GP) with 85% standard density. What will be the deflection ratio (%) and critical buckling pressure of the pipe?

Solution: The maximum load applied on the pipe is given by

$$W_c = \frac{\left(\sum \gamma_i \cdot H_i \right) \cdot D_o}{(1 - n \cdot d/12)} \quad (9.18)$$

$$= \frac{[(115)(2) + (60)(100) + (115)(1) + (110)(3.5) + (90)(0.5)] \times 8/12}{(1 - 4 \times 0.25/12)}$$

$$= \frac{(230 + 6,000 + 115 + 385 + 45) \times 8/12}{0.917}$$

$$= \frac{6,775 \times 8/12}{0.917}$$

$$= 4,925 \text{ lb/ft} = 410 \text{ lb/in} \text{ (72 kN/in)}$$

The maximum pressure applied on the pipe can be obtained from

$$P_{ip} = W_c/D_o = 410/8 = 51.3 \text{ lb/in}^2 \text{ (354 kN/m}^2\text{)}$$

From Table 9.5,

$$P_{ip} = 40 \text{ lb/in}^2, E_s = 4,100 \text{ lb/in}^2$$

and $P_{ip} = 60 \text{ lb/in}^2$, $E_s = 4,700 \text{ lb/in}^2$

For $P_{ip} = 51.3 \text{ lb/in}^2$,

$$E_s = 4,100 + (51.3 - 40)(4,700 - 4,400)/20 = 4,100 + 339 = 4,439 \text{ lb/in}^2$$

The soil reaction modulus is given by

$$E' = 2 \cdot E_s = 2 \times 4,439 = 8,878 \text{ lb/in}^2 (61,200 \text{ kN/m}^2) \quad (9.29)$$

The thickness of pipe is given by

$$\begin{aligned} t &= D_o / SDR \\ &= 8/11 = 0.73 \text{ in (0.0185 m)} \end{aligned} \quad (9.6)$$

The mean diameter of pipe is

$$\begin{aligned} D &= D_o - t \\ &= 8 - 0.73 = 7.27 \text{ in (0.1847 m)} \end{aligned} \quad (9.20)$$

Also,

Deflection lag factor, $D_L = 1.0$;

Bedding angle $\theta = 0^\circ$, $K = 0.11$;

Mean radius of the pipe, $r = 3.635 \text{ in (0.0923 m)}$;

Elastic modulus of the pipe material, $E = 28,200 \text{ lb/in}^2 (194,000 \text{ kN/m}^2)$;

Soil reaction modulus, $E' = 8,878 \text{ lb/in}^2 (61,200 \text{ kN/m}^2)$;

and

Inertia moment of the pipe wall per unit length, $\text{in}^4/\text{in} = \text{in}^3$, given by

$$I = t^3/12 = (0.73)^3/12 = 0.389/12 = 0.0324 \text{ in}^3 (5.276 \times 10^{-7} \text{ m}^3)$$

Modified Iowa Formula:

$$\begin{aligned} \Delta X &= \frac{D_L \cdot K \cdot W_c \cdot r^3}{E \cdot I + 0.061 E' \cdot r^3} \\ &= \frac{(1.0)(0.11)(410)(3.635)^3}{(28,200)(0.0324) + (0.061)(8,878)(3.635)^3} \\ &= \frac{(1.0)(0.11)(410)(48.03)}{(28,200)(0.0324) + (0.061)(8,878)(48.03)} \\ &= \frac{2,166}{914 + 26,011} \\ &= 0.08 \text{ in (2.0 mm)} \end{aligned} \quad (9.16)$$

Deflection Ratio:

$$\begin{aligned} \text{Deflection Ratio} &= (\Delta Y/D) \times 100\% \\ &= (0.08/7.27) \times 100\% \\ &= 1.1\% < 2.7\% \text{ (ok, as shown in Table 9.4)} \end{aligned} \quad (9.19)$$

Wall Buckling of Pipe:

Modulus of soil reaction, $E' = 8,878 \text{ lb/in}^2$, $(61,200 \text{ kN/m}^2)$;

Poisson's ratio of pipe material, $\mu = 0.3$;
 Modulus of elasticity of the pipe material, $E = 28,200 \text{ lb/in}^2$ ($194,000 \text{ kN/m}^2$);
 Moment of inertia of the pipe wall per unit length, $I = 0.0324 \text{ in}^3$ ($5.276 \times 10^{-7} \text{ m}^3$);
 Mean radius of the pipe, $r = 3.635 \text{ in}$ (0.0923 m).
 Thus,

$$\begin{aligned}
 P_{cr} &= 2 \cdot \{ [E' / (1 - \mu^2)] (E \cdot I / r^3) \}^{1/2} & (9.30) \\
 &= 2 \times \{ [8,878 / (1 - 0.3^2)] [(28,200 \times 0.0324) / (3.635)^3] \}^{1/2} \\
 &= 2 \times [9,756 \times (913.68 / 48.03)]^{1/2} \\
 &= 2 \times (185,589)^{1/2} \\
 &= 2 \times 431 \\
 &= 862 \text{ lb/in}^2 \text{ (5,943 kN/m}^2\text{)}
 \end{aligned}$$

The factor of safety for pipe wall buckling is, then,

$$FS = P_{cr} / P_{tp} = 862 / 51.3 = 16.8 > 2 \text{ (OK)} \quad (9.33)$$

9.5 SUMP AND RISER PIPES

Leachate collection sumps are low points in the landfill liner constructed to collect and removal leachate. The sumps are filled with gravel to provide the maximum space (volume) for leachate accumulation, as well as to support the weight of the overlying waste, cover system, and post-closure loadings. Commonly, the composite liner system is slightly depressed or indented to create these sumps (shown in Figures 9.9 and 9.10). The absence of sketches illustrating continued gravity flow of leachate beyond the limits of the cells and/or landfill using liner penetrations is intentional. The authors do not recommend such practice due to the difficulty of making liner seams in this remote of all locations. With double liner systems, the situation is even more difficult. Even with the sketches of Figures 9.9 and 9.10 it is difficult to test the geomembrane seaming in such sumps because of the slope and corners at which the seams occur. Because of the difficulty in seam testing sumps, sump areas often are designed with an additional layer of geomembrane. Sulfates are one of the most common and abundant constituents in landfill leachate. Accordingly, all concrete components in a sump (e.g., riser pipe and foundation pad) must be constructed using low water/cement ratios and sulfate resistant, Class V Portland cement (ACI, 1998). Failure to observe this precaution can lead to sulfate attack and disintegration of the concrete. Sulfate attack occurs when calcium, alumina, and sulfate combine to form the mineral ettringite ($3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 32\text{H}_2\text{O}$) in the cement matrix. The volume of ettringite is over 200% that of the original constituents, which can result in massive swelling and cracking when sufficient ettringite forms by the sulfation of alumina. Alternatively, many sumps now are being constructed using premanufactured units made of HDPE, with large-diameter HDPE pipe or HDPE manholes. Although more costly, the factory manufactured sumps can be thoroughly tested and installed as a unit.

Figure 9.9 shows details of vertical riser (manhole) removal designs for primary and secondary leachate collection systems. The manhole riser extends vertically

**APPLICATION FOR PERMIT
SUNDANCE WEST**

**VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 5: PIPE LOADING CALCULATIONS**

ATTACHMENT III.5.B

SHARMA, HARI .D. AND SANGEETA P. LEWIS. 1994.

***WASTE CONTAINMENT SYSTEMS, WASTE STABILIZATION AND LANDFILLS:
DESIGN AND EVALUATION.***

NEW YORK: JOHN WILEY AND SONS

WASTE CONTAINMENT SYSTEMS, WASTE STABILIZATION, AND LANDFILLS: DESIGN AND EVALUATION

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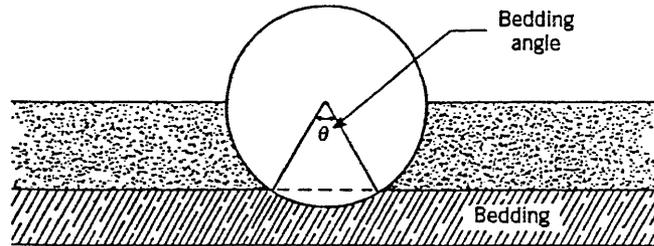


Figure 9.29 Bedding angle. (From Moser, 1990.)

approximately 1.5 times greater than the load determined using Marston's equation. The bedding constant is dependent on the bedding angle, as depicted in Figure 9.29. Values for the bedding constant are given in Table 9.12.

In the preceding paragraphs on soil stiffness we discussed the modulus of passive resistance of the soil, e , and noted that the units for e were not dimensionally correct. The Iowa formula was therefore modified and the following equation is known as the modified Iowa formula:

$$\Delta X \approx \Delta Y = \frac{D_L K W_c r^3}{EI + 0.061 E' r^3} \tag{9.34}$$

where $E' = er$. E' is known as the modulus of soil reaction. Methods for establishing this value were given in the preceding soil stiffness paragraphs. Actual deflections may be estimated using the modified Iowa formula by assuming that horizontal and vertical deflections are equal.

WATKINS' RING STABILITY EQUATION. Deflection may also be calculated using Watkins' (1989) ring stability equation. The ring stability equation is based on assuming incipient collapse of the pipe; however, it is important to note that incipient collapse does not mean imminent collapse. Rather, it refers to a condition of possible col-

TABLE 9.12 Values of Bedding Constant, K

Bedding Angle (deg)	K
0	0.110
30	0.108
45	0.105
60	0.102
90	0.096
120	0.090
180	0.083

Source: Moser (1990).

**APPLICATION FOR PERMIT
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**VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 5: PIPE LOADING CALCULATIONS**

ATTACHMENT III.5.C

WASHINGTON STATE DEPARTMENT OF ECOLOGY. 1987.

SOLID WASTE LANDFILL DESIGN MANUAL.

WASHINGTON: WDOE

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APPENDIX 4C

COLLECTION PIPE MATERIALS AND STRUCTURAL REQUIREMENTS

4C.1 COLLECTION PIPE MATERIALS

Pipe that may be suitable for leachate collection systems is manufactured to meet nationally recognized product specifications. Some materials are more appropriate than others for use in a leachate collection system and the various types of pipe should be evaluated carefully. Various factors to consider are:

- Intended use (type of leachate)
- Flow requirements
- Scour or abrasion conditions
- Corrosion conditions
- Product characteristics
- Physical properties
- Installation requirements
- Handling requirements
- Cost effectiveness

No single pipe product will provide optimum capability in every characteristic for all leachate collection system design conditions. Specific application requirements should be evaluated prior to selecting pipe materials.

Pipe materials for leachate collection applications fall within the two commonly accepted classifications of rigid pipe and flexible pipe. Rigid pipe materials derive a substantial part of their basic earth load carrying capacity from the structural strength inherent in the rigid pipe wall, while flexible pipe materials derive load carrying capacity from the interaction of the flexible pipe and the embedment soils. Products commonly available within these two classes are:

1. Rigid Pipe
 - a. Asbestos-cement pipe (ACP)
 - b. Cast iron pipe (CIP)
 - c. Concrete pipe (CP)
 - d. Vitrified clay pipe (VCP)
2. Flexible Pipe
 - a. Ductile iron pipe (DIP)
 - b. Steel pipe (SP)
 - c. Thermoplastic pipe
 - Acrylonitrile-butadiene-styrene (ABS)
 - ABS composite
 - Polyethylene (PE)
 - Polyvinyl chloride (PVC)
 - d. Thermoset plastic pipe
 - Reinforced plastic mortar (RPM)

- Reinforced thermosetting resin (RTR)

Within the rigid pipe classification, the suitability of cast iron and concrete pipe for leachate collection systems is limited by the difficulty of incorporating perforations in the pipe walls and their susceptibility to corrosion by acidic leachates. The use of asbestos-cement pipe is limited by its low beam strength. It is also susceptible to attack by acidic leachates. Vitrified clay pipe can be perforated and is highly resistant to chemical corrosion, but its relatively low beam strength limits the fill height that can be placed over it. For these reasons, rigid pipes have very limited use potential in leachate collection systems.

As a group, flexible pipes offer good potential for use in leachate collection systems. Within the flexible pipe group, however, only certain products are suitable. Ductile iron and steel pipe have little application for leachate collection systems primarily because of their susceptibility to attack by acidic leachates. Also, although ductile iron pipe has high load bearing capacity, incorporating perforations in the pipe walls is difficult. Thermoplastic and thermoset plastic pipe are more suitable products for leachate collection systems.

Thermoplastic materials are characterized by their ability to be repeatedly softened by heating and hardened by cooling through a temperature range characteristic for each plastic. Materials suitable for use in leachate collection systems include ABS pipe, ABS composite pipe, PE pipe, and PVC pipe. All of these materials are subject to attack by certain organic chemicals, so compatibility with the leachate must be considered in this selection. ABS is generally not as resistant to acids as PVC and neither of these two materials has good resistance to concentrated ketones and esters. Pipes manufactured from any of these materials are subject to excessive deflection when improperly bedded and haunched, so proper design and construction are important. With the exception of PVC pipe, these pipes are also subject to environmental stress cracking. Thermoplastic pipe product design should be based on long-term data.

Thermoset plastic materials, cured by heat or other means, are substantially infusible and insoluble. The two categories of thermoset plastic materials suitable for leachate collection systems include RPM pipe and RTR pipe. RPM pipe is manufactured containing reinforcements, such as fiberglass, and aggregates, such as sand, embedded in or surrounded by cured thermosetting resin. RTR pipe is manufactured using a number of methods including centrifugal casting, pressure laminating, and filament winding. In general, the product contains fibrous reinforcement materials, such as fiberglass, embedded in or surrounded by cured thermosetting resin. Pipes manufactured from both of these materials are subject to strain corrosion in some environments, attack by certain organic chemicals, and excessive deflection when improperly bedded and haunched. Therefore, leachate compatibility and proper design and construction are important when thermoset plastic pipe is used in leachate collection systems.

4C.1.1 Pipe Perforations

By nature of their intended use, leachate collection lines must be perforated. The size and spacing of the openings should be determined based on hydraulic considerations. The effects of the perforations should be considered in the structural design of the leachate collection pipes.

4C.1.1.1 Size and Spacing

A leachate collection line, to function correctly, must be capable of accepting all the leachate flowing to it through the gravel drainage layer. After the pipe is sized to handle the flow, the size and spacing of the perforations should be selected. The rate of flow into the leachate collection pipes through the perforations is dependent on several factors, including the hydraulic conductivity of the gravel material around the pipe and the head loss due to convergence of flow to the perforations in the pipe.

W.T. Moody, as cited in U.S. * Department of the Interior (1978) determined the theoretical relationship among the above factors and concluded that increasing the hydraulic conductivity of the gravel envelope around the pipe was a more effective method for increasing the rate of flow into the pipe than increasing the size of the openings. Therefore, the selection of the size and spacing of the perforations should be based on: consideration of standard perforated pipe commonly available from manufacturer; bedding and backfill requirements for the particular installation; and effects on pipe strength. For a given rate of leachate inflow and a perforated pipe, the minimum required hydraulic conductivity of the gravel envelope around the pipe can be determined using a procedure similar to that presented in U.S. Department of the Interior (1978).

4C.1.1.2 Effects on Load Capacity

The various design procedures for rigid and flexible pipes and the various pipe performance limits are based on solid wall pipe. Pacey, et al., as cited in Dietzler (1984) has suggested that the effect of perforations could be compensated by arbitrarily increasing the earth load on the pipe. Data presented in Dietzler (1984) indicated the inclusion of typical perforations in the lower quarters of 6-inch ABS and PVC pipe has little influence on pipe stiffness and deflection versus load performance. Others have stated there are indications that perforations will reduce the effective length of pipe available to carry loads and resist deflection suggest taking the effect of perforations into account by increasing the load in proportion to the reduction in the effective length. This latter method appears to be an adequately conservative approach. If L_p equals the cumulative length of the perforations per unit length of the pipe, L , then the actual load on the pipe should be increased as follows:

$$\text{Design Load} = \text{Actual Load} \times \frac{L}{L - L_p} \quad (4C-1)$$

Methods to determine the actual load are discussed in the following sections.

4C.2 STRUCTURAL REQUIREMENTS

Leachate collection systems installed underneath a landfill must be designed to withstand the anticipated height and weight of refuse to be placed over them. It is not uncommon to find heights in excess of 100 feet. Appropriately, leachate collection systems must be designed for vertical pressure acting at the base of the landfill, considering the height of the landfill and the weighted average density of the refuse, daily cover, final cover system, and any superimposed loads during the life of the landfill. Perimeter collection systems that generally lie outside the landfill should be designed for the earth loads acting on them along with any superimposed loads.

The supporting strength of a leachate collection pipe is a function of installation conditions as well as the strength of the pipe itself. Structural analysis and design of the collection system are problems of soilstructure interaction. This section presents general procedures for determining the structural requirements of the pipes in a leachate collection system. Detailed discussions concerning structural design of pipelines may be found in ASCE and WPCF (1982). The design procedure for the selection of pipe strength consists of the following:

- Determination of loading condition
- Determination of refuse and earth loads
- Determination of superimposed loads
- Selection of bedding and determination of bedding factor
- Application of factor of safety
- Selection of pipe strength

4C.2.1 Loading Conditions

The load transmitted to a pipe is largely dependent on the type of installation. The common types of installation conditions are shown in Figure 4C.1 and include trench, positive projecting embankment, negative projecting embankment, and induced trench. Jacked or tunneled is also an installation condition, but has little application for leachate collection systems. The difficulty in controlling the placement of the embankment material greatly limits the potential use of the induced trench condition for leachate collection systems.

Trench installation* conditions are defined as those in which the pipe is installed in a relatively narrow trench cut in undisturbed ground and covered with backfill to the original ground surface. Embankment conditions are defined as those in which the pipe is covered above the original ground surface or in which a trench in undisturbed soil is so wide that wall friction does not affect the load on the pipe. The embankment classification is further subdivided into positive projecting and negative projecting classification. Pipe is positive projecting when its top is above the adjacent original ground surface. Negative projecting pipe is installed with its top below the adjacent original ground surface in a trench that is narrow with respect to the pipe and depth of cover.

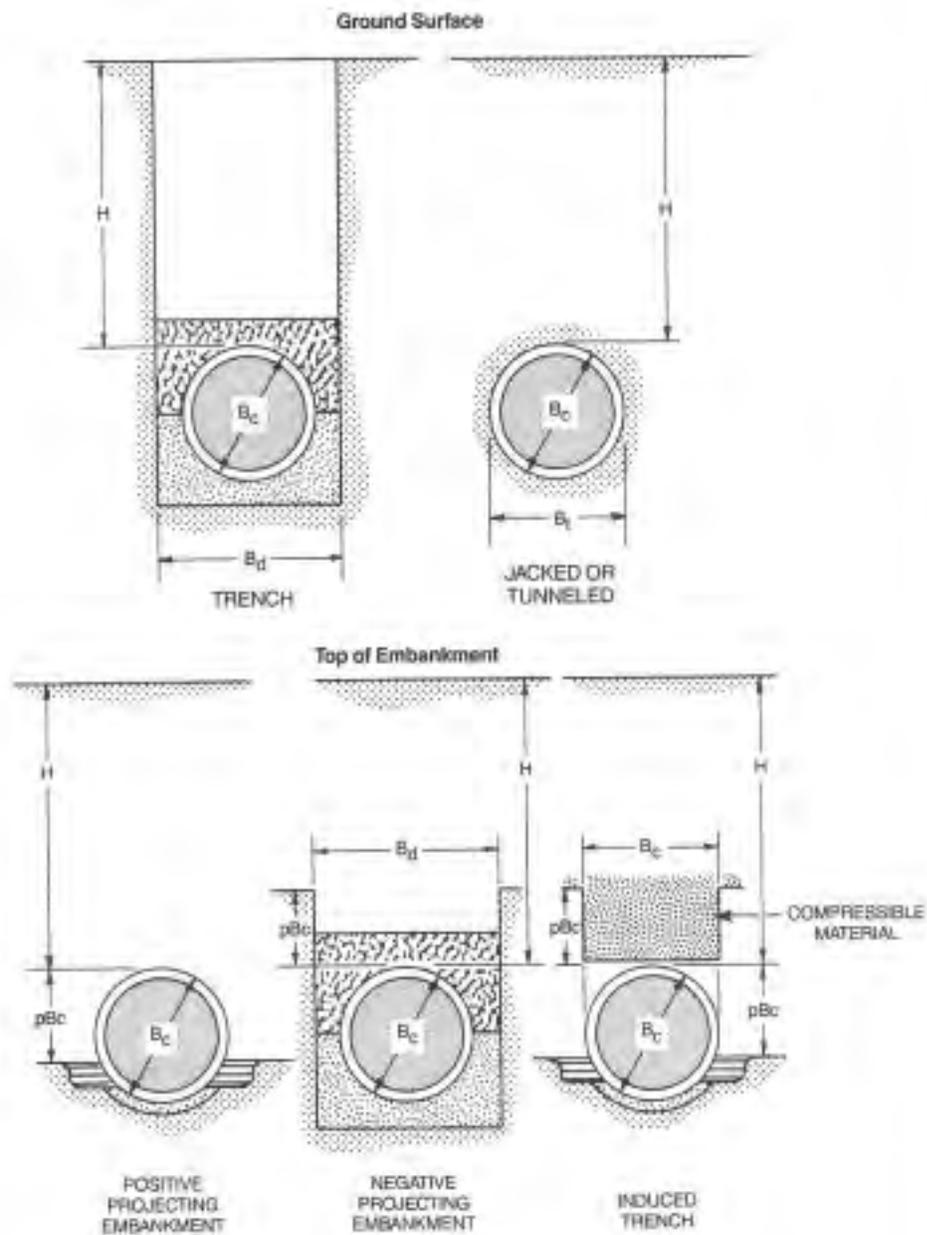


Figure 4C.1
Installation Conditions

Both the trench condition and either of the embankment conditions may be appropriate in the design of leachate collection systems. A perimeter collection system may be designed for either the trench condition or the negative projecting embankment condition, depending on trench width. Leachate collection systems underneath the landfill would generally be designed for one of the embankment conditions.

4C.2.2 Refuse and Earth Loads

The methods for determining the vertical load on buried conduits caused by soil forces were developed by Marston for all of the most commonly encountered construction conditions (ASCE and WPCF, 1982). The general form of the Marston equation is:

$$W = CWB^2 \quad (4C-2)$$

where: W = Vertical load per unit length acting on the pipe because of gravity soil loads

v = Unit weight of the soil

B = Trench or pipe width, depending on installation conditions

C = Dimensionless coefficient that measures the effects of the following variables:

- The ratio of the height of fill to width of trench or pipe
- The shearing forces between interior and adjacent soil prisms
- The direction and amount of relative settlement between interior and adjacent soil prisms for embankment conditions

While the general form of the Marston equation includes all the factors necessary to analyze all types of installation conditions, it is convenient to write a specialized form of the equation for each of the installation conditions described in the previous subsection.

4C.2.2.1 Loads for Trench Conditions

In the trench condition, the load on the pipe is caused by both the waste fill and the trench backfill (U.S. EPA, 1983). These two components of the total vertical pressure on the pipe are computed separately and then added to obtain the total vertical pressure acting on the top of the pipe.

The waste fill is assumed to develop a uniform surcharge pressure, Q_f , at the base of the fill. The magnitude of Q_f is given by the expression:

$$Q_f = (w_f)(H_f) \quad (4C-3)$$

where: Q_f = Vertical pressure at the base of the waste fill (lbs/sq ft)

w_f = Weighted average density of the waste fill including refuse, intermediate cover, and final cover system (lbs/cu ft)

H_f = Height of waste fill including cover (ft)

The weighted average density of the waste fill, w_f is computed as follows:

$$w_f = \frac{(w_r)(H_r) + (w_i)(T_i) + (w_c)(T_c)}{H_f} \quad (4C-4)$$

where: w_r = Average in-place wet density of the refuse (lbs/cu ft)

H_r = Height of refuse excluding cover layers (ft)

w_i = Wet density of intermediate cover (lbs/cu ft)

T_i = Total thickness of intermediate cover layers (ft)

w_c = Wet density of the final cover system (lbs/cu ft)

T_c = Thickness of the final cover system (ft)

$H_f = H_r + T_i + T_c$

The value of the vertical pressure at the top of the pipe due to the waste fill, P_{vf} (in lbs/sq ft), is determined from the following:

$$P_{vf} = (Q_f)(C_{us}) \quad (4C-5)$$

where: C_{us} = Dimensionless load coefficient that is a function of the ratio of the depth of the trench, H (measured from the original ground surface to the top of the pipe) to the trench width, B_d , and of the friction between the backfill and the sides of the trench.

The load coefficient, C_{us} , may be calculated from the following equation or obtained from Figure 4C.2:

$$C_{us} = e^{-2Ku'(H/B_d)} \quad (4C-6)$$

where: e = Base of natural logarithms

K = Rankine's ratio of lateral pressure to vertical pressure

u' = Coefficient of friction between backfill material and the sides of the trench

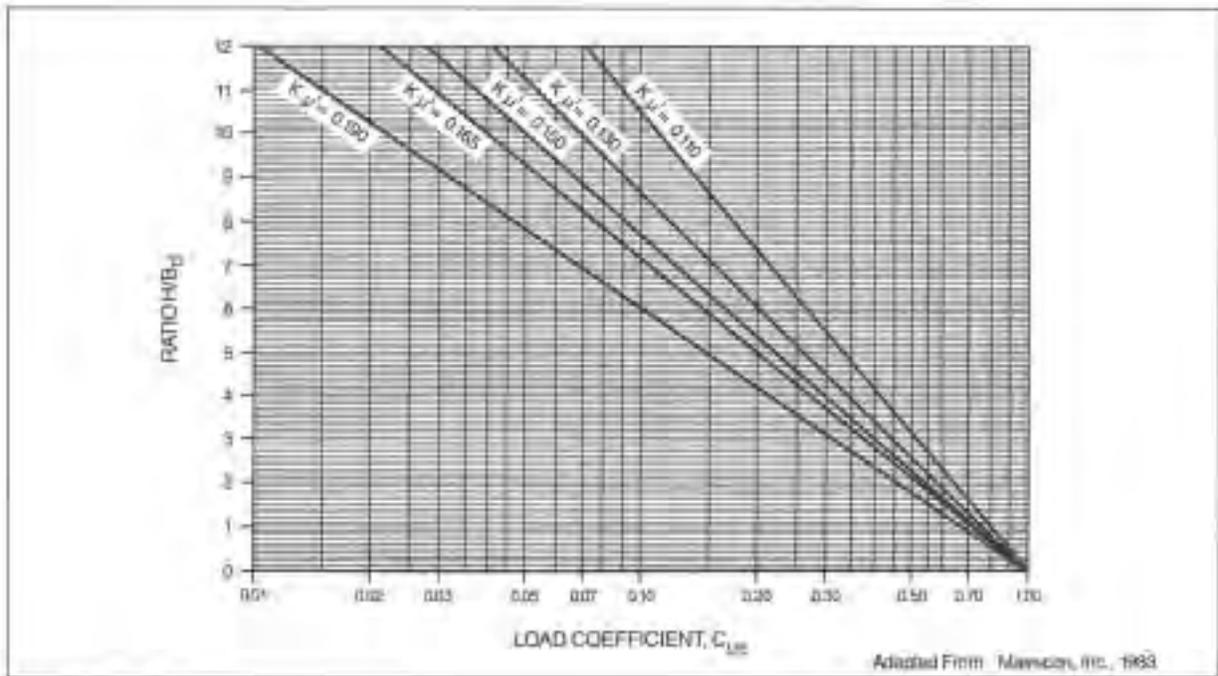


Figure 4C.2
Trench Condition—Values of Load Coefficient C_{us} (Trench Uniform Surcharge)

H = Depth of trench from original ground surface to top of pipe (ft)

B_d = Width of trench at top of pipe (ft)

The product of K_u' is characteristic for a given combination of backfills in natural, undisturbed soil. Maximum values of K_u' for typical soils are listed in Table 4C.1.

Table 4C.1. Maximum Value of K_u' for Typical Backfill Soils

Type of Soil	Maximum Value of K_u'
Granular Materials Without Cohesion	0.19
Sand and Gravel	0.165
Saturated Topsoil	0.150
Clay	0.130
Saturated Clay	0.110

Source: U.S. EPA (1983)

The value of the vertical pressure at the top of the pipe due to the trench backfill is determined from the following equation developed by Marston (see U.S. EPA, 1983):

$$P_{vt} = (B_d)(w)(C_d) \quad (4C-7)$$

where:

P_{vt} = Value of the vertical pressure at the top of the pipe (lbs/sq ft)

W = Unit weight of trench backfill (lbs/cu ft)

C_d = Dimensionless load coefficient which is a function of the ratio of the depth of the trench, H , to the trench width, B_d , and of the friction between the backfill and the sides of the trench

The load coefficient, C_d , may be computed from the following equation or obtained from Figure 4C.3:

$$C_d = \frac{1 - e^{-2Ku'(H/B_d)}}{2Ku'} \quad (4C-8)$$

in which the terms are as previously defined.

The total vertical pressure at the top of the pipe, P_v , is equal to:

$$P_v = P_{vf} + P_{vt} \quad (4C-9)$$

$$P_v = (Q_f)(C_{us}) + (B)(w)(C_d) \quad (4C-10)$$

Based on Marston's formula, the load on a rigid pipe in the trench condition would be:

$$w_e = P_v B_d \quad (4C-11)$$

or:

$$w_c = (B_d)(Q_f)(C_{us}) + (B_d)^2 (w)(C_d) \quad (4C-12)$$

where: w_c = Force per unit length of pipe (lb/ft)

For flexible pipe in the trench condition, the load as given by Marston's formula would be:

$$w_c = P_v B_c \quad (4C-13)$$

or:

$$w_c = (B)(Q_f)(C_{us}) + (B_d)(w)(C_d)(B_c) \quad (4C-14)$$

where: B_c = Outside diameter of pipe (ft)

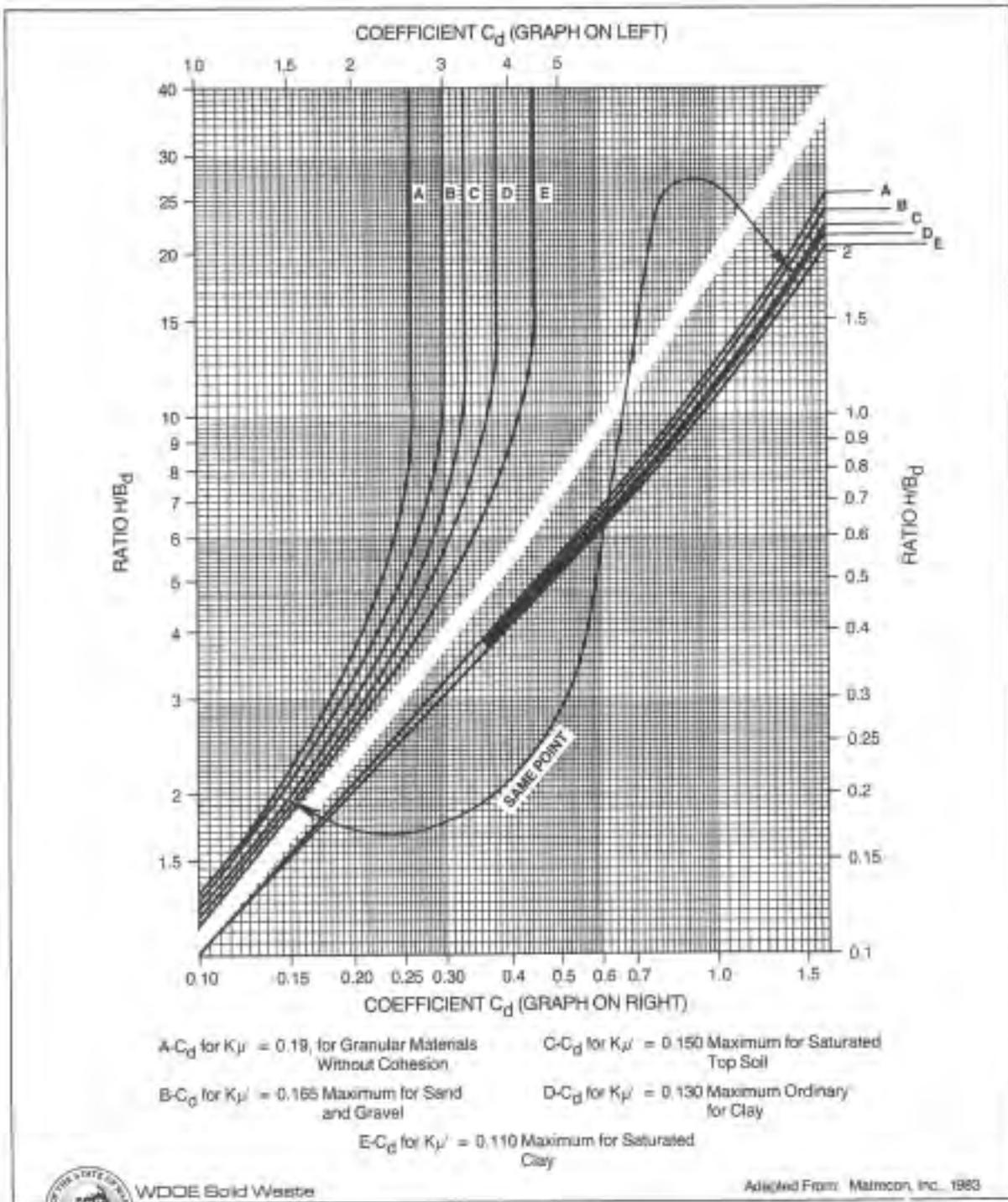


Figure 4C.3
Trench Condition—Values of Load Coefficient C_d (Backfill)

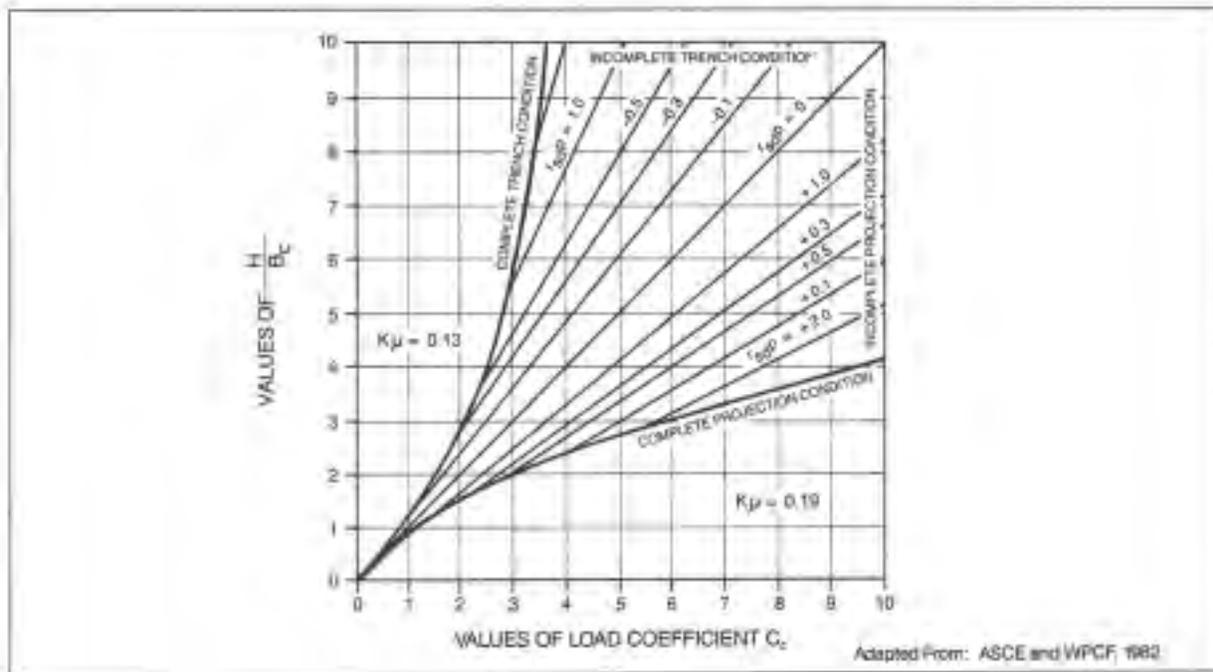


Figure 4C.4
Diagram for Load Coefficient C_c for Positive Projecting Pipes

This formula is applicable to flexible pipes only if the backfill material at the sides of the pipe is compacted so that it will deform under vertical load less than the pipe itself will deform. In this condition, the side fills between the sides of the pipe and the sides of the trench may be expected to carry their proportional share of the total load. If this condition does not exist, then the loads are determined as described below for the embankment conditions.

4C.2.2.2 Loads for Positive Protecting Embankment Conditions

Marston's formula for the fill load on a pipe in the positive projecting embankment condition is:

$$W_c = C_c w_f B_c^2 \quad (4C-15)$$

where: W_c = Load on the pipe (lbs/ft)

w_f = Weighted average density of the waste fill (lbs/cu ft)

B_c = Outside width of pipe (ft)

C_c = Load coefficient

A complete discussion of this load coefficient may be found in the Concrete Pipe Design Manual developed by the American Concrete Pipe Association (1980)

and Gravity Sanitary Sewer Design and Construction published by the ASCE and WPCF (1982). Values of C_c may be obtained from Figure 4C.4.

Table 4C.2. Recommended Design Values of r_{sd} (Positive, Projecting Embankment Conditions).

Type of Pipe	Soil Conditions	Settlement Ratio, r_{sd}
Rigid	Rock or unyielding foundation	+1.0
Rigid	Ordinary foundation	+0.5 to +0.8
Rigid	Yielding foundation	0 to +0.5
Rigid	Negative projecting installation	-0.3 to -0.5
Flexible	Poorly compacted side fills	-0.4 to 0
Flexible	Well compacted side fills	0

Source: ASCB and WPCF, 1982, p. 178

The fill load on a pipe installed in a positive projecting embankment condition is influenced by the product of the settlement ratio (r_{sd}) and the projecting ratio (p'). The settlement ratio is the relationship between the pipe deflection and the relative settlement between the prism of fill directly above the pipe and the adjacent material. Design values of the settlement ratio is the vertical distance the pipe projects above the original ground divided by the outside vertical height of the pipe, and can be determined when the size and elevation of pipe has been established.

In the last three cases shown in Table 4C.2, the settlement ratio may be conservatively assumed to be zero which results in designing for the weight of the prism of material directly above the pipe. In such cases, C_c is equal to H/B_c and Marston's formula for the prism load becomes:

$$W_c = (H)(w_f)(B_c) \quad (4C-16)$$

where: W_c = Load on pipe (lbs/ft)

H = Height of the fill above the pipe (ft)

w_f = Weighted average density of the waste fill, including gravel backfill above the pipe, refuse, intermediate cover, and final cover system (lbs/cu ft)

B_c = Outside diameter of the pipe (ft)

The load on the pipe is also influenced by the coefficient of internal friction of the embankment material. ASCE and WPCF (1982) recommends the following values of the product K_u for use in Figure 4C.4.

For a positive settlement ratio: $K_u = 0.19$

For a negative settlement ratio: $K_u = 0.13$

4C.2.2.3 Loads for Negative Projecting Embankment and Induced Trench Conditions

The formula for the fill load on a negative projecting pipe is:

$$W_c = C_n w B_d^2 \quad (4C-17)$$

where: W_c = Load on the pipe (lbs/ft)

w = Density of fill above pipe (lbs/cu ft)

B_d = Width of trench (ft)

C_n = Load coefficient

In the case of induced trench pipe, B_c is substituted for B_d in the preceding equation. B_c is the outside diameter of the sewer pipe which is assumed to be the width of the trench.

A complete discussion of the load coefficient, C_n , may be found in American Concrete Pipe Association (1980) and ASCE and WPCF (1982). Values of C_n may be obtained from Figure 4C.5.

As in the case of the positive projecting embankment condition, the fill load is influenced by the product of the settlement ratio (r_{sd}) and the projection ratio (p'). The settlement ratio for the negative projecting embankment condition is the quotient obtained by taking the difference between the settlement of the firm ground surface and the settlement of the plane in the trench backfill which was originally level with the ground surface and dividing this difference by the compression of the column of material in trench. Values for the negative projecting settlement ratio range from -0.1 for $P' = 0.5'$ to -1.0 for $P' = 2.0'$ for rigid pipe (American Concrete Pipe Association, 1980, p. 162). Induced trench settlement ratios range from -0.3 to 0.5 (ASCE and WPCF, 1982). The projection ratio for this condition, p' is equal to the vertical distance from the firm ground surface down to the top of the pipe, divided by the width of the trench, B_d .

4C.2.3 **Superimposed Loads**

Leachate collection pipes in a landfill may be subjected to two types of superimposed loads: concentrated loads and distributed loads. Loads of pipes caused by these loadings can be determined by application of the Boussinesq equations (ASCE and WPCF, 1982).

4C.2.3.1 Concentrated Loads

The formula for load caused by a superimposed concentrated load, such as a

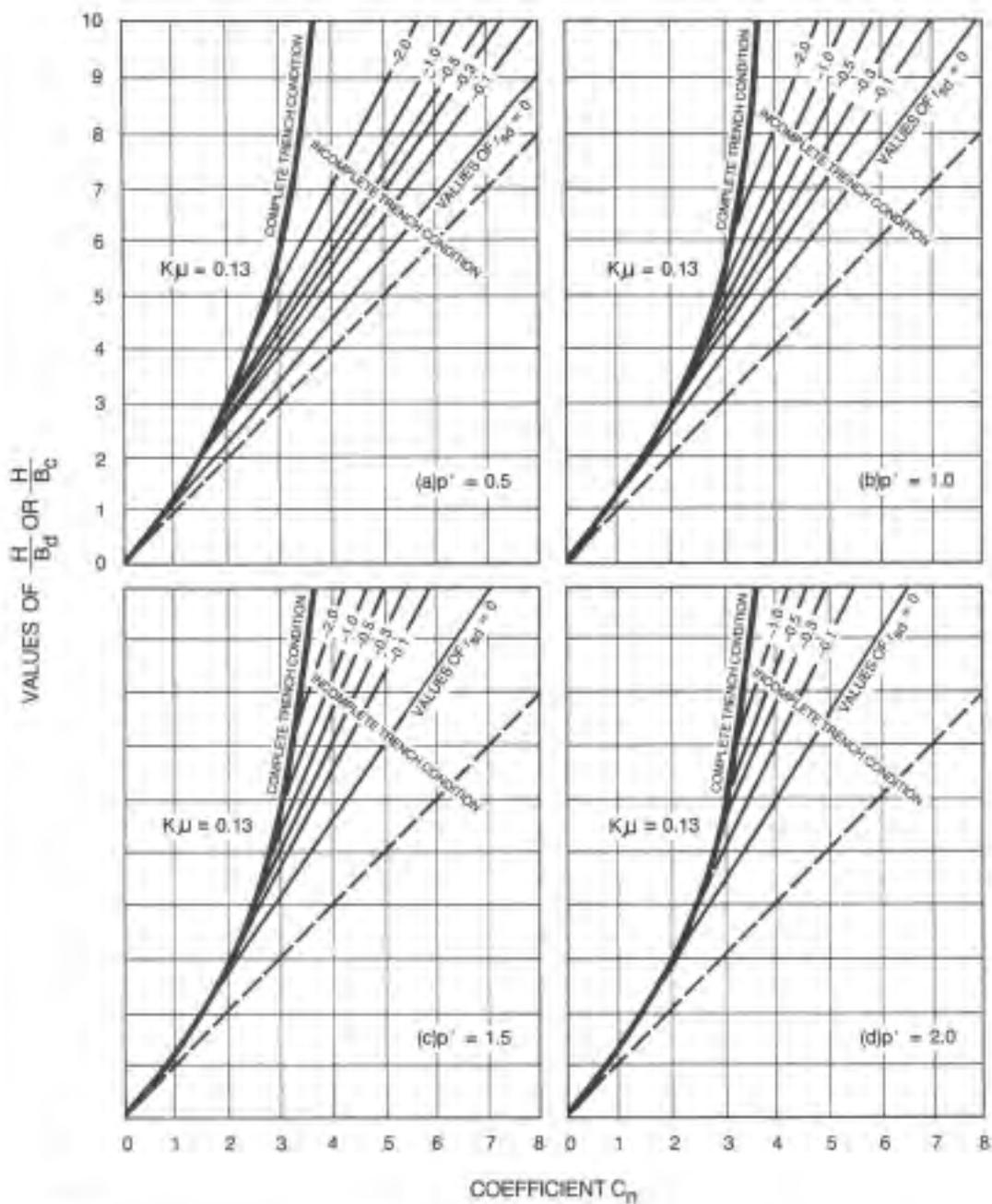


Figure 4C.5
Diagrams for Load Coefficient C_n for Negative
Projecting and Induced Trench Pipes

wheel load during construction, is given the following form (ASCE and WPCF, 1982):

$$W_{sc} = \frac{PF}{C_s L} \quad (4C-18)$$

where: W_{sc} = Load on pipe (lbs/ft)

P = Concentrated load (lbs)

F = Impact factor

L = Effective length of pipe (ft)

C_s = Load coefficient

The load coefficient, C_s , is a function of $B_c/2H$ and $L/2H$, in which B_c is the outside diameter of the pipe and H is the height of fill from the top of the pipe to the ground surface. Table 4C.3 lists values of the load coefficients for concentrated and distributed superimposed loads centered over the pipe.

The effective length, L , is the length over which the average load caused by surface wheels produces nearly the same stress in the pipe wall as does the actual load which varies in intensity from point to point. ASCE and WPCF (1982) recommends using an effective length equal to 3 feet for pipes greater than 3 feet long and using the actual length of pipes shorter than 3 feet.

The impact factor, F , reflects the influence of dynamic loads caused by traffic at ground surface. The impact factors recommended by AASHTO are listed in Table 4C.4 (American Concrete Pipe Association, 1980).

Various equipment loads that may occur during construction are listed in Table 4C.5.

Loads on pipes resulting from concentrated loads during construction may be greater than the loads caused by the refuse placed in the landfill. It is important that both construction loads and long-term loads be considered in determining the maximum load expected on pipes.

4C.2.3.2 Distributed Loads

Superimposed loads distributed over an area of considerable extent such as a truck load during construction may be determined from the following equation (ASCE and WPCF, 1982):

$$W_{sd} = CspFBc \quad (4C-19)$$

where: W_{sd} = Load on pipe (lbs/ft)

p = Intensity of distributed load (lbs/sq ft)

F = Impact factor

Table 4C.1. Values of Load Coefficients, C_g , for Concentrated and Distributed Superimposed Loads Vertically Centered over Sewer Pipe.

$\frac{D_c}{2H}$ or	$\frac{M}{2H}$ or $\frac{L}{2H}$													
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.5	2.0	5.0
0.1	0.019	0.037	0.053	0.065	0.079	0.089	0.097	0.103	0.108	0.112	0.117	0.121	0.124	0.128
0.2	0.037	0.072	0.103	0.131	0.155	0.174	0.189	0.202	0.211	0.219	0.229	0.238	0.244	0.248
0.3	0.053	0.103	0.149	0.190	0.224	0.252	0.274	0.292	0.306	0.318	0.333	0.345	0.355	0.360
0.4	0.067	0.131	0.190	0.241	0.284	0.320	0.349	0.373	0.391	0.405	0.425	0.440	0.454	0.460
0.5	0.079	0.155	0.224	0.284	0.336	0.379	0.414	0.441	0.463	0.481	0.505	0.525	0.540	0.548
0.6	0.089	0.174	0.252	0.320	0.379	0.428	0.467	0.499	0.524	0.544	0.572	0.596	0.613	0.624
0.7	0.097	0.189	0.274	0.349	0.414	0.467	0.511	0.546	0.584	0.597	0.628	0.650	0.674	0.688
0.8	0.103	0.202	0.292	0.373	0.441	0.499	0.546	0.584	0.615	0.639	0.674	0.703	0.725	0.740
0.9	0.108	0.211	0.306	0.391	0.463	0.524	0.574	0.615	0.647	0.673	0.711	0.742	0.766	0.784
1.0	0.112	0.219	0.318	0.405	0.481	0.544	0.597	0.639	0.673	0.701	0.740	0.774	0.800	0.816
1.2	0.117	0.229	0.333	0.425	0.505	0.572	0.628	0.674	0.711	0.740	0.783	0.820	0.849	0.868
1.5	0.121	0.238	0.345	0.440	0.525	0.596	0.650	0.703	0.742	0.774	0.820	0.861	0.894	0.916
2.0	0.124	0.244	0.355	0.454	0.540	0.613	0.674	0.725	0.766	0.800	0.849	0.894	0.930	0.956

Bc = Outside diameter of pipe (ft)

Cs = Load coefficient

Table 4C.4 Superimposed Concentrated Load Impact Factors, F.

Height of Cover	Impact Factor
0 - 1.0 ft.	1.3
1.1 - 2.0 ft.	1.2
2.1 - 2.9 ft.	1.1
3.0 ft. and greater	1.0

Table 4C.5 Equipment Loads

<u>Equipment</u>	<u>Operating Weight (lbs)</u>	<u>Ground Contact</u>	<u>Track or Wheel Load (lbs)</u>
Caterpillar D-6	32,850	181101 9.011	16,425 Track Load
Caterpillar D-8	81,950	2211x 1016.5	40,975 Track Load
Scrapers, loaded 21/31 cu yd capacity (631 D)	168,410	Wheel load	45,470 Drive Wheel Load
Compactor Caterpillar 825-C	71,429	81 Width Coverage	35,715 Roller Load

Adapted From: Caterpillar Performance Handbook, 1984

The load coefficient, Cs, is a function of D/2H and M/2H, in which H is the height from the top of the pipe to the ground surface and D and M are the width and length, respectively, or the area over which the distributed load acts. Table 4C.3 lists the values of the load coefficients for loads centered over the pipe. A method for determining the loads on the pipe from offset uniform loads may be found in ASCE and WPCF, 1982. A typical offset uniform load would be the waste fill placed inside and adjacent to a perimeter leachate collection system.

4C.2.4 Design Safety Factor

The factor of safety for a pipe is defined as the ratio of the maximum performance limit to the design or service performance limit. The selection of a suitable safety factor is an essential part of the structural design of leachate collection pipes. The factor of safety should be related either to an allowable working stress or to a pre-established ultimate failure condition. Factors of safety compensate for poor construction practice or for inadequate inspection. Properly established design performance values and adequate factors of safety must be realized in installation and operation to provide reasonable assurance of long-term leachate collection system performance.

The relationship between safety factors and design performance values is similar for rigid and flexible pipes. However, there are differences in the design requirements for each type of pipe and these affect the form of the safety factor associated with each.

4C.2.4.1 Rigid Pipe

Design performance limits for rigid pipes are expressed in terms of strength under load. Testing is generally used to determine the service strength for rigid pipe. Strengths of rigid pipe are measured in terms of 1) the ultimate three-edge bearing strength, and 2) the ultimate and 0.01-inch crack, three-edge bearing strengths for reinforced concrete pipe. A safety factor of 1.0 should be applied to the specified minimum ultimate three-edge bearing strength to determine the working strength for other rigid pipes (ASCE and WPCF, 1982). Common practice is to use a factor of safety of 1.25 for the ultimate load of reinforced concrete pipe, and up to 1.50 for vitrified clay.

4C.2.4.2 Flexible Pipe

Design performance limits for flexible pipes are most commonly expressed in terms of deflection. The design limit varies with different pipe materials and the pipe manufacturing process. Flexible pipes must be able to deflect without experiencing cracking, liner failure, or other distress; and they should be designed with a reasonable factor of safety.

Manufacturers should be consulted on the value of the deflection limits for various types of flexible pipes. The PVC pipe manufacturers suggest limiting the deflection of buried PVC pipe to 7-1/2 percent. This strain is one-fourth the minimum strain level at which cracking and reverse curvature reportedly occurs when subjecting PVC pipe to testing in accordance with ASTM D 2412. To maintain this same factor of safety (FS-4.0) with ABS pipe, the allowable strain for ABS pipe should be limited to 5-1/2 percent. The high safety factor of 4.0 is intended to compensate for the long-term effects of creep of the plastic. Dietzler (1984) suggests that deflections of ABS and PVC pipe should be limited to one-third the deflection at which reverse curvature of splitting occurs in ASTM D 2412, including a deflection lag factor.

4C.3 RIGID PIPE DESIGN

For reasons previously indicated rigid pipes have limited use potential in leachate collection systems. In situations where they are used, their structural design should follow the recognized procedures for the various rigid pipe products available. The design of rigid pipe systems relates to the product's performance limit, expressed in terms of strength of the installed pipe. When determining field strength of rigid pipes, it is convenient to classify the *installation conditions* as either trench or embankment. For each of these conditions, bedding classes and corresponding bedding factors have been developed for use in determining and the required pipe strength.

4C-3-1 Classes of Bedding and Bedding Factors

4C.3-1.1 Trench Beddings

Four general classes of bedding for installation of rigid pipes in a trench condition are illustrated in Figure 4C.6. The bedding factor for each of the classes of pipe bedding are also listed in Figure 4C.6. Because leachate collection pipes are normally installed with granular material *surrounding* the pipe, the appropriate bedding class is usually Class B with a bedding factor of 1.9.

4C.3.1.2 Embankment Beddings

Four general classes of bedding for the installation of rigid pipes in a positive projecting embankment condition are illustrated in Figure 4C.7. Most leachate collection lines installed in a positive projecting embankment condition would have Class B or C bedding, depending on the projection ratio, p , of the actual installation. For pipe installed in a positive projecting embankment condition, active lateral pressure is exerted against the sides of the pipe. The bedding factor, L_f , for this type of installation is computed by the equation:

$$L_f = \frac{A}{N-xq} \quad (4C-20)$$

where:	A	Pipe shape factor
	N	A parameter that is a function of the bedding class
	x	A parameter dependent on the area over which lateral pressure effectively acts
	q	Ratio of total lateral pressure to total vertical load on the pipe

For circular pipe, A has a value of 1.431. Values of N for various classes of bedding are given in Table 4C.6. Values of x are listed in Table 4C.7.

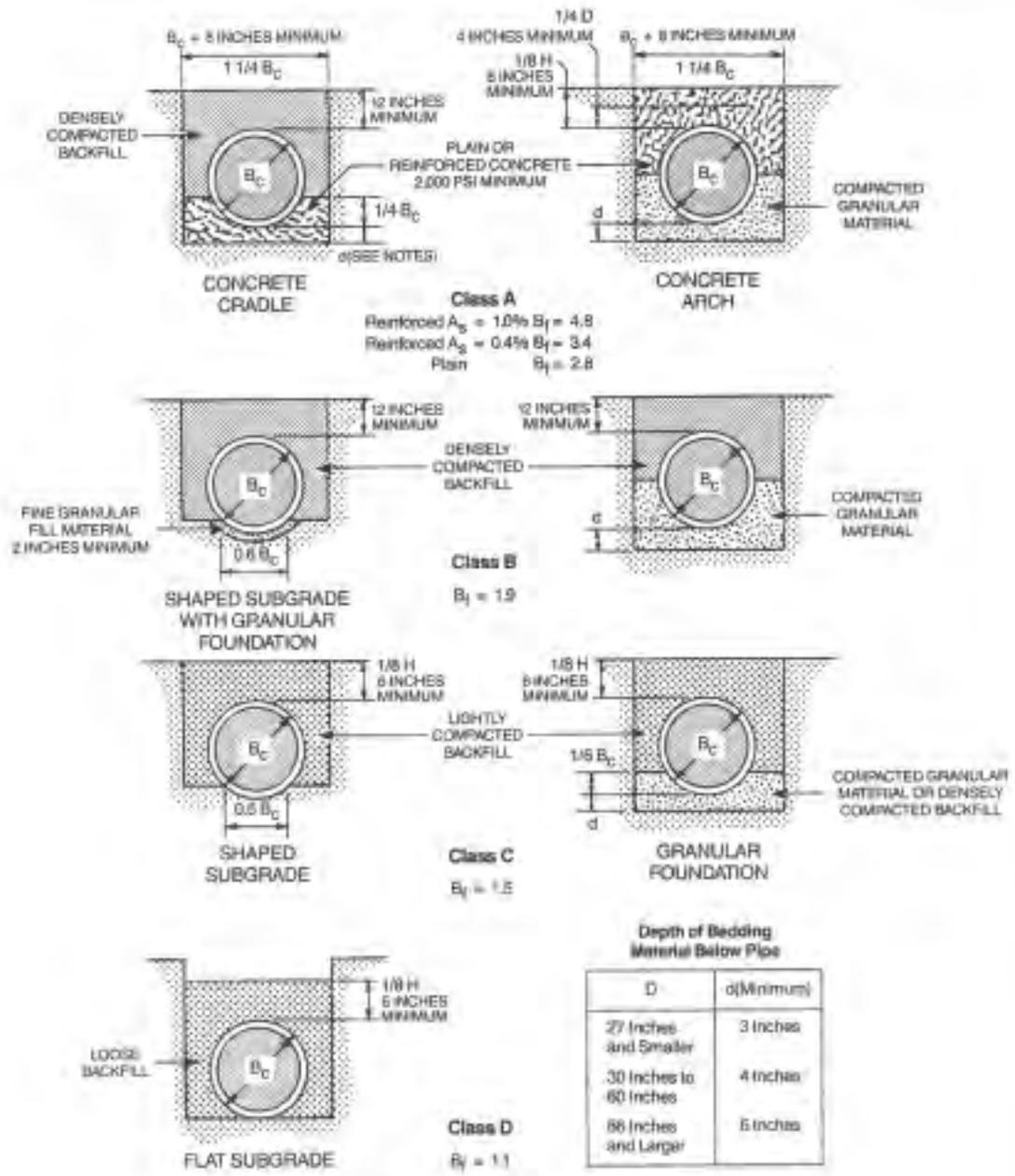


Figure 4C.6
Trench Beddings:
Circular Pipe

B_c = Outside Diameter D = Inside Diameter
 H = Backfill Cover Above Top of Pipe A_s = Area of Transverse Steel in the Cradle of Arch Expressed as a Percentage of Area of Concrete at Invert or Crown
 d = Depth of Bedding Material Below Pipe

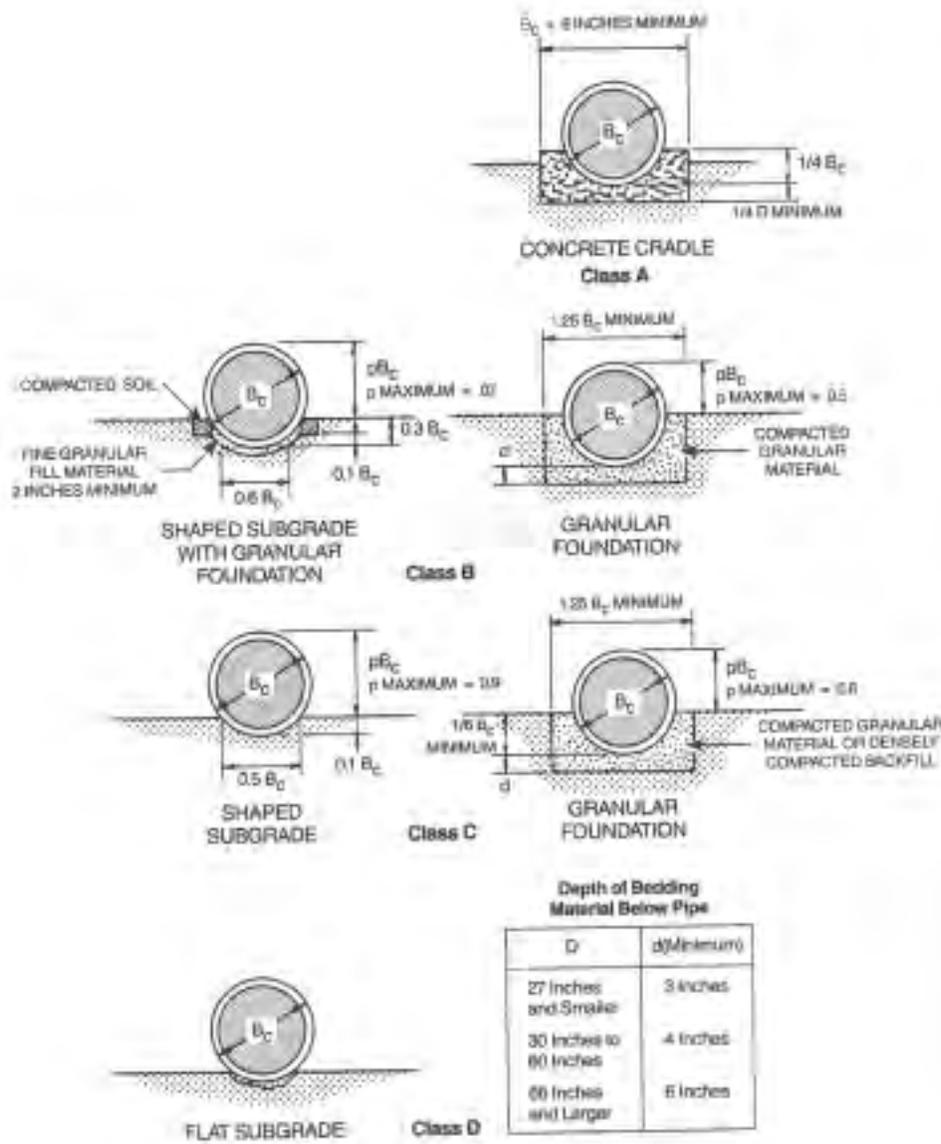


Figure 4C.7
Positive Projecting Embankment Beddings:
Circular Pipe

- B_c = Outside Diameter
- H = Backfill Cover Above Top of Pipe
- D = Inside Diameter
- d = Depth of Bedding Material Below Pipe

Table 4C.6 Values of N for Circular Pipe

<u>Class of Bedding</u>	<u>N</u>
A (reinforced cradle)	0.421 to 0.505
Aa (unreinforced cradle)	0.505 to 0.636
B	0.707
C	0.840
D	1.310

Adapted from: ASCE and WPCF (1982)

The projection ratio, m , in Table 4C.7 refers to the fraction of the vertical pipe diameter over which lateral pressure is effective. For pressure acting on the top half of the pipe above the horizontal diameter, m equals 0.5. Values for q may be estimated by the formula:

$$q = \frac{mk}{C_c} \left[\frac{H}{B_c} + \frac{m}{2} \right] \quad (4C-21)$$

where: k Ratio of unit lateral pressure to unit vertical pressure (Rankine's ratio)

A value of k equal to 0.33 usually be sufficiently accurate. Values of C_c may be found in Figure 4C.4.

Table 4C.7 Values of x for Circular Pipe

<u>Fraction of Pipe Subjected to Lateral Pressure, m</u>	<u>Class A Bedding</u>	<u>Other Than Class A Bedding</u>
0	0.150	0
0.3	0.743	0.217
0.5	0.856	0.423
0.7	0.811	0.594
0.9	0.678	0.655
1.0	0.638	0.638

Adapted from: ASCE and WPCF (1982)

The classes of bedding for rigid pipes installed in a negative projecting embankment condition are the same as those for the trench condition. The trench condition bedding factors listed in Figure 4C.6 should be used for

negative projecting embankment installations. For leachate collection lines, this would generally be Class B bedding and a bedding factor of 1.9.

4C.3.2 Selection of Pipe Strength

The design strength of rigid pipes is commonly related to a three-edge bearing strength measured at the manufacturing plant in accordance with recognized national testing standards. For pipes installed under specified conditions of bedding and backfilling, the required three-edge bearing strength for a given class of bedding and design load can be determined from the following:

$$\text{Required Three Edge Bearing Strength (lb/ft)} = \frac{\text{Design Load (lb/ft)} \times \text{Factor of Safety}}{\text{Bedding Factor}}$$

The strength of reinforced concrete pipe at either the 0.01-inch crack or ultimate load divided by the internal diameter of the pipe is defined as the D-load strength. The D-load concept provides strength classification of pipe independent of pipe diameter. The required three-edge bearing strength of reinforced concrete pipe expressed as D-load is determined by the following equation:

$$\text{D-Load (lbs)} = \frac{\text{Design Load (lbs/ft)} \times \text{Safety Factor}}{\text{Bedding Factor} \times \text{Diameter (ft)}}$$

The above equations are applicable to rigid pipes installed in both trench conditions and embankment conditions. After determining the design load, the selection of the pipe strength involves applying the appropriate safety factor and bedding factor for the installation conditions in either of the above equations.

4C.4 FT BLE PIPE DESIGN

4C.4.1 General Approach

Flexible pipes derive the majority of their load supporting ability from the passive resistance of the soil in side fills as the pipe deflects under load. Because of this resistance, it is important to examine the interaction between the bedding or fill material and the pipe, rather than simply studying pipe characteristics. The extent to which flexible pipe deflects as installed is most commonly used as a basis for design since it reflects this interaction. The approximate long-term deflection of flexible pipe in place can be calculated using the Modified Iowa Formula developed by Spangler and Watkins (ASCE and WPCF, 1982):

$$Y = \frac{D_i K_b W_c r^3}{EI + 0.061 E' r^3} \quad (4C-22)$$

where: Y = Vertical deflection (inches), assumed to approximately equal horizontal deflection

- D_1 = Deflection lag factor
- K_b = Bedding constant
- W_c = Load (lbs/inch)
- r = Mean radius of pipe (inches)
- E = Modulus of tensile elasticity (lbs/sq in)
- I = Moment of inertia per length (in⁴/in)
- E' = Modulus of soil reaction (lbs/sq in)

The above equation can be rewritten to express pipe deflection as a decimal fraction of the pipe outside diameter, B_c , and relate it to the vertical stress on the pipe, P_v , as follows:

$$\frac{W_c}{B_c} = P_v = \frac{Y(EI + 0.061 E'n^3)}{B_c(D_1K_b r^3)} \quad (4C-23)$$

Pipe manufacturers may establish limits for pipe deflection or vertical stress on the pipe (P_v). Maximum vertical stress is often referred to as critical buckling pressure.

The deflection lag factor, D_1 , compensates for time consolidation of the bedding, which may permit flexible pipes to continue to deform after installation. Long-term deflection will be greater with low degrees of compaction of the bedding in the side fills compared to higher degrees of compaction. Values recommended for this factor range from 1.25 to 1.50 (ASCE and WPCF, 1982), although values over 2.5 have been recorded in dry soil. A deflection lag factor of 2.0 may be realistic for design of leachate collection pipes if weathering and/or softening of the bedding material is likely to occur over the life of the landfill or if the bedding material is rounded or may be placed with minimal compaction (Dietzler, 1984).

Values for the bedding constant, K_b , are listed in Table 4C.8. Spangler's data suggested a K_b value of 0.10 for pipe embedded in native soil with no bedding and a K_b value of 0.083 for pipe embedded in gravel up to the spring line. The installation of leachate collection pipes is more closely represented by the latter case, and a K_b value of 0.083 should therefore be used in lieu of actual field data.

Table 4C.8. Values of Bedding Constant, K_b -

Bedding Angle (Degrees)	K_b
0	0.110
30	0.108
45	0.105
60	0.102
90	0.096
120	0.090
180	0.083

Source: ASCE and WPCF (1982)

Values for the soil reaction modulus, EI , range from 0 to 3,000, depending on the soil type of the bedding material and relative degree of compaction (ASCE and WPCF, 1982). The use of a high value for EI is not realistic for leachate collection pipes in many localities (Dietzler, 1984). In a situation where a rounded river gravel will be used for the bedding material and a high degree of compaction may be unobtainable in the bedding around the leachate collection pipe, a realistic value for E , of 400 may be appropriate (Dietzler, 1984).

The first term in the denominator (EI) of the Modified Iowa Formula is the stiffness factor and reflects the influence of the inherent stiffness of the pipe on deflection. The second term, $0.061 EI d$, reflects the influence of the passive pressure on the side of the pipe. With flexible pipes, the second term is normally predominant.

After the allowable strain level in the pipe has been determined, the design procedure for flexible pipes is to perform a trial and adjustment analysis to find a class of pipe that will result in deflections less than the established limit. There are slight variations in the procedure for the various types of flexible pipe.

4C.4.2 Selection of Plastic Pipe

The standard test to determine pipe stiffness or the load deflection characteristic of plastic pipe is the parallel-plate loading test conducted in accordance with ASTM D 2412. The test determines the pipe stiffness, PS , at a prescribed deflection, Y , which for convenience in testing is arbitrarily set at 5 percent. The pipe stiffness is defined as the value obtained by dividing the load per unit length, F , by the resulting deflection at the prescribed percentage deflection:

$$PS = \frac{F}{Y} \quad (4C-24)$$

The stiffness factor, SF, in the Modified Iowa Formula is related to the pipe stiffness by the following expression:

$$SF = EI = 0.149r^3(PS) \quad (4C-25)$$

in which the terms are as previously defined.

For circular plastic pipes, the approximate deflection based on pipe stiffness can be determined by using the following simplified version of the Modified Iowa Formula:

$$Y = \frac{D_1 K_b W_c}{0.149(PS) + 0.061 E'} \quad (4C-26)$$

The pipe stiffness for the various plastic pipe materials and diameters of pipe may be obtained from the manufacturer or may be determined by tests performed in accordance with ASTM D 2412.

4C.4.3 Selection of Other Flexible Pipes

Flexible pipes of material other than plastic, such as ductile iron and corrugated metal, have little potential for general use in leachate collection systems for reasons previously discussed. However, if they are found suitable for a specific installation, their structural design should follow recognized procedures for the particular flexible pipe being considered. Procedures for designing ductile iron and corrugated metal pipes are described in ASCE and WPCF (1982). Manufacturers of the specific products should also be consulted.

4C.4.4 Bedding Material

Bedding provides a: contact between a pipe and the foundation on which it rests. The total load that a pipe will support depends on the width of the contact area and the quality of the contact between the pipe and the bedding material. The influence of the bedding on the supporting strength of the pipe is a factor that must be considered in the design of a leachate collection pipe. This section discusses bedding material considerations. More detailed requirements are given in previous sections of this Appendix.

An important consideration in selecting a material for bedding is positive contact between the bed and the pipe. A well-graded crush stone or a well-graded gravel are suitable bedding materials based on supporting strength considerations, and both are more suitable than a uniformly graded pea gravel (ASCE and WPCF, 1982). Larger particle sizes give greater stability; however, the maximum size and shape of the bedding material should be related to the pipe material and the recommendations of the manufacturer. For small pipes, the maximum size of the bedding material should be limited to about 10 percent of the pipe diameter and, in general, well-graded crush stone or gravel ranging in size from 3/4 inch to the No. 4 sieve will provide the most satisfactory pipe bedding (ASCE and WPCF, 1982).

In addition to providing support, bedding for leachate collection pipes must allow unrestricted flow of leachate through the bedding into the perforated leachate collection pipes. The bedding material must also be resistant to attack from the leachate. Redundancy in the design of leachate collection systems is important to minimize the effects of failures when they occur. One of the primary ways to provide redundancy is to design the bedding to meet drainage requirements through the gravel layer alone if flow through the pipe is restricted (Bass, 1984).

A well-graded material with 100 percent passing the 1-1/2 inch clear, square screen openings and not more than 5 percent passing the No. 50 U.S. Standard Series sieve is recommended for drainage purposes (U.S. Department of the Interior, 1978). To determine whether the material is well-graded, the coefficient of uniformity which describes the slope of the gradation curve must be greater than 4 for gravels and greater than 6 for sands. In addition, the coefficient of curvature that describes the shape of the curve must be between 1 and 3 for both gravels and sands. These coefficients are defined as follows:

$$\text{Coefficient of uniformity, } C_u, = \frac{D_{60}}{D_{10}} \quad (4C-27)$$

and

$$\text{Coefficient of curvature, } C_c, = \frac{(D_{30})^2}{(D_{10})(D_{60})} \quad (4C-28)$$

where: D_{10} , D_{30} , and D_{60} Diameter of particles in millimeters passing the 10, 30, and 60 percent points, respectively, on the base material gradation curve.

Based on the above criteria for supporting strength and drainage, a bedding material for leachate collection pipes should be well-graded gravel with the following properties:

Gradation:	100% passing 1-1/2" sieve 5% maximum passing No. 50 sieve
C_u :	4.0 or greater
C_c :	1.0 to 3.0

The actual bedding material should be selected within these limits after consideration of the pipe material, availability of bedding material, and its resistance to leachate attack.

**APPLICATION FOR PERMIT
SUNDANCE WEST**

**VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 5: PIPE LOADING CALCULATIONS**

ATTACHMENT III.5.D

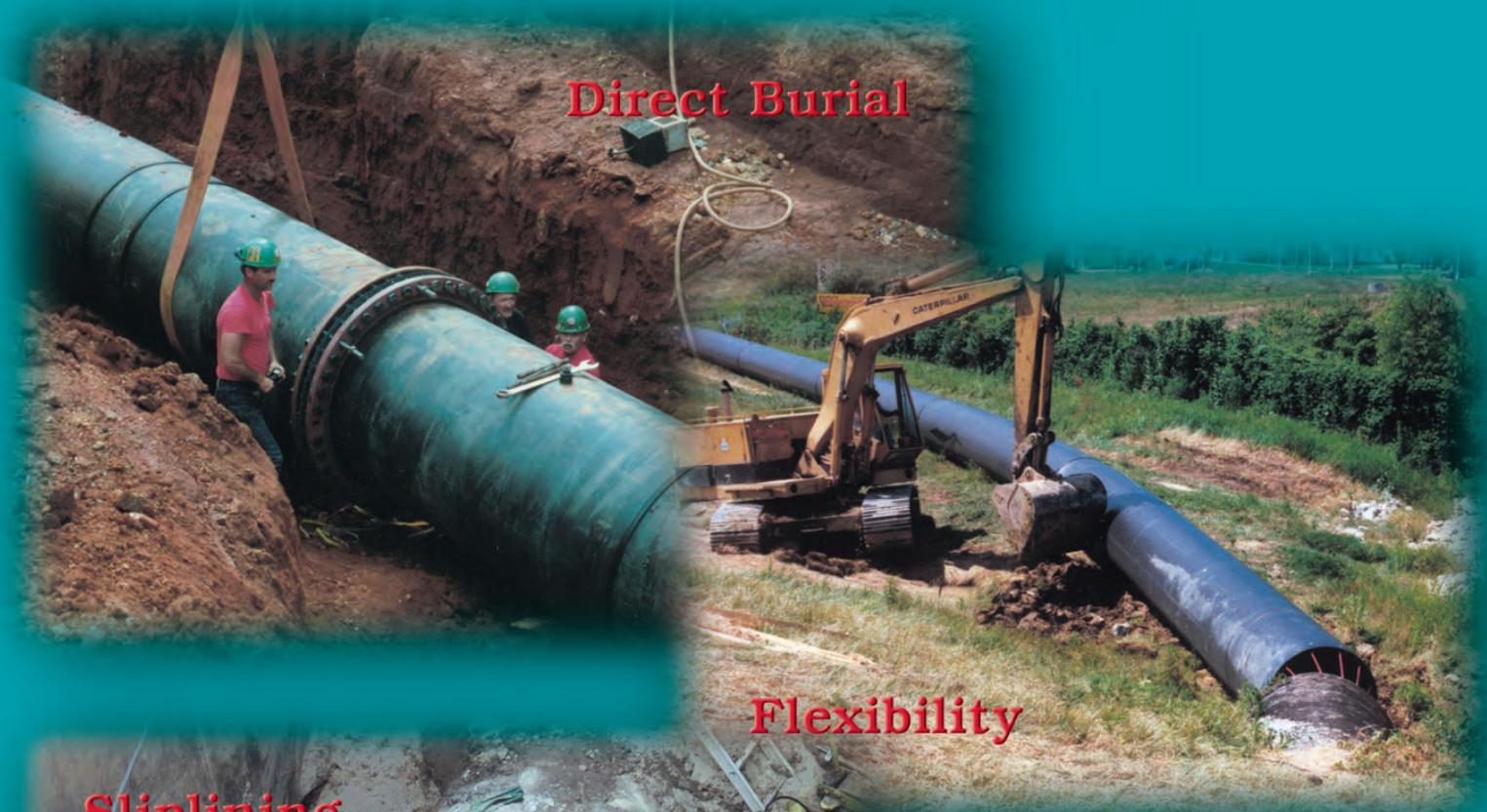
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Flexibility



Sliplining

Marine Applications



*Design and Engineering Guide
for Polyethylene Piping*

Table A-2 (cont'd)
PIPE WEIGHTS AND DIMENSIONS (IPS)
PE3608 (BLACK)

OD			SDR	Nominal ID		Minimum Wall		Weight	
Nominal in.	Actual			in.	mm.	in.	mm.	lb. per foot	kg. per meter
	in.	mm.							
			7	2.44	61.98	0.500	12.70	2.047	3.047
			7.3	2.48	63.08	0.479	12.18	1.978	2.943
			9	2.68	67.96	0.389	9.88	1.656	2.464
			9.3	2.70	68.63	0.376	9.56	1.609	2.395
			11	2.83	71.77	0.318	8.08	1.387	2.065
3	3.500	88.90	11.5	2.85	72.51	0.304	7.73	1.333	1.984
			13.5	2.95	74.94	0.259	6.59	1.153	1.716
			15.5	3.02	76.74	0.226	5.74	1.015	1.511
			17	3.06	77.81	0.206	5.23	0.932	1.386
			21	3.15	79.93	0.167	4.23	0.764	1.136
			26	3.21	81.65	0.135	3.42	0.623	0.927
			7	3.14	79.68	0.643	16.33	3.384	5.037
			7.3	3.19	81.11	0.616	15.66	3.269	4.865
			9	3.44	87.38	0.500	12.70	2.737	4.073
			9.3	3.47	88.24	0.484	12.29	2.660	3.958
			11	3.63	92.27	0.409	10.39	2.294	3.413
4	4.500	114.30	11.5	3.67	93.23	0.391	9.94	2.204	3.280
			13.5	3.79	96.35	0.333	8.47	1.906	2.836
			15.5	3.88	98.67	0.290	7.37	1.678	2.497
			17	3.94	100.05	0.265	6.72	1.540	2.292
			21	4.05	102.76	0.214	5.44	1.262	1.879
			26	4.13	104.98	0.173	4.40	1.030	1.533
			32.5	4.21	106.84	0.138	3.52	0.831	1.237
			7	3.88	98.51	0.795	20.19	5.172	7.697
			7.3	3.95	100.27	0.762	19.36	4.996	7.435
			9	4.25	108.02	0.618	15.70	4.182	6.224
			9.3	4.29	109.09	0.598	15.19	4.065	6.049
			11	4.49	114.07	0.506	12.85	3.505	5.216
5	5.563	141.30	11.5	4.54	115.25	0.484	12.29	3.368	5.012
			13.5	4.69	119.11	0.412	10.47	2.912	4.334
			15.5	4.80	121.97	0.359	9.12	2.564	3.816
			17	4.87	123.68	0.327	8.31	2.353	3.502
			21	5.00	127.04	0.265	6.73	1.929	2.871
			26	5.11	129.78	0.214	5.43	1.574	2.343
			32.5	5.20	132.08	0.171	4.35	1.270	1.890
			7	4.62	117.31	0.946	24.04	7.336	10.917
			7.3	4.70	119.41	0.908	23.05	7.086	10.545
			9	5.06	128.64	0.736	18.70	5.932	8.827
			9.3	5.11	129.92	0.712	18.09	5.765	8.579
			11	5.35	135.84	0.602	15.30	4.971	7.398
6	6.625	168.28	11.5	5.40	137.25	0.576	14.63	4.777	7.109
			13.5	5.58	141.85	0.491	12.46	4.130	6.147
			15.5	5.72	145.26	0.427	10.86	3.637	5.413
			17	5.80	147.29	0.390	9.90	3.338	4.967
			21	5.96	151.29	0.315	8.01	2.736	4.072
			26	6.08	154.55	0.255	6.47	2.233	3.322
			32.5	6.19	157.30	0.204	5.18	1.801	2.680

See ASTM D3035, F714 and AWWA C-901/906 for OD and wall thickness tolerances.
Weights are calculated in accordance with PPI TR-7.

EARTHLOADING

PolyPipe[®], due to its flexibility, will deflect when it is buried. The degree of deflection will depend upon the soil conditions, burial conditions, trench width, and the depth of burial. The degree of deflection of the pipe is limited by the soil around its periphery, especially in the lateral direction. When the soil compacts around the pipe, there is a supportive effect from the soil itself, and as compaction occurs, there is soil friction and cohesion over the pipe that reduces the direct load on the pipe.

PolyPipe[®], as do other flexible conduits, depends on the surrounding soil for support, and has to be considered as one component in a pipe/soil system. The presence of the soil arch and the support derived from the lateral movement limitations are highly beneficial to the efficiency of the system. Therefore, the flexibility of **PolyPipe**[®] is the major reason for these advantages. As has been stated, the durability of polyethylene is the reason for its resistance to high levels of mechanical abuse, and this is no less true for buried systems where forced deflections may occur due to subsidence, washout and settlement.

External loading analysis must be conducted to determine the application's feasibility. There are two loading calculations necessary when designing or engineering below ground applications of **PolyPipe**[®]. These calculations are ring deflection and wall buckling. Wall crushing, calculated using the allowable compressive strength of the PE material, is usually not critical when using solid wall **PolyPipe**[®], as ring deflection and wall buckling are predominant parameters.

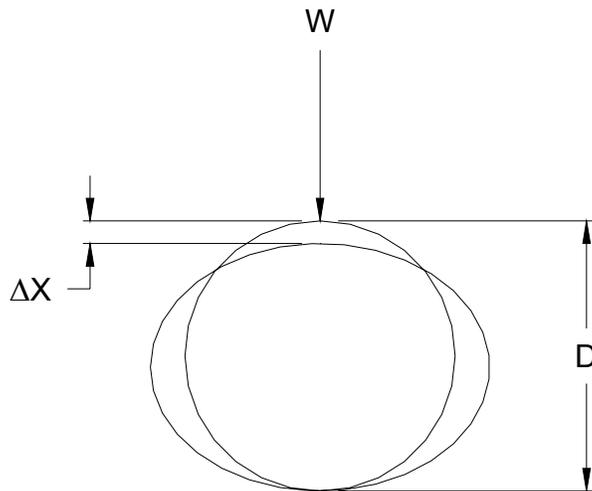
RING DEFLECTION

PolyPipe[®], when buried in loose soil conditions, will exhibit the tendency to deflect, called ring deflection. Listed below are the recommended maximum allowable design limits for ring deflection of **PolyPipe**[®] for the different available Dimension Ratios (DR).

Table C-1
Design Limits for Ring Deflection

DR	Safe Deflection, % of Diameter
32.5	8.0
26	7.0
21	6.0
17	5.0

Figure C-1



PolyPipe®, due to its inherent physical properties of flexibility, resilience and toughness can withstand significant deflection without failure. It can be flattened without causing a fracture of the pipe wall. However, this condition is unacceptable as far as service is concerned. A deflection of 15% would be acceptable for a butt fused polyethylene system, although a reduction in flow would be noted. It would also be difficult to utilize conventional cleaning equipment with this severity of deflection. Ring deflection resulting in hydraulic flow area reductions should be taken into account when engineering the flow characteristics. Refer to Table C-2 for the percentage of area reduction based on percent of ring deflection.

Table C-2
AREA REDUCTION DUE TO RING DEFLECTION

Ring Deflection, %	Area Reduction, %
2	0.04
4	0.16
5	0.25
6	0.36
8	0.64
10	1.00
12	1.44
14	1.96
15	2.25
16	2.56

In calculating the soil load placed on a buried pipe, the designer must be able to calculate to some degree of accuracy the type and condition of the backfill material. Saturated clay would be more difficult to place and adequately compact than would coarse granular material that would not stick together. It is important in the pipe/soil system that the backfill material utilized for haunching and initial backfill (see Installation, Section F, for explanation of terminology) be granular and non-cohesive, free of debris, organic matter, frozen earth and rocks larger than 1½ inch in diameter. This material can be described as Class I or II of ASTM D2321 "Angular ¼ to 1½ inch Graded Stone, Slag, Cinders, Crushed Shells and Stone or Sands and Gravel Containing Small Percentages of Fines, Generally Granular and Non-Cohesive, Wet or Dry." This material can easily be worked into the pipe haunch, and compacted in approximately 4-6 inch lifts.

To determine the ring deflection of externally loaded **PolyPipe®**, you must first determine the earthload in pounds per linear inch of pipe by use of the following modified Marston formula⁵:

$$W = \frac{C_d \cdot \rho \cdot B_d \cdot D}{144} \quad (17)$$

Where

- W = Earthload per unit length of pipe, lbs/in
- C_d = Trench Coefficient, (dimensionless) (See Figure C-2)
- ρ = Soil density, lbs/ft³
- D = Outside diameter, inches
- B_d = Trench width at top of pipe, feet

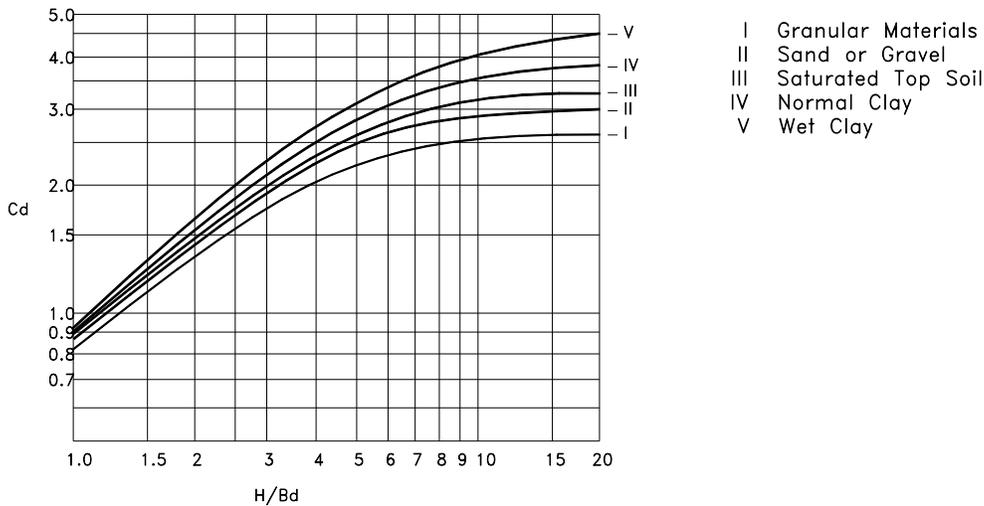
⁵ Moser, A.P. Buried Pipe Design. 2nd Edition. New York: McGraw-Hill, 2001.

**Table C-3
CLASSIFICATION OF BACKFILL MATERIAL
PER ASTM D2321***

Class	Comments
<u>Class I</u> - Angular graded stone, ¼" to 1½", including a number of fill materials that have regional significance such as coral, slag, cinders, crushed stone, crushed gravel and crushed shells.	100 - 200 pounds per cubic foot. Pipe sizes less than 10" should limit maximum particle size to ½" to ¾" for ease of placement.
<u>Class II</u> - Coarse sands and gravel with maximum particle size of 1½", including variously graded sands and gravel containing small percentages of fines, generally granular and non-cohesive, wet or dry.	110 - 130 pounds per cubic foot. Pipe sizes less than 10" should limit maximum particle size to ½" to ¾" inch for ease of placement.
<u>Class III</u> - Fine sand and clay gravel, including fine sands, sand-clay mixtures, and gravel-clay mixtures.	140 - 150 pounds per cubic foot.
<u>Class IV</u> - Silt, silty clays, and clays, including inorganic clays and silts of medium to high plasticity and liquid limits.	150 - 180 pounds per cubic foot.
<u>Class V</u> - Includes organic soils as well as soils containing frozen earth, debris, rocks larger than 1½" in diameter, and other foreign materials.	Not recommended for backfill except in the final backfill zone.

* For further classification of soils the designer may want to review ASTM D2487, "Standard Test Method for Classification of Soil for Engineering Purposes."

**Figure C-2
TRENCH COEFFICIENT, C_d
DEPENDENT ON SOIL TYPE AND DITCH CONFIGURATION**



In general practice, the trench width can be kept to a minimum of six inches per side greater than the pipe diameter itself. Although this may seem narrow in comparison to trenching of conventional materials, it must be noted that **PolyPipe®** can be pre-assembled above ground and later placed into the trench. The trench width should be maintained as narrow as possible as the soil loading on the pipe is a relationship of the trench width.

The linear deflection of the pipe can be calculated from the following modified Spangler equation⁶:

$$\Delta x = \frac{D_i \cdot K \cdot W}{\left(\frac{2E}{3(DR-1)^3} \right) + 0.061E'} \quad (18)$$

- Where
- Δx = Horizontal deflection or change in diameter, inches
 - D_i = Deflection lag factor, **PolyPipe**[®] recommends 1.0 (dimensionless)
 - K = Bedding constant, **PolyPipe**[®] recommends 0.1 (dimensionless)
 - W = Earthload, lbs/inch (See Equation (17))
 - E = Modulus of elasticity of pipe, 30,000 psi
 - E' = Soil modulus, psi
 - DR = Dimension ratio, (dimensionless)

* For further values of K see reference.

The percent deflection can be calculated by use of the following formula⁶:

$$d = \frac{\Delta x}{D} \cdot 100 \quad (19)$$

- Where
- d = Percent deflection, %
 - Δx = Horizontal deflection, inches (See Equation (18))
 - D = Outside diameter, inches

**Table C-4
TYPICAL SOIL MODULUS VALUES (PSI)**

Type of Soil	Depth of Cover		Standard AASHTO relative compaction			
	ft	m	85%	90%	95%	100%
Fine-grained soils with less than 25% sand content (CL, ML, CL-ML)	0-5	0-1.5	500	700	1000	1500
	5-10	1.5-3.1	600	1000	1400	2000
	10-15	3.0-4.6	700	1200	1600	2300
	15-20	4.6-6.1	800	1300	1800	2600
Coarse-grained soils with fines (SM., SC)	0-5	0-1.5	600	1000	1200	1900
	5-10	1.5-3.0	900	1400	1800	2700
	10-15	3.0-4.6	1000	1500	2100	3200
	15-20	4.6-6.1	1100	1600	2400	3700
Coarse-grained soils with little or no fines (SP, SW, GP, GW)	0-5	0-1.5	700	1000	1600	2500
	5-10	1.5-3.0	1000	1500	2200	3300
	10-15	3.0-4.6	1050	1600	2400	3600
	15-20	4.6-6.1	1100	1700	2500	3800

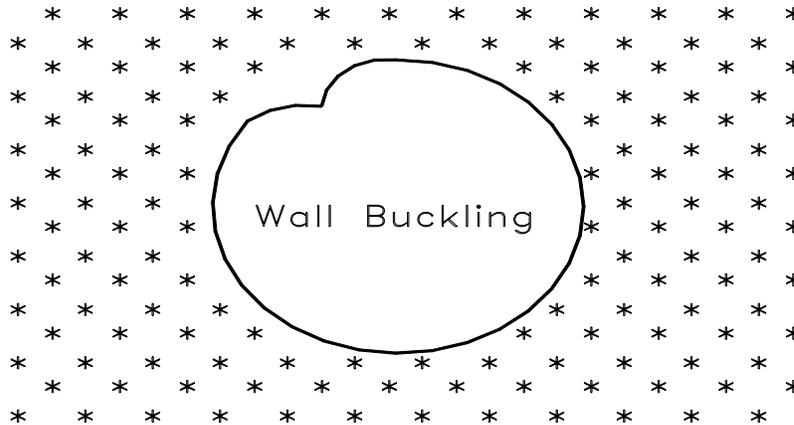
⁶ Plastics Pipe Institute. Underground Installation of Polyethylene Pipe, 1996.

Values of modulus of soil reaction, E' (psi) based on depth of cover, type of soil, and relative compaction. Soil type symbols are from the United Classifications System. Source: Hartley, James D. and Duncan, James M., "E' and its Variation with Depth," Journal of Transportation, Division of ASCE, Sept. 1987.

WALL BUCKLING

PolyPipe[®], when buried in dense soil conditions and subjected to excessive external loading, will exhibit the tendency of wall buckling. As seen in Figure C-3, wall buckling is a longitudinal wrinkle that usually occurs between the 10:00 and 2:00 positions. Wall buckling should become a design consideration when the total vertical load exceeds the critical buckling stress of **PolyPipe**[®].

Figure C-3



Vertical loading can be determined by the summation of the calculated dead load (load resulting from backfill overburden and static surface loads) and live load (loads resulting from cars, trucks, trains, etc.).

BACKFILL LOAD¹

$$P_b = \frac{\rho_{soil} \cdot H}{144} \quad (20)$$

Where P_b = Backfill load, psi
 ρ_{soil} = Backfill density, lbs/ft³
 H = Height of backfill above pipe, feet

SURFACE LOAD

Surface loads are those forces exerted by permanent structures in close proximity to buried **PolyPipe**[®]. These loads can be buildings, storage tanks, or other structures of significant weight that could add to the backfill loading. The force exerted on **PolyPipe**[®] by structural surface loads can be approximated by use of the following Boussinesq¹⁷ formulation:

$$P_s = \frac{3Lz^3}{144 \cdot 2\pi R^5} \quad (21)$$

Where P_s = Surface load on pipe, psi
 L = Static surface load, lbs.
 z = Vertical distance from top of pipe to surface load level, feet
 R = Straight line distance from the top of pipe to surface load, feet

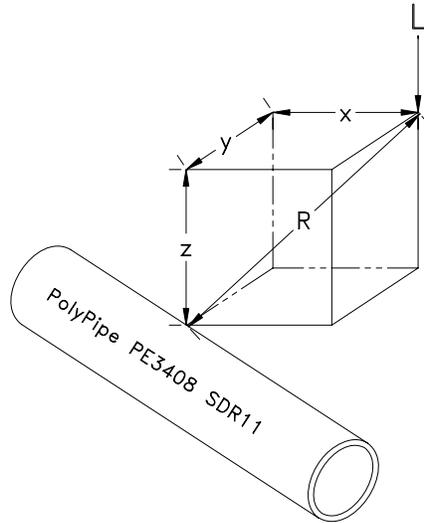
Where,

¹ Nayyar, Mohinder L. Ed. Piping Handbook, 6th Edition. New York: McGraw-Hill, Inc., 1992.
¹⁷ Chen, W. F., Liew, Richard L. Y. The Civil Engineering Handbook. New York: CRC Press, 2003. 2nd Edition.

$$R = \sqrt{x^2 + y^2 + z^2} \quad (22)$$

Where x = Horizontal distance from surface load, feet (Refer to Figure C-4)
 y = Horizontal distance from surface load, feet (Refer to Figure C-4)
 z = Vertical distance from top of pipe to surface load level, feet (Refer to Figure C-4)

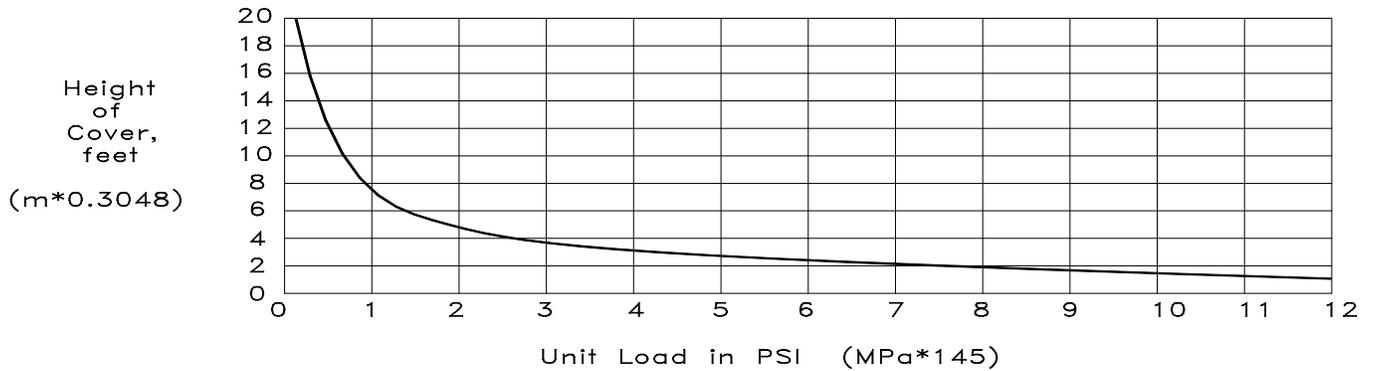
**Figure C-4
 RESULTANT SURFACE LOAD**



LIVE LOAD

Live loading can be determined by extracting the load from Figure C-5 for H20 highway loading or from Figure C-6 for Cooper E-80 loading or by estimating, using available analytical techniques.

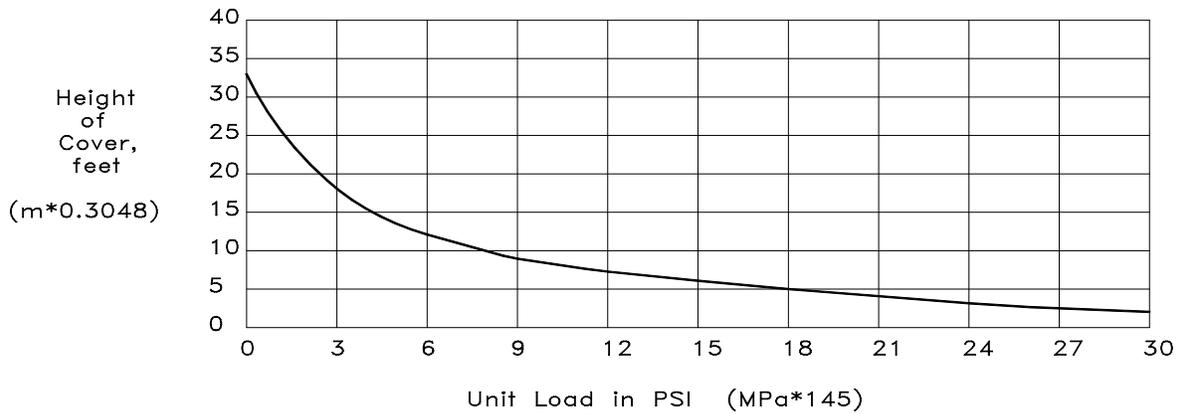
**Figure C-5
 H20 HIGHWAY LOADING**



Note: The H20 live load assumes two 16,000 lb. loads applied to two 18" x 20" areas, one located over the point in question, and the other located at a distance of 72" away. In this manner, a truckload of 20 tons is simulated.

Source: American Iron and Steel Institute, Washington, DC

**Figure C-6
COOPER E-80**



Note: The Cooper E-80 live load assumes 80,000 pounds applied to three 2' x 6' areas on 5' centers, such as might be encountered through live loading from a locomotive with three 80,000 pounds axle loads.

Source: American Iron and Steel Institute, Washington, DC

TOTAL EXTERNAL LOADING

Total Load = Live Load + Backfill Load + Surface Load

$$P_t = P_l + P_b + P_s \tag{23}$$

Once the external loading on buried **PolyPipe®** has been determined, it will be necessary to calculate the critical buckling stress for contained **PolyPipe®** to determine if the pipe can withstand the external loading. The external loading capacity, or critical buckling stress, can be determined by the use of the following Von Mises formula:

$$P_{cb} = \frac{1}{SF} \cdot \left(\frac{2.67 \cdot R_w \cdot B \cdot E_s \cdot E}{DR^3} \right)^{1/2} \tag{24}$$

- Where P_{cb} = Critical buckling stress, psi
- SF = Safety factor, **PolyPipe®** recommends SF=2
- R_w = Water buoyancy factor, (dimensionless)
- B = Empirical Coefficient of Elastic Support, (dimensionless)
- E_s = Soil modulus, (See Table C-4)
- E = Pipe modulus of elasticity, psi
- DR = Dimension Ratio

Where,

$$R_w = 1 - \left(0.33 \cdot \frac{H_w}{H} \right) \tag{25}$$

- H_w = Height of water table above pipe, feet
- H = Height of soil cover above pipe, feet

Note: H_w must be less than H

and,

$$B = \frac{1}{1 + 4 \cdot e^{-0.065 \cdot H}} \quad (26)$$

Where $e = 2.718$
 $H =$ Height of soil cover above pipe, feet

If the total external loading, Equation (23), is less than the critical buckling stress ($P_t < P_{cb}$), then the application should be considered safe. However, if this is not the case ($P_t > P_{cb}$), then the required parameters can be determined for a safe application from the following variations of the above equation:

$$DR = \left(\frac{2.67 \cdot R_w \cdot B \cdot E_s \cdot E}{SF^2 \cdot P_{cb}^2} \right) \quad (27)$$

or

$$E_s = \frac{P_{cb}^2 \cdot SF^2 \cdot DR^3}{2.67 \cdot R_w \cdot B \cdot E} \quad (28)$$

NOTICE:

The data contained herein is a guide to the use of **PolyPipe**[®] polyethylene pipe and fittings and is believed to be accurate and reliable. However, general data does not adequately cover specific applications, and its suitability in particular applications should be independently verified. In all cases, the user should assume that additional safety measures might be required in the safe installation or operation of the project. Due to the wide variation in service conditions, quality of installation, etc., no warranty or guarantee, expressed or implied, is given in conjunction with the use of this material.

**APPLICATION FOR PERMIT
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**VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 5: PIPE LOADING CALCULATIONS**

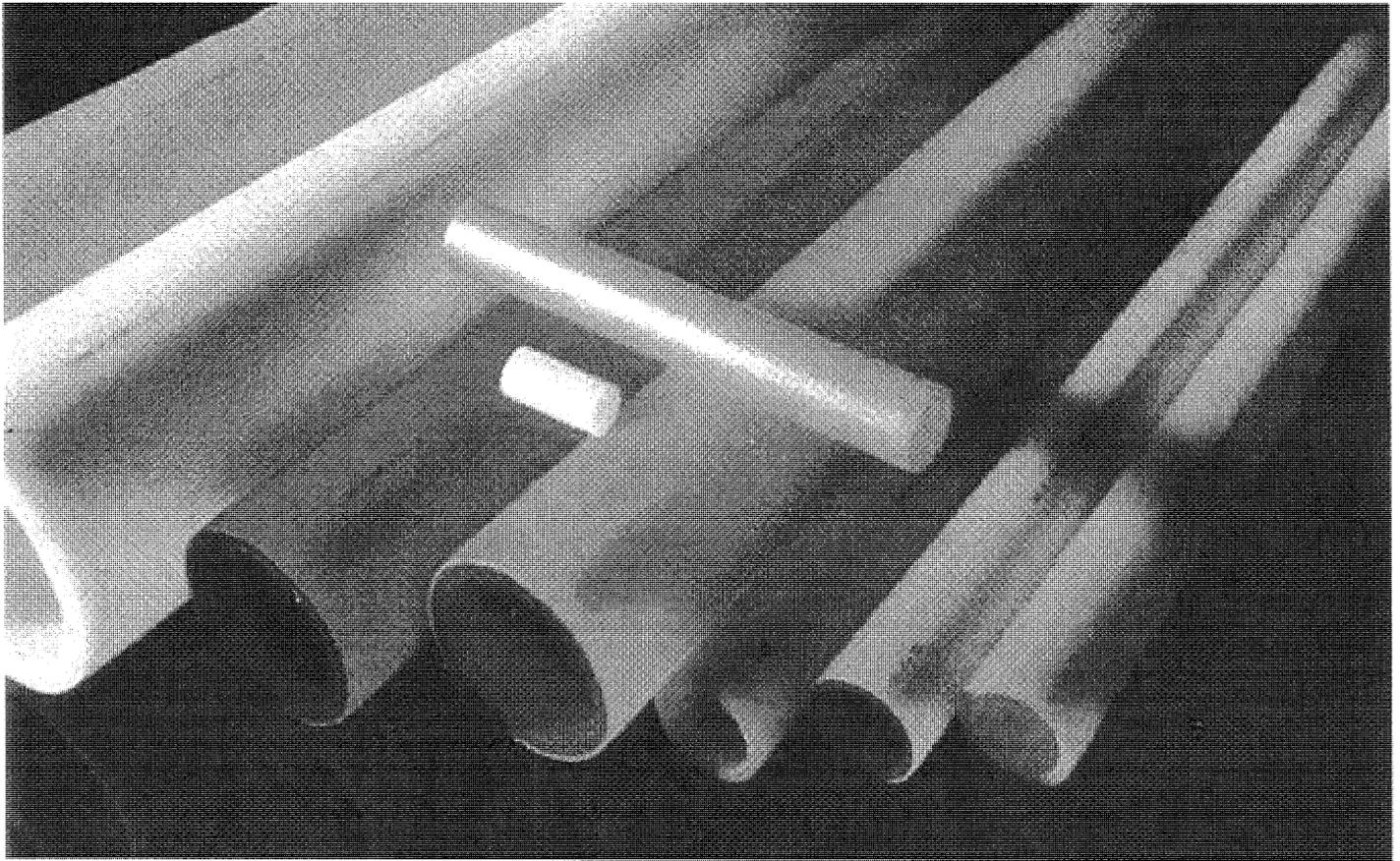
ATTACHMENT III.5.E

DRISCOPIPE, INC. 2008.

POLYETHYLENE PIPING SYSTEMS MANUAL



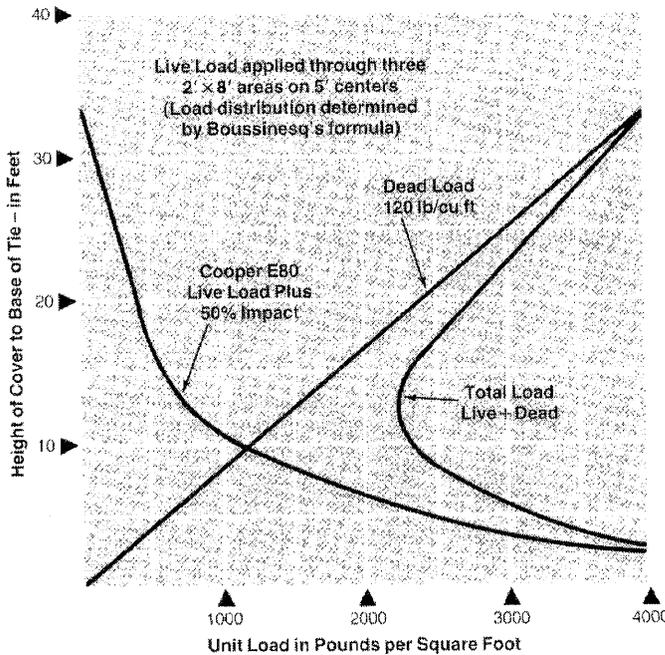
Polyethylene Piping Systems Manual



*Innovative Supplier of
Quality Piping Systems.*



FIGURE 6: COOPER E-80 LIVE LOADING



Note: Cooper E-80 live load assumes 80,000 pounds applied to three 2' x 8' areas on 5' centers such as might be encountered through live loading from a locomotive with three 80,000 pound axle loads.

Source: American Iron and Steel Institute, Washington, DC

APPARENT EXTERNAL PRESSURE DUE TO INTERNAL VACUUM, P_1 Vacuum generates a compressive hoop stress in the wall of a pipe and acts to collapse the pipeline. Under vacuum conditions, the value of P_1 is positive. P_1 is added to the other two external pressure components, P_S and P_L , to obtain the total external pressure, P_T , acting on the pipe. An internal vacuum generates pressure equal to the absolute value of the vacuum. The maximum apparent external pressure due to a vacuum inside the pipe is 14.7 psi (2,117 psf).

BURIAL DESIGN GUIDELINES The design engineer must select the proper pipe DR and specify the backfill conditions to obtain the desired performance of the “pipe-soil” system.

DESIGN BY WALL CRUSHING Wall crushing occurs when external vertical pressure causes the compressive stress in the pipe wall to exceed the long-term compressive strength of the pipe material. To design for wall crushing, the following check should be made:

$$S_A = \frac{(SDR - 1)}{2} P_T$$

Where: S_A = Actual compressive stress, psi
 SDR = Standard Dimension Ratio
 P_T = Total external pressure on the top of the pipe, psi

Safety Factor = 1500 psi / S_A (where 1500 psi is the compressive yield strength of Driscopipe HDPE pipe)

DESIGN BY WALL BUCKLING Local wall buckling is a longitudinal wrinkling of the pipe wall. Buckling can occur over the long term in non-pressurized pipe if the total external soil pressure, P_T , exceeds the pipe-soil system's critical buckling pressure, P_{cb} . Although wall buckling is seldom the limiting factor in the design of a Driscopipe system, a check of non-pressurized pipelines can be made according to the following steps to insure $P_T < P_{cb}$. All pipe diameters with the same DR in the same burial situation have the same critical collapse and critical buckling endurance.

1. Calculate or estimate the total soil pressure, P_T , at the top of the pipe.
2. Calculate the stress, S_a , in the pipe wall:

$$S_a = \frac{(SDR - 1)P_T}{2}$$

3. Based upon the stress S_a and the estimated time duration of non-pressurization, find the value of the pipe's modulus of elasticity, E , in psi (approximate value for E is 35,000 psi).
4. Calculate the pipes hydrostatic, critical-collapse differential pressure, P_c

$$P_c = \frac{2E(t/D)^3 (D_{MIN} / D_{MAX})^3}{(1 - \mu^2)} \quad \text{or} \quad P_c = \frac{2.32(E)}{SDR^3}$$

Where: $(D_{MIN}/D_{MAX}) = 0.95$
 μ = Poission's Ratio = 0.45 for polyethylene pipe
 E = stress and time dependent tensile modulus of elasticity, psi
 $E = 35,000$ psi (approximate)
 D = Outside Diameter, in.
 t = thickness, in.

- 5 Calculate the soil modulus, E' , by plotting the total external soil pressure, P_T , against a specified soil density to derive the soil strain as shown in the example problem below Figure 7.
6. Calculate the critical buckling pressure at the top of the pipe by the formula:

$$P_{cb} = 0.8\sqrt{(E')(P_c)}$$

Where: P_{cb} = Critical buckling soil pressure at the top of the pipe, psi
 E' = Soil Modulus, psi
 P_c = Hydrostatic critical-collapse differential pressure, psi

7. Calculate the Safety Factor: $SF = P_{cb} / P_T$.
8. The above procedures can be reversed to calculate the minimum pipe DR required for a given soil pressure and an estimated soil density.

In a direct burial pressurized pipeline, the internal pressure is usually great enough to exceed the external critical-buckling soil pressure. When a pressurized line is to be shut down for a period, wall buckling should be examined.

**APPLICATION FOR PERMIT
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ATTACHMENT III.5.F

CHEVRON PHILLIPS CHEMICAL COMPANY, LP. 2003.

PERFORMANCE PIPE ENGINEERING MANUAL.

BULLETIN: PP 900

DriscoPlex™ 2000 SPIROLITE® pipe is manufactured to ASTM F 894, which states that profile pipe designed for 7.5% deflection will perform satisfactorily when installed in accordance with ASTM D 2321. Deflection is measured at least 30 days after installation.

Manufacturing processes for DriscoPlex™ 2000 SPIROLITE® and DriscoPlex™ OD controlled pipe differ. Deflection limitations for OD controlled pipe are controlled by long-term material strain.

Ring Bending Strain

As pipe deflects, bending strains occur in the pipe wall. For an elliptically deformed pipe, the pipe wall ring bending strain, ε , can be related to deflection:

$$\varepsilon = f_D \frac{\Delta X}{D_M} \frac{2C}{D_M} \quad (7-39) \leftarrow$$

Where

- ε = wall strain
- f_D = deformation shape factor
- ΔX = deflection, in
- D_M = mean diameter, in
- C = distance from outer fiber to wall centroid, in

For DriscoPlex™ 2000 SPIROLITE® pipe

$$C = h - z \quad (7-40)$$

For DriscoPlex™ OD Controlled pipe

$$C = 0.5(1.06 t) \quad (7-41) \leftarrow$$

Where

- h = pipe wall height, in
- z = pipe wall centroid, in
- t = pipe minimum wall thickness, in

For elliptical deformation, $f_D = 4.28$. However, buried pipe rarely has a perfectly elliptical shape. Irregular deformation can occur from installation forces such as compaction variation alongside the pipe. To account for the non-elliptical shape many designers use $f_D = 6.0$.

Lytton and Chua report that for high performance polyethylene materials such as those used by Performance Pipe, 4.2% ring bending strain is a conservative value for non-pressure pipe. Jansen reports that high performance polyethylene material at an 8% strain level has a life expectancy of at least 50 years.

When designing non-pressure heavy wall OD controlled pipe (DR less than 17), and high RSC (above 200) DriscoPlex™ 2000 SPIROLITE® pipe, the ring bending strain at the predicted deflection should be calculated and compared to the allowable strain.

In pressure pipe, the combined stress from deflection and internal pressure should not exceed the material's long-term design stress rating. Combined stresses are incorporated into Table 7-9 values, which presumes deflected pipe at full pressure. At reduced pressure, greater deflection is allowable.

**APPLICATION FOR PERMIT
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**VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 6: GEOSYNTHETICS APPLICATION AND
COMPATIBILITY DOCUMENTATION**

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Attachment No.	Title
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III.6.B	GEOTEXTILE REFERENCE DOCUMENTATION
III.6.C	GEONET REFERENCE DOCUMENTATION
III.6.D	GEOSYNTHETIC CLAY LINER REFERENCE DOCUMENTATION
III.6.E	HDPE PIPE REFERENCE DOCUMENTATION
III.6.F	PVC PIPE REFERENCE DOCUMENTATION
III.6.G	SUNDANCE WEST SOLID WASTE AND WASTEWATER LABORATORY RESULTS

**APPLICATION FOR PERMIT
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**VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 6: GEOSYNTHETICS APPLICATION AND
COMPATIBILITY DOCUMENTATION**

1.0 INTRODUCTION

Sundance West (Sundance West Facility) is a proposed Surface Waste Management Facility for oil field waste processing and disposal services. The proposed Sundance West Facility is subject to regulation under the New Mexico Oil and Gas Rules, specifically 19.15.36 NMAC, administered by the Oil Conservation Division (OCD). The Facility has been designed in compliance with 19.15.36 NMAC, and will be constructed and operated in compliance with a Surface Waste Management Facility Permit issued by the OCD. The Facility is owned by, and will be constructed and operated by, Sundance West, Inc.

1.1 Description

The Sundance West site is comprised of a 320-acre ± tract of land located approximately 3 miles east of Eunice, 18 miles south of Hobbs, and approximately 1.5 miles west of the Texas/New Mexico state line in the South ½ of Section 30, Township 21 South, Range 38 East Lea County, New Mexico (NM). Site access will be provided via NM 18 and Wallach Lane. The Sundance West Facility will include two main components; a liquid oil field waste Processing Area (80 acres ±), and an oil field waste Landfill (120 acres ±). Oil field wastes are anticipated to be delivered to the Sundance West Facility from oil and gas exploration and production operations in southeastern NM and west Texas. The Site Development Plan provided in the **Permit Plans, Sheet 3**, identifies the locations of the Processing Area and Landfill facilities.

2.0 SUMMARY

19.15.36.14 NMAC Specific requirements applicable to Landfills:

D. Liner specifications and requirements.

(1) General requirements.

(a) Geomembrane liner specifications. Geomembrane liners shall consist of a 30-mil flexible PVC or 60-mil HDPE liner, or an equivalent liner approved by the division. Geomembrane liners shall have a hydraulic conductivity no greater than 1×10^{-9} cm/sec. Geomembrane liners shall be

composed of impervious, geosynthetic material that is resistant to petroleum hydrocarbons, salts and acidic and alkaline solutions. Liners shall also be resistant to ultraviolet light, or the operator shall make provisions to protect the material from sunlight. Liner compatibility shall comply with EPA SW-846 method 9090A.

19.15.36.17 NMAC *Specific requirements applicable to evaporation, storage, treatment, and skimmer ponds:*

B. *Construction, standards.*

(3) *Liner specifications. Liners shall consist of a 30-mil flexible PVC or 60-mil HDPE liner, or an equivalent liner approved by the division. Synthetic (geomembrane) liners shall have a hydraulic conductivity no greater than 1×10^{-9} cm/sec. Geomembrane liners shall be composed of an impervious, synthetic material that is resistant to petroleum hydrocarbons, salts and acidic and alkaline solutions. Liner materials shall be resistant to ultraviolet light, or the operator shall make provisions to protect the material from sunlight. Liner compatibility shall comply with EPA SW-846 method 9090A.*

Geosynthetics have a proven track record in a variety of civil engineering applications. Fluid containment construction provides a unique opportunity to incorporate a range of engineered materials that exceed the equivalent performance of soils. The design of the Sundance West Facility includes several examples of geosynthetics used for their superior characteristics, usually applied in conjunction with soil layers:

- Geomembranes (flexible membrane liners) provided as barrier layers in the primary and secondary liner (**Attachment III.6.A**).
- Geonets used as drainage layer in the leak detection system (**Attachment III.6.B**).
- Geotextiles serving as cushioning layers and as filters to maintain flow (**Attachment III.6.C**).
- Geosynthetic clay liners (GCLs) employed as secondary composite layers for liners (**Attachment III.6.D**).
- The use of HDPE (High Density Polyethylene; **Attachment III.6.E**) and PVC (Polyvinyl Chloride; **Attachment III.6.F**) piping systems.

Geosynthetics are selected in the design process for their performance characteristics in the project's site-specific environmental setting. Laboratory analysis was completed on the proposed oil field wastewater and solid waste. The results of this analysis are presented in **Attachment III.6.G**. Toluene and Acetone were the only constituents detected which could have an effect on the properties of the HDPE liner. However, at the low concentration of 56 micrograms/liter (g/l) and 600 mg/l respectively in the wastewater, there should be no impact to the performance of the HDPE liner.

This section provides demonstrations, as required by 19.15.36.14.D.1 and 19.15.36.17.B that the geosynthetic components are compatible with the fluids to be contained within the cells and basins. The attached compatibility documentation includes published reports and test results; and is further endorsed by industry experience and proven installations by the design engineer. For the performance criteria of both soil and geosynthetic components to be achieved, they must be constructed in strict accordance with the **Permit Plans (Volume III.1)** and the Liner Construction Quality Assurance (CQA) Plan, (**Volume II.7**) of this Application for Permit.

Table III.6.1 provides an index of compatibility data provided for each of the prescribed geosynthetic materials and their function in the engineering design.

TABLE III.6.1
Geosynthetic Applications and Compatibility Documentation
Sundance West

MATERIAL	FUNCTION	ATTACHED REFERENCE DOCUMENTATION
EPA	Guidance	III.3.A <i>EPA SW-846 Method 9090A</i>
HDPE Geomembrane	Primary and secondary barrier layer for liner.	<i>Chemical Compatibility of Poly-Flex Liners</i>
		<i>Chemical Resistance Table Low Density and High Density Polyethylene</i>
Geonets	Drainage layer in LDS/LCS.	III.3.B <i>NSC, Contaminant Solutions for Industrial Waste; HDPE Geomembrane</i>
		<i>Poly-Flex, Inc. – Chemical Resistance</i>
		<i>Agru America - Geonet</i>
Geotextile	Cushion layer above geomembrane and on geonets.	The chemical compositions of HDPE Geomembranes and Geonets are essentially identical; therefore they refer to the same compatibility document. <i>Amoco Technical Note No. 7, Chemical Resistance of Amoco Polypropylene Geotextiles</i> <i>Amoco Technical Note No. 14, Geotextile Polymers for Waste Applications</i>
HDPE Pipe	Solid and slotted piping (LDS).	<i>Chemical Resistance of Plastics and Elastomers Used in Pipeline Construction</i> <i>Driscopipe Engineering Characteristics</i> <i>Plexco Chemical Resistance Information</i>
PVC Pipe	Solid and slotted piping (LDS).	III.5.E <i>Certainteed - PVC Chemical Resistance</i>
Wastewater	Laboratory Results	III.5.F <i>Sundance West Solid Waste and Wastewater Laboratory Results</i>

Acronyms used:

- FML: Flexible Membrane Liner
- PVC: Polyvinyl Chloride
- HDPE: High Density Polyethylene
- LDS: Leak Detection System
- LCS : Leachate Collection System

**APPLICATION FOR PERMIT
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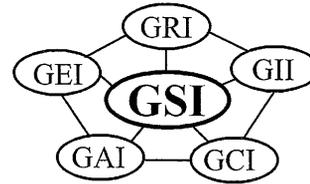
**VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 6: GEOSYNTHETICS APPLICATIONS AND
COMPATIBILITY DOCUMENTATION**

ATTACHMENT III.6.A

HDPE GEOMEMBRANES REFERENCE DOCUMENTATION

Geosynthetic Institute

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Folsom, PA 19033-1208 USA
TEL (610) 522-8440
FAX (610) 522-8441



GRI White Paper #6

- on -

**Geomembrane Lifetime Prediction:
Unexposed and Exposed Conditions**

by

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June 7, 2005

Geomembrane Lifetime Prediction: Unexposed and Exposed Conditions

1.0 Introduction

Without any hesitation the most frequently asked question we have had over the past 25 years' is "how long will a particular geomembrane last".* The two-part answer to the question, largely depends on whether the geomembrane is covered in a timely manner or left exposed to the site-specific environment. Before starting, however, recognize that the answer to either covered or exposed geomembrane lifetime prediction is neither easy, nor quick, to obtain. Further complicating the answer is the fact that all geomembranes are formulated materials consisting of (at the minimum), (i) the resin from which the name derives, (ii) carbon black or colorants, (iii) short-term processing stabilizers, and (iv) long-term antioxidants. If the formulation changes (particularly the additives), the predicted lifetime will also change. See Table 1 for the most common types of geomembranes and their approximate formulations.

Table 1 - Types of commonly used geomembranes and their approximate formulations
(based on weight percentage)

Type	Resin	Plasticizer	Fillers	Carbon Black	Additives
HDPE	95-98	0	0	2-3	0.25-1
LLDPE	94-96	0	0	2-3	0.25-3
fPP	85-98	0	0-13	2-4	0.25-2
PVC	50-70	25-35	0-10	2-5	2-5
CSPE	40-60	0	40-50	5-10	5-15
EPDM	25-30	0	20-40	20-40	1-5

HDPE = high density polyethylene PVC = polyvinyl chloride (plasticized)
 LLDPE = linear low density polyethylene CSPE = chlorosulfonated polyethylene
 fPP = flexible polypropylene EPDM = ethylene propylene diene terpolymer

* More recently, the same question has arisen but focused on geotextiles, geogrids, geopipe, fibers of GCLs, etc. This White Paper, however, is focused on geomembranes due to the general lack of information on the other geosynthetics.

The possible variations being obvious, one must also address the degradation mechanisms which might occur. They are as follows accompanied by some generalized commentary.

- Ultraviolet - occurs only when the geosynthetic is exposed; it will be the focus of the second part of this communication.
- Oxidation - this occurs in all polymers and is the major mechanism in polyolefins (polyethylene and polypropylene) under covered conditions.
- Ozone - this occurs in all polymers that are exposed to the environment. The site-specific environment is critical in this regard.
- Hydrolysis - this is the primary mechanism in polyesters and polyamides.
- Chemical - can occur in all polymers and can vary from water (least aggressive) to organic solvents (most aggressive).
- Radioactive - not a factor unless the polymer is exposed to radioactive materials of sufficiently high intensity to cause chain scission, e.g., high level radioactive waste materials.
- Biological - generally not a factor unless biologically sensitive additives (such as low molecular weight plasticizers) are included in the formulation.
- Stress State - a complicating factor which is site-specific and should be appropriately modeled in the incubation process.
- Temperature - clearly, the higher the temperature the more rapid the degradation of all of the above mechanisms; temperature is critical to lifetime and furthermore is the key to time-temperature-superposition which is the basis of the laboratory incubation methods which will be followed.

2.0 Lifetime Prediction: Unexposed Conditions

Lifetime prediction studies at GRI began at Drexel University under U. S. EPA contract from 1991 to 1997 and have continued under GSI consortium funding since that time. Focus to date has been on HDPE geomembranes beneath solid waste landfills due to its common use in this particular challenging application. Incubation of the coupons has been in landfill simulation cells (see Figure 1) maintained at 85, 75, 65 and 55°C. The specific conditions within these cells are oxidation beneath, chemical (water) from above, and the equivalent of 50 m of solid waste mobilizing compressive stress. Results have been forthcoming over the years insofar as three distinct lifetime stages; see Figure 2.

Stage A - Antioxidant Depletion Time

Stage B - Induction Time to Onset of Degradation

Stage C - Time to Reach 50% Degradation (Half-life)

2.1 Stage A - Antioxidant Depletion Time

The purposes of stabilizer antioxidants are to (i) prevent polymer degradation during processing, and (ii) prevent oxidation reactions from taking place during Stage A of service life, respectively. Obviously, there can only be a given amount of antioxidants in any formulation. Once the antioxidants are depleted, additional oxygen will begin to attack the polymer chains, leading to subsequent stages as shown in Figure 2. The duration of the antioxidant depletion stage depends on both the type and amount of antioxidants.

The depletion of antioxidants is the consequence of two processes: (i) chemical reactions with the oxygen diffusing into the geomembrane, and (ii) physical loss of antioxidants from the geomembrane. The chemical process involves two main functions; the scavenging of free radicals converting them into stable molecules, and the reaction with unstable hydroperoxide

(ROOH) forming a more stable substance. Regarding physical loss, the process involves the distribution of antioxidants in the geomembrane and their volatility and extractability to the site-specific environment.

Hence, the rate of depletion of antioxidants is related to the type and amount of antioxidants, the service temperature, and the nature of the site-specific environment. See Hsuan and Koerner (1998) for additional details.

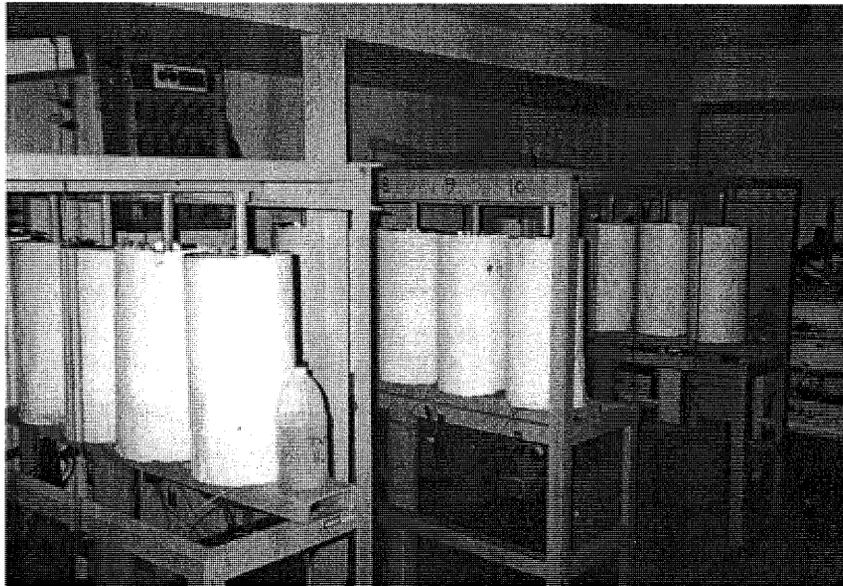
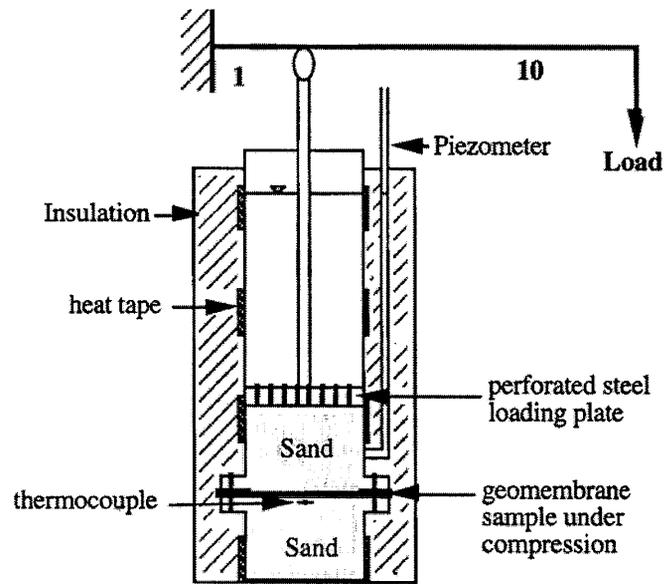


Figure 1. Incubation schematic and photograph of multiple cells maintained at various constant temperatures.

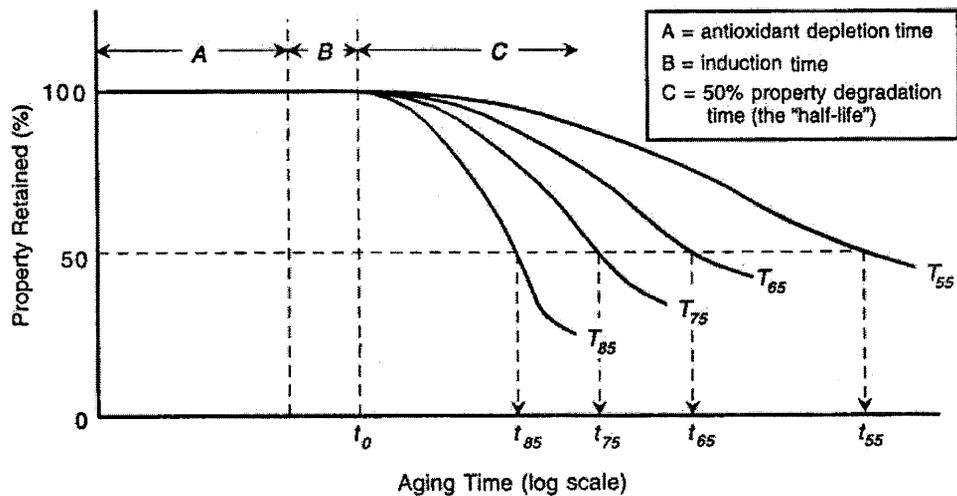


Figure 2. Three conceptual stages in chemical aging of polyolefin geomembranes.

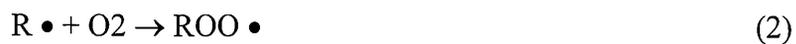
2.2 Stage B - Induction Time to Onset of Degradation

In a pure polyolefin resin, i.e., one without carbon black and antioxidants, oxidation occurs extremely slowly at the beginning, often at an immeasurable rate. Eventually, oxidation occurs more rapidly. The reaction eventually decelerates and once again becomes very slow. This progression is illustrated by the S-shaped curve of Figure 3(a). The initial portion of the curve (before measurable degradation takes place) is called the induction period (or induction time) of the polymer. In the induction period, the polymer reacts with oxygen forming hydroperoxide (ROOH), as indicated in Equations (1)-(3). However, the amount of ROOH in this stage is very small and the hydroperoxide does not further decompose into other free radicals which inhibits the onset of the acceleration stage.

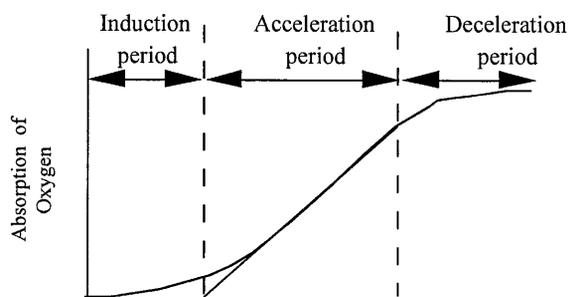
In a stabilized polymer such as one with antioxidants, the accelerated oxidation stage takes an even longer time to be reached. The antioxidants create an additional depletion time stage prior to the onset of the induction time, as shown in Figure 3(b).



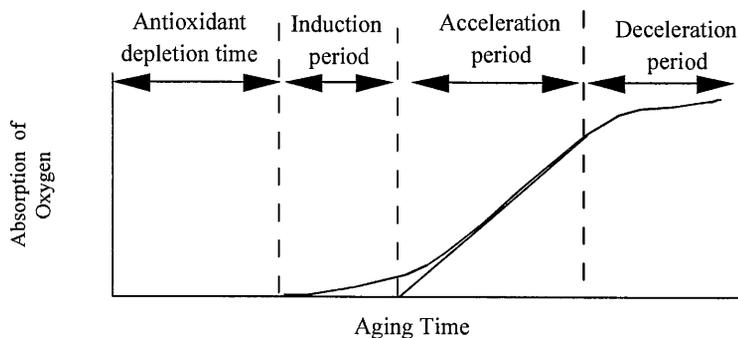
(aided by energy or catalyst residues in the polymer)



In the above, RH represents the polyethylene polymer chains; and the symbol “•” represents free radicals, which are highly reactive molecules.



(a) Pure unstabilized polyethylene

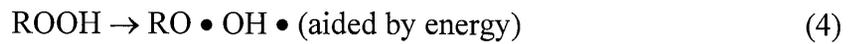


(b) stabilized polyethylene

Figure 3. Curves illustrating various stages of oxidation.

2.3 Stage C - Time to Reach 50% Degradation (Half-life)

As oxidation continues, additional ROOH molecules are being formed. Once the concentration of ROOH reaches a critical level, decomposition of ROOH begins, leading to a substantial increase in the amount of free radicals, as indicated in Equations (4) to (6). The additional free radicals rapidly attack other polymer chains, resulting in an accelerated chain reaction, signifying the end of the induction period, Rapoport and Zaikov (1986). This indicates that the concentration of ROOH has a critical control on the duration of the induction period.



A series of oxidation reactions produces a substantial amount of free radical polymer chains ($\text{R} \bullet$), called alkyl radicals, which can proceed to further reactions leading to either cross-linking or chain scission in the polymer. As the degradation of polymer continues, the physical and mechanical properties of the polymer start to change. The most noticeable change in physical properties is the melt index, since it relates to the molecular weight of the polymer. As for mechanical properties, both tensile break stress (strength) and break strain (elongation) decrease. Ultimately, the degradation becomes so severe that all tensile properties start to change (tear, puncture, burst, etc.) and the engineering performance is jeopardized. This signifies the end of the so-called “service life” of the geomembrane.

Although quite arbitrary, the limit of service life of polymeric materials is often selected as a 50% reduction in a specific design property. This is commonly referred to as the half-life time, or simply the “half-life”. It should be noted that even at half-life, the material still exists and

can function, albeit at a decreased performance level with a factor-of-safety lower than the initial design value.

2.4 Summary of Lifetime Research-to-Date

Stage A, that of antioxidant depletion for HDPE geomembranes as required in the GRI-GM13 Specification, has been well established by our own research and corroborated by others, e.g., Sangram and Rowe (2004). The GRI data for Standard and High Pressure Oxidative Induction Time (OIT) is given in Table 2. The values are quite close to one another. Also, as expected, the lifetime is strongly dependent on the service temperature; with the higher the temperature the shorter the lifetime.

Table 2 - Lifetime prediction of HDPE (nonexposed) at various field temperatures

In Service Temperature (°C)	Stage "A" (yrs.)		Stage "B" (yrs.)	Stage "C" (yrs.)		Total Lifetime (ave. values)
	Std OIT	HP-OIT	Field Data	(max.)	(min.)	
20	200	215	30	255	149	449
25	135	144	25	132	77	270
30	95	98	20	70	41	173
35	65	67	15	38	22	111
40	45	47	10	21	12	73

of
68
77
86
95
104

Notes: Stage "A" measured values from Hsuan and Guan (1997) research via GRI
 Stage "B" estimated values from field samples by GRI
 Stage "C" literature values from Gedde, et al. (1994)

Stage "B", that of induction time, has been obtained by comparing 30-year old polyethylene water and milk containers (containing no long-term antioxidants) with currently produced containers. The data shows that degradation is just beginning to occur as evidenced by slight changes in break strength and elongation, but not in yield strength and elongation. The lifetime for this stage is also given in Table 2.

Stage "C", the time for 50% change of mechanical properties is given in Table 2 as well. The data depends on the activation energy, or slope of the Arrhenius curve, which is very

sensitive to material and experimental techniques. The data is from Gedde, et al. (1994) which is typical of the HDPE resin used for gas pipelines.

Summarizing Stages A, B, and C, it is seen in Table 2 that the half-life of covered HDPE geomembranes (formulated according to the current GRI-GM13 Specification) is estimated to be 449-years at 20°C. This, of course, brings into question the actual temperature for a covered geomembrane such as beneath a solid waste landfill. Figure 4 presents multiple thermocouple monitoring data of a municipal waste landfill liner in Pennsylvania for over 10-years, Koerner and Koerner (2005). Note that for 6-years the temperature was approximately 20°C. At that time and for the subsequent 4-years the temperature increased to approximately 30°C. Thus, the half-life of this geomembrane is predicted to be from 270 to 449 years within this temperature range. The site is still being monitored, see Koerner and Koerner (2005).

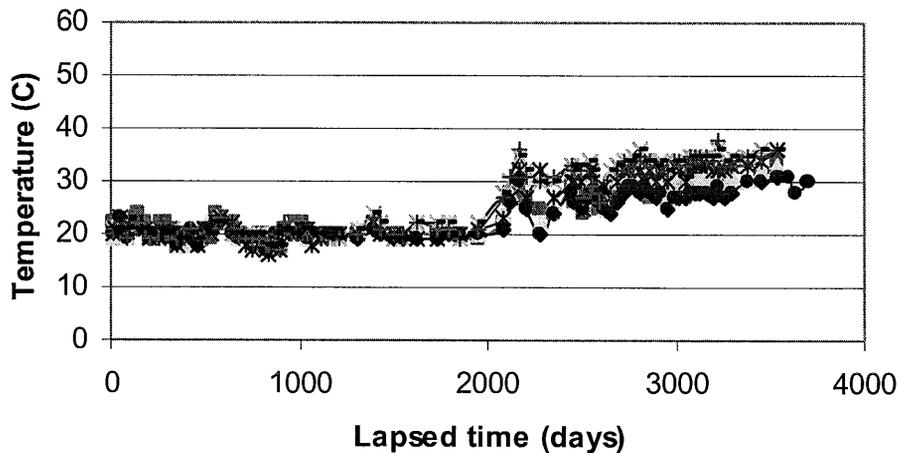


Figure 4. Long-term monitoring of an HDPE liner beneath a municipal solid waste landfill in Pennsylvania.

2.5 Lifetime of Other Covered Geomembranes

By virtue of its widespread use as liners for solid waste landfills, HDPE is by far the widest studied type of geomembrane. Note that in most countries (other than the U.S.), HDPE is the required geomembrane type for solid waste containment. Some commentary on other-than HDPE geomembranes (recall Table 1) follows:

2.5.1 Linear Low Density Polyethylene (LLDPE) geomembranes

The nature of the LLDPE resin and its formulation is very similar to HDPE. The fundamental difference is that LLDPE is a lower density, hence lower crystallinity, than HDPE; e.g., 10% versus 50%. This has the effect of allowing oxygen to diffuse into the polymer structure quicker, and likely decreases Stages A and C. How much is uncertain since no data is available, but it is felt that the lifetime of LLDPE will be somewhat reduced with respect to HDPE.

2.5.2 Plasticizer migration in PVC geomembranes

Since PVC geomembranes necessarily have plasticizers in their formulations so as to provide flexibility, the migration behavior must be addressed for this material. In PVC the plasticizer bonds to the resin and the strength of this bonding versus liquid-to-resin bonding is significant. One of the key parameters of a stable long-lasting plasticizer is its molecular weight. The higher the molecular weight of the plasticizer in a PVC formulation, the more durable will be the material. Conversely, low molecular weight plasticizers have resulted in field failures even under covered conditions. See Miller, et al. (1991), Hammon, et al. (1993), and Giroud and Tisinger (1994) for more detail in this regard.

2.5.3 Crosslinking in EPDM and CSPE geomembranes

The EPDM geomembranes mentioned in Table 1 are crosslinked thermoset materials. The oxidation degradation of EPDM takes place in either ethylene or propylene fraction of the co-polymer via free radical reactions, as expressed in Figure 5, which are described similarly by Equations (4) to (6).

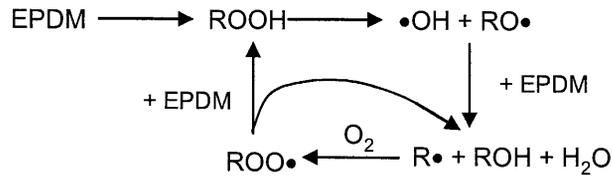


Figure 5. Oxidative degradation of crosslinked EPDM geomembranes, (Wang and Qu, 2003).

For CSPE geomembranes, the degradation mechanism is dehydrochlorination by losing chlorine and generating carbon-carbon double bonds in the main polymer chain, as shown in Figure 6. The carbon-carbon double bonds become the preferred sites for further thermodegradation or cross-linking in the polymer, leading to eventual brittleness of the geomembrane.

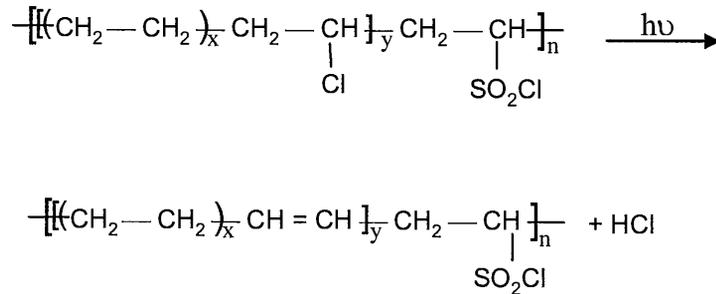


Figure 6. Dechlorination degradation of crosslinked CSPE geomembranes (Chailan, et al., 1995).

Neither EPDM nor CSPE has had a focused laboratory study of the type described for HDPE reported in the open literature. Most of lifetime data for these geomembranes is antidotal by virtue of actual field performance. Under covered conditions, as being considered in this section, there have been no reported failures by either of these thermoset polymers to our knowledge.

3.0 Lifetime Prediction: Exposed Conditions

Lifetime prediction of exposed geomembranes have taken two very different pathways; (i) prediction from anecdotal feedback and field performance, and (ii) from laboratory weathermometer predictions.

3.1 Field Performance

There is a large body of anecdotal information available on field feedback of exposed geomembranes. It comes from two quite different sources, i.e., dams in Europe and flat roofs in the USA.

Regarding exposed geomembranes in dams in Europe, the original trials were using 2.0 mm thick polyisobutylene bonded directly to the face of the dam. There were numerous problems encountered as described by Scuero (1990). Similar experiences followed using PVC geomembranes. In 1980, a geocomposite was first used at Lago Nero which had a 200 g/m² nonwoven geotextile bonded to the PVC geomembrane. This proved quite successful and led to the now-accepted strategy of requiring drainage behind the geomembrane. In addition to thick nonwoven geotextiles, geonets, and geonet composites have been successful. Currently over 50 concrete and masonry dams have been rehabilitated in this manner and are proving successful for over 30-years of service life. The particular type of PVC plasticized geomembranes used for these dams is proving to be quite durable. Tests by the dam owners on residual properties show only nominal changes in properties, Cazzuffi (1998). As indicated in Miller, et al. (1991) and Hammond, et al. (1993), however, different PVC materials and formulations result in very different behavior; the choice of plasticizer and the thickness both being of paramount importance.

Regarding exposed geomembranes in flat roofs, past practice in the USA is almost all with EPDM and CSPE and, more recently, with fPP. Manufacturers of these geomembranes regularly warranty their products for 20-years and such warrants appear to be justified. EPDM and CSPE, being thermoset or elastomeric polymers, can be used in dams without the necessity of having seams by using vertical attachments spaced at 2 to 4 m centers, see Scuero and Vaschetti (1996). Conversely, fPP can be seamed by a number of thermal fusion methods. All of these geomembrane types have good conformability to rough substrates as is typical of concrete and masonry dam rehabilitation. It appears as though experiences (both positive and negative) with geomembranes in flat roofs should be transferred to all types of waterproofing in civil engineering applications.

3.2 Laboratory Weatherometer Predictions

For an accelerated simulation of direct sunlight using a laboratory weatherometer one usually considers a worst-case situation which is the solar maximum condition. This condition consists of global, noon sunlight, on the summer solstice, at normal incidence. It should be recognized that the UV-A range is the target spectrum for a laboratory device to simulate the naturally occurring phenomenon, see Hsuan and Koerner (1993), and Suits and Hsuan (2001).

The Xenon Arc Weatherometer (ASTM G155) was introduced in Germany in 1954. There are two important features; the type of filters and the irradiance settings. Using a quartz inner and borosilicate outer filter (quartz/boro) results in excessive low frequency wavelength degradation. The more common borosilicate inner and outer filters (boro/boro) shows a good correlation with solar maximum conditions, although there is an excess of energy below 300 nm wavelength. Irradiance settings are important adjustments in shifting the response although they do not eliminate the portion of the spectrum below 300 nm frequency. Nevertheless, the Xenon

Arc weatherometer is commonly used method for exposed lifetime prediction of all types of geosynthetics.

UV Fluorescent Lamps (ASTM G154) are an alternative type of accelerated laboratory test device which became available in the early 1970's. They reproduce the ultraviolet portion of the sunlight spectrum but not the full spectrum as in Xenon Arc weatherometers. Earlier FS-40 and UVB-313 lamps give reasonable short wavelength output in comparison to solar maximum. The UVA-340 lamp was introduced in 1987 and its response is seen to reproduce ultraviolet light quite well. This device (as well as other types of weatherometers) can handle elevated temperature and programmed moisture on the test specimens.

Research at the Geosynthetic Institute (GSI) is actively pursuing both Xenon and UV Fluorescent devices on a wide range of geomembranes. Table 3 gives the geomembranes being incubated and the current number of hours of exposure.

Table 5 - Details of the GSI laboratory exposed weatherometer study on various types of geomembranes

Geomembrane Type	Thickness (mm)	UV Fluorescent Exposure*	Xenon Exposure*	Comment
1. HDPE (GM13)	1.50	8000 hrs.	6600 hrs.	Basis of GRI-GM13 Spec
2. LLDPE (GM17)	1.00	8000	6600	Basis of GRI-GM-17 Spec
3. PVC (No. Amer.)	0.75	8000	6600	Low Mol. Wt. Plasticizer
4. PVC (Europe)	2.50	7500	6600	High Mol. Wt. Plasticizer
5. fPP (BuRec)	1.00	2745**	4416**	Field Failure at 26 mos.
6. fPP-R (Texas)	0.91	100	100	Field Failure at 8 years
7. fPP (No. Amer.)	1.00	7500	6600	Expected Good Performance

*As of 12 July 2005 exposure is ongoing

**Light time to reach halflife of break and elongation

3.3 Laboratory Weatherometer Acceleration Factors

The key to validation of any laboratory study is to correlate results to actual field performance. For the nonexposed geomembranes of Section 2 such correlations will take hundreds of years for properly formulated products. For the exposed geomembranes of Section

3, however, the lifetimes are significantly shorter and such correlations are becoming possible. In particular, Geomembrane #5 (flexible polypropylene) of Table 3 was an admittedly poor geomembrane formulation which failed in 26 months of exposure at El Paso, Texas, USA. The reporting of this failure is available in the literature, Comer, et al. (1998). Note that for both UV Fluorescent and Xenon Arc laboratory testing of this material, failure (halflife to 50% reduction in strength and elongation) occurred at 2745 and 4416 hours, respectively. The comparative analysis of laboratory and field for this case history allows for the obtaining of acceleration factors for the two incubation devices.

3.3.1 Comparison between field and UV Fluorescent weatherometer

The light source used in the UV fluorescent weatherometer is UVA with wavelengths from 295-400 nm. In addition, the intensity of the radiation is controlled by the Solar Eye irradiance control system. The UV energy output throughout the test is 68.25 W/m².

The time of exposure to reach 50% elongation at break

$$\begin{aligned} &= 2745 \text{ hr. of light} \\ &= 9,882,000 \text{ seconds} \end{aligned}$$

$$\begin{aligned} \text{Total energy in MJ/m}^2 &= 68.25 \text{ W/m}^2 \times 9,882,000 \\ &= 674.4 \text{ MJ/m}^2 \end{aligned}$$

The field site was located at El Paso, Texas. The UVA radiation energy (295-400 nm) at this site is estimated based on data collected by the South Florida Testing Lab in Arizona (which is a similar atmospheric location). For 26 months of exposure, the accumulated UV radiation energy is 724 MJ/m² which is very close to that generated from the UV fluorescent weatherometer. Therefore, direct comparison of the exposure time between field and UV fluorescent is acceptable.

Field time	vs.	Fluorescent UV light time:	Thus,	the acceleration factor is 6.8.
= 26 Months		= 3.8 Months		

3.3.2 Comparison between field and Xenon Arc weatherometer

The light source of the Xenon Arc weatherometer simulates almost the entire sunlight spectrum from 250 to 800 nm. Depending of the age of the light source and filter, the solar energy ranges from 340.2 to 695.4 W/m², with the average value being 517.8 W/m².

The time of exposure to reach 50% elongation at break

$$\begin{aligned} &= 4416 \text{ hr. of light} \\ &= 15,897,600 \text{ seconds} \end{aligned}$$

$$\begin{aligned} \text{Total energy in MJ/m}^2 &= 517.8 \text{ W/m}^2 \times 15,897,600 \\ &= 8232 \text{ MJ/m}^2 \end{aligned}$$

The solar energy in the field is again estimated based on data collected by the South Florida Testing Lab in Arizona. For 26 months of exposure, the accumulated solar energy (295-800 nm) is 15,800 MJ/m², which is much higher than that from the Xenon Arc weatherometer. Therefore, direct comparison of halflives obtained from the field and Xenon Arc weatherometer is not anticipated to be very accurate. However, for illustration purposes the acceleration factor based on Xenon Arc weatherometer would be as follows:

$$\begin{array}{l} \text{Field} \quad \quad \quad \text{vs.} \quad \text{Xenon Arc} \quad : \quad \text{Thus,} \quad \text{the acceleration factor is 4.3.} \\ = 26 \text{ Months} \quad \quad \quad = 6.1 \text{ Months} \end{array}$$

4.0 Summary and Recommendations

This White Paper has described research on the geomembrane type which has had the majority of research effort, that being nonexposed HDPE used in landfill applications. While this material promises service lifetime of hundreds of years, the elevated temperatures of exposed or nearly exposed geomembranes in other applications (dams, canals, reservoirs, etc.) is expected to be greatly reduced. It was shown that HDPE decreases its predicted halflife from 449-years at 20°C, to 73-years at 40°C. Other geomembrane types (LLDPE, PVC, EPDM and CSPE) have had essentially no focused effort on lifetime prediction of the type described herein. All are candidates for additional research in this regard.

Exposed geomembrane lifetime was addressed from the perspective of field performance which is very unequivocal. Experience in Europe, mainly with relatively thick PVC containing high molecular weight plasticizers, has given 25-years of service and the geomembranes are still in use. Experience in the USA with exposed geomembranes on flat roofs, mainly with EPDM and CSPE, has given 20⁺-years of service. The newest geomembrane type in such applications is fPP which currently carries similar warranties. To be noted, however, is that degradation is a very slow process and every time a formulation changes there is uncertainty as to its long-time field performance versus the previous formulation.

Alternatively, exposed geomembrane lifetime can be addressed by using accelerating laboratory weatherometers. GSI is fully involved in such an activity using UV Fluorescent and Xenon Arc weatherometers. Two types of polyethylene, two PVCs, and three fPP geomembranes (seven in total) are being incubated for sufficient time to reach their respective lifetimes. One type of fPP has reached this level and correlation to actual field failure time is reasonable. Analysis of this (poorly formulated) geomembrane results in acceleration factors of 6.8 for UV Fluorescent, and 4.3 for Xenon Arc devices. Based on such acceleration factors, for 20-year lifetime exposed geomembranes typical laboratory weatherometer exposure will be 3-years, or longer. As noted in Table 2 such testing is ongoing and will be continued so as to report our findings at a future date. In this regard we are proceeding as follows so as to develop the required confidence needed for use of geomembranes in long-term, permanent, systems.

- (i) Extend HDPE laboratory studies on nonexposed geomembranes to other polymer types such as PVC, LLDPE, fPP, EPDM and CSPE.
- (ii) Evaluate, to the extent possible, various additives particularly antioxidants in polyolefins (HDPE, LLDPE and fPP) and plasticizers in PVC.

- (iii) Document and analyze geomembrane dam rehabilitation in Europe (and elsewhere) with particular emphasis on durability.
- (iv) Document and analyze geomembrane use in flat roofs and other exposed applications, e.g., pond and reservoir liners as well as canal liners.
- (v) Initiate a broad research program on lifetime prediction of exposed geomembranes (of all types and formulations) using laboratory weatherometers such as the ongoing study described herein.

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CHEMICAL COMPATIBILITY OF POLY-FLEX LINERS

Chemical compatibility or resistance as applied to geomembranes is a relative term. Actually compatibility would mean that one material will dissolve in the other such as alcohol in water or grease in gasoline. An example of incompatibility would be oil and water. In liners it is undesirable to have the chemicals dissolve in the liner hence the term compatibility is the reverse of what is normally meant in the chemical industry. In the strictest sense and from a laboratory prospective, chemical compatibility, as the term applies to this industry, would imply that the chemical has no effect on the liner. On the other hand, from an engineering prospective, chemical compatibility means that a liner will survive the exposure to a given chemical even though the chemical could have some effect on the performance of the liner, but not enough to cause failure. Therefore, one must understand and define chemical compatibility for a specific project.

Generally polyethylene will be effected by chemicals in one of three ways.

1. No effect—This means that the chemical in question and the polyethylene do not interact. The polyethylene does not gain (lose) weight, swell, and the physical properties are not significantly altered.
2. Oxidizes (cross linking)—Chemicals classed as oxidizing agents will cause the polyethylene molecules to cross link and cause irreversible changes to the physical properties of the liner. Basically it makes the liner brittle.
3. Plasticizes—Chemicals in this classification are soluble in the polyethylene structure. They do not change the structure of the polyethylene itself but will act as a plasticizer. In doing so, the liner will experience weight gain of 3-15%, may swell by up to 10%, and will have measurable changes in physical properties (i.e. the tensile strength at yield may decrease by up to 20%). Even under these conditions the liner will maintain its integrity and will not be breached by liquids, provided the liner has not been subjected to any stress. These effects are reversible once the chemicals are removed and the liner has time to dry out.

Aside from the effect that chemicals have on a liner is the issue of vapor permeation through the liner. Vapor permeation is molecular diffusion of chemicals through the liner. Vapor transmission for a given chemical is dependent primarily on liner type, contact time, chemical solubility, temperature, thickness, and concentration gradient, but not on hydraulic head or pressure. Transmission through the liner can occur in as little as 1-2 days. Normally, a small amount of chemical is transmitted. Generally HDPE has the lowest permeation rate of the liners that are commercially available.

As stated above chemical compatibility is a relative term. For example, the use of HDPE as a primary containment of chlorinated hydrocarbons at a concentration of 100% may not be recommended, but it may be acceptable at 0.1% concentration for a limited time period or may be acceptable for secondary containment. Factors that go into assessment of chemical compatibility are type of chemical(s), concentration, temperature and the type of application. No hard and fast rules are available to make decisions on chemical compatibility. Even the EPA 9090 test is just a method to generate data so that an opinion on chemical compatibility can be more reliably reached.

A simplified table on chemical resistance is provided to act as a screening process for chemical containment applications.

CHEMICAL RESISTANCE INFORMATION

CHEMICAL CLASS	CHEMICAL EFFECT	PRIMARY CONTAINMENT (LONG TERM CONTACT)		SECONDARY CONTAINMENT (SHORT TERM CONTACT)	
		HDPE	LLDPE	HDPE	LLDPE
CARBOXYLIC ACID	1				
- Unsubstituted (e.g. Acetic acid)		B	C	A	C
- Substituted (e.g. Lactic acid)		A	B	A	A
- Aromatic (e.g. Benzoic acid)		A	B	A	A
ALDEHYDES	3				
- Aliphatic (e.g. Acetaldehyde)		B	C	B	C
- Hetrocyclic (e.g. Furfural)		C	C	B	C
AMINE	3				
- Primary (e.g. Ethylamine)		B	C	B	C
- Secondary (e.g. Diethylamine)		C	C	B	C
- Aromatic (e.g. Aniline)		B	C	B	C
CYANIDES (e.g. Sodium Cyanide)	1	A	A	A	A
ESTER (e.g. Ethyl acetate)	3	B	C	B	C
ETHER (e.g. Ethyl ether)		C	C	B	C
HYDROCARBONS	3				
- Aliphatic (e.g. Hexane)		C	C	B	C
- Aromatic (e.g. Benzene)		C	C	B	C
- Mixed (e.g. Crude oil)		C	C	B	C
HALOGENATED HYDROCARBONS	3				
- Aliphatic (e.g. Dichloroethane) +A4		C	C	B	C
- Aromatic (e.g. Chlorobenzene)		C	C	B	C
ALCOHOLS	1				
- Aliphatic (e.g. Ethyl alcohol)		A	A	A	A
- Aromatic (e.g. Phenol)		A	C	A	B
INORGANIC ACID					
- Non-Oxidizers (e.g. Hydrochloric acid)	1	A	A	A	A
- Oxidizers (e.g. Nitric Acid)	2	C	C	B	C
INORGANIC BASES (e.g. Sodium hydroxide)	1	A	A	A	A
SALTS (e.g. Calcium chloride)	1	A	A	A	A
METALS (e.g. Cadmium)	1	A	A	A	A
KETONES (e.g. Methyl ethyl ketone)	3	C	C	B	C
OXIDIZERS (e.g. Hydrogen Peroxide)	2	C	C	C	C

Chemical effect (see discussion on Chemical Resistance)

1. No Effect--Most chemicals of this class have no or minor effect.
2. Oxidizer--Chemicals of this class will cause irreversible degradaton.

3. Plasticizer--Chemicals of this class will cause a reversible change in physical properties.

Chart Rating

- A. Most chemicals of this class have little or no effect on the liner.
Recommended regardless of concentration or temperature (below 150° F).
- B. Chemicals of this class will effect the liner to various degrees.
Recommendations are based on the specific chemical, concentration and temperature.
Consult with Poly-Flex, Inc.
- C. Chemicals of this class at high concentrations will have significant effect on the physical properties of the liner.
Generally not recommended but may be acceptable at low concentrations and with special design considerations.
Consult with Poly-Flex, Inc.

This data is provided for informational purposes only and is not intended as a warranty or guarantee. Poly-Flex, Inc. assumes no responsibility in connection with the use of this data. Consult with Poly-Flex, Inc. for specific chemical resistance information and liner selection.

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CHEMICAL COMPATIBILITY OF POLY-FLEX LINERS

Chemical compatibility or resistance, as applied to geomembranes, is a relative term. Actual compatibility would mean that one material dissolves in the other such as alcohol in water or grease in gasoline. An example of incompatibility would be oil and water. In liners it is undesirable to have the chemicals dissolve in the liner, hence the term compatibility is the reverse of what is normally meant in the chemical industry. In the strictest sense and from a laboratory perspective, chemical compatibility, as the term applies to this industry, would imply that the chemical has no effect on the liner. On the other hand, from an engineering perspective, chemical compatibility means that a liner survives the exposure to a given chemical even though the chemical could have some effect on the performance of the liner, but not enough to cause failure. Therefore, one must understand and define chemical compatibility for a specific project.

Generally polyethylene is effected by chemicals in one of three ways.

1. No effect—This means that the chemical in question and the polyethylene do not interact. The polyethylene does not gain (lose) weight or swell, and the physical properties are not significantly altered.
2. Oxidizes (cross linking)—Chemicals classed as oxidizing agents cause the polyethylene molecules to cross link and cause irreversible changes to the physical properties of the liner. Basically they make the liner brittle.
3. Plasticizes—Chemicals in this classification are soluble in the polyethylene structure. They do not change the structure of the polyethylene itself but act as a plasticizer. In doing so, the liner experiences weight gain of 3-15%, may swell by up to 10%, and has measurable changes in physical properties (e.g. the tensile strength at yield may decrease by up to 20%). Even under these conditions the liner maintains its integrity and is not breached by liquids, provided the liner has not been subjected to any stress. These effects are reversible once the chemicals are removed and the liner has time to dry out.

Aside from the effect that chemicals have on a liner is the issue of vapor permeation through the liner. Vapor permeation is molecular diffusion of chemicals through the liner. Vapor transmission for a given chemical is dependent primarily on liner type, contact time, chemical solubility, temperature, thickness, and concentration gradient, but not on hydraulic head or pressure. Transmission through the liner can occur in as little as 1-2 days. Normally, a small amount of chemical is transmitted. Generally HDPE has the lowest permeation rate of the liners that are commercially available.

As stated above chemical compatibility is a relative term. For example, the use of HDPE as a primary containment of chlorinated hydrocarbons at a concentration of 100% may not be recommended, but it may be acceptable at 0.1% concentration for a limited time period or may be acceptable for secondary containment. Factors that go into assessment of chemical compatibility are type of chemical(s), concentration, temperature and the type of application. No hard and fast rules are available to make decisions on chemical compatibility. Even the EPA 9090 test is just a method to generate data so that an opinion on chemical compatibility can be more reliably reached.

A simplified table on chemical resistance is provided to act as a screening process for chemical containment applications.

CHEMICAL RESISTANCE INFORMATION

CHEMICAL CLASS	CHEMICAL EFFECT	PRIMARY CONTAINMENT (LONG TERM CONTACT)		SECONDARY CONTAINMENT (SHORT TERM CONTACT)	
		HDPE	LLDPE	HDPE	LLDPE
CARBOXYLIC ACID - Unsubstituted (e.g. Acetic acid) - Substituted (e.g. Lactic acid) - Aromatic (e.g. Benzoic Acid)	1	B A A	C B B	A A A	C A A
ALDEHYDES - Aliphatic (e.g. Acetaldehyde) - Hetrocyclic (e.g. Furfural)	3	B C	C C	B B	C C
AMINE - Primary (e.g. Ethylamine) - Secondary (e.g. Diethylamine) - Aromatic (e.g. Aniline)	3	B C B	C C C	B B B	C C C
CYANIDES (e.g. Sodium Cyanide)	1	A	A	A	A
ESTER (e.g. Ethyl acetate)	3	B	C	B	C
ETHER (e.g. Ethyl ether)		C	C	B	C
HYDROCARBONS - Aliphatic (e.g. Hexane) - Aromatic (e.g. Benzene) - Mixed (e.g. Crude oil)	3	C C C	C C C	B B B	C C C
HALOGENATED HYDROCARBONS - Aliphatic (e.g. Dichloroethane) +A4 - Aromatic (e.g. Chlorobenzene)	3	C C	C C	B B	C C
ALCOHOLS - Aliphatic (e.g. Ethyl alcohol) - Aromatic (e.g. Phenol)	1	A A	A C	A A	A B
INORGANIC ACID - Non-oxidizers (e.g. Hydrochloric acid) - Oxidizers (e.g. Nitric Acid)	1 2	A C	A C	A B	A C
INORGANIC BASES (e.g. Sodium hydroxide)	1	A	A	A	A
SALTS (e.g. Calcium chloride)	1	A	A	A	A
METALS (e.g. Cadmium)	1	A	A	A	A
KETONES (e.g. Methyl ethyl ketone)	3	C	C	B	C
OXIDIZERS (e.g. Hydrogen peroxide)	2	C	C	C	C

Chemical Effect (see discussion on Chemical Resistance)

1. No Effect—Most chemicals of this class have no or minor effect.
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Chemicals Resistance Table

Low Density and High Density Polyethylene

INTRODUCTION

The table in this document summarises the data given in a number of chemical resistance tables at present in use in various countries, derived from both practical experience and test results.

Source: ISO/TR 7472, 7474; Carlowitz: "Kunststofftabellen-3. Auflage".

The table contains an evaluation of the chemical resistance of a number of fluids judged to be either aggressive or not towards low and high density polyethylene. This evaluation is based on values obtained by immersion of low and high density polyethylene test specimens in the fluid concerned at 20 and 60°C and atmospheric pressure, followed in certain cases by the determination of tensile characteristics.

A subsequent classification will be established with respect to a restricted number of fluids deemed to be technically or commercially more important, using equipment which permits testing under pressure and the determination of the coefficient of chemical resistance for each fluid. These tests will thus furnish more complete indications on the use of low and high density polyethylene products for the transport of stated fluids, including their use under pressure.

SCOPE AND FIELD APPLICATION

This document establishes a provisional classification of the chemical resistance of low and high density polyethylene with respect to about 300 fluids. It is intended to provide general guidelines on the possible utilisation of low and high density polyethylene:

- at temperatures up to 20 and 60°C
- in the absence of internal pressure and external mechanical stress (for example flexural stresses, stresses due to thrust, rolling loads etc).

DEFINITIONS, SYMBOLS AND ABBREVIATIONS

The criteria of classification, definitions, symbols and abbreviations adopted in this document are as follows:

S = Satisfactory

The chemical resistance of low or high density polyethylene exposed to the action of a fluid is classified as "satisfactory" when the results of test are acknowledged to be satisfactory by the majority of the countries participating in the evaluation.

L = Limited

The chemical resistance of low or high density polyethylene exposed to the action of a fluid is classified as "limited" when the results of tests are acknowledged to be "limited" by the majority of the countries participating in the evaluation.

Also classified as "limited" are the resistance to the action of chemical fluids for which judgements "S" and "NS" or "L" are pronounced to an equal extent.

NS = Not satisfactory

The chemical resistance of low or high density polyethylene exposed to the action of a fluid is classified as "not satisfactory" when the results of tests are acknowledged to be "not satisfactory" by the majority of the countries participating in the evaluation.

Also classified as "not satisfactory" are materials for which judgements "L" and "NS" are pronounced to an equal extent.

Sat.sol Saturated aqueous solution, prepared at 20°C

Sol Aqueous solution at a concentration higher than 10 %, but not saturated

Dil.sol Dilute aqueous solution at a concentration equal to or lower than 10 %

Work.sol Aqueous solution having the usual concentration for industrial use

Solution concentrations reported in the text are expressed as a percentage by mass. The aqueous solutions of sparingly soluble chemicals are considered, as far as chemical action towards low or high density polyethylene is concerned, as saturated solutions.

In general, common chemical names are used in this document.

The table is made as a first guideline for user of polyethylene. If a chemical compound is not to be found or if there is an uncertainty on the chemical resistance in an application, please contact Borealis for advise and proposal on testing.

**Chemical resistance of low density and high density polyethylene,
not subjected to mechanical stress, to various fluids at 20 and 60°C**

Chemical or product	Concentration	LD °C		HD °C	
		20	60	20	60
Acetaldehyde	100 %	L	NS	S	L
Acetanilide	—			S	S
Acetic acid	10 %	S	S	S	S
Acetic acid	60 %	S	L	S	S
Acetic acid, glacial	Greater than 96 %	L	NS	S	L
Acetic anhydride	100 %	L	NS	S	L
Acetone	100 %	L	NS	L	L
Acrylnitrile	—	S	S	S	S
Acetylsilicacid	—	S	S	S	S
Adipic acid	Sat.sol	S	S	S	S
After shave	—	NS	NS	NS	NS
Aliphatic hydrocarbons	—	L	NS	L	L
Allyl acetate	—	S	L	S	L
Allyl alcohol	100 %	L	NS	—	—
Allyl alcohol	96 %	—	—	S	S
Allyl chloride	—	L	NS	L	NS
Aluminium chloride	Sat.sol	S	S	S	S
Aluminium fluoride	Sat.sol	S	S	S	S
Aluminium hydroxide	Sat.sol	S	S	S	S
Aluminium nitrate	Sat.sol	S	S	S	S
Aluminium oxychloride	Sat.sol	S	S	S	S
Al/potassium sulphate	Sat.sol	S	S	S	S
Aluminium sulphate	Sat.sol	S	S	S	S
Alums	Sol	S	S	S	S
Aminobenzoic acid	—	S	S	S	S
Ammonia, dry gas	100 %	S	S	S	S
Ammonia, liquid	100 %	L	L	S	S
Ammonia, aqueous	Dil.sol	S	S	S	S
Ammonium acetate	—	S	S	S	S
Ammonium carbonate	Sat.sol	S	S	S	S
Ammonium chloride	Sat.sol	S	S	S	S
Ammonium fluoride	Sol	S	—	S	S
Ammonium hexafluorosilicate	Sat.sol	S	S	S	S
Ammonium hydrogen carbonate	Sat.sol	S	S	S	S
Ammonium hydroxide	10 %	S	S	S	S
Ammonium hydroxide	30 %	S	S	S	S

Chemical or product	Concentration	LD °C		HD °C	
		20	60	20	60
Ammonium metaphosphate	Sat.sol	S	S	S	S
Ammonium nitrate	Sat.sol	S	S	S	S
Ammonium oxalate	Sat.sol	S	S	S	S
Ammonium phosphate	Sat.sol	S	S	S	S
Ammonium persulphate	Sat.sol	S	S	S	S
Ammonium sulphate	Sat.sol	S	S	S	S
Ammonium sulphide	Sol	S	S	S	S
Ammonium thiocyanate	Sat.sol	S	S	S	S
Amyl acetate	100 %	NS	NS	L	L
Amyl alcohol	100 %	L	L	S	L
Amyl chloride	100 %	NS	NS	-	-
Amyl phthalate	-	L	L	S	L
Aniline	100 %	NS	NS	S	L
Anilinchlorohydrate	-	L	-	-	-
Antimony (III) chloride	90 %	-	-	S	S
Antimony (III) chloride	Sat.sol	S	S	S	S
Antimony trichloride	Sol	S	S	S	S
Apple juice	Sol	-	-	S	L
Aqua regia	HCl/HNO ₃ = 3/1	NS	NS	NS	NS
Aromatic hydrocarbons	-	NS	NS	NS	NS
Arsenic acid	Sat.sol	S	S	S	S
Asorbic acid	10 %	S	S	S	S
Barium bromide	Sat.sol	S	S	S	S
Barium carbonate	Sat.sol	S	S	S	S
Barium chloride	Sat.sol	S	S	S	S
Barium hydroxide	Sat.sol	S	S	S	S
Barium sulphate	Sat.sol	S	S	S	S
Barium sulphide	Sat.sol	S	S	S	S
Beer	-	S	S	S	S
Benzaldehyde	100 %	L	NS	S	L
Benzene	100 %	NS	NS	L	L
Benzoic acid	Sat.sol	S	S	S	S
Benzoylchloride	-	S	L	S	L
Benzyl alcohol	-	S	L	S	S
Benzylsulphonic acid	10 %	S	S	S	S
Bismuth carbonate	Sat.sol	S	S	S	S
Bitumen	-	S	L	S	S
Bleach lye	10 %	S	S	S	S

Chemical or product	Concentration	LD °C		HD °C	
		20	60	20	60
Borax	Sat.sol	S	S	S	S
Boric acid	Sat.sol	S	S	S	S
Boron trifluoride	-	L	NS	L	NS
Brake fluid	-	L	NS	L	NS
Brine	-	S	S	S	S
Bromine, dry gas	100 %	NS	NS	NS	NS
Bromine, liquid	100 %	NS	NS	NS	NS
Bromoform	100 %	NS	NS	NS	NS
Butandiol	10 %	S	S	S	S
Butandiol	60 %	S	S	S	S
Butandiol	100 %	S	S	S	S
Butane, gas	100 %	-	-	S	S
Butanol	100 %	S	L	S	S
Butter	-	S	S	S	S
Butyl acetate	100 %	S	L	S	L
Butyl alcohol	100 %	S	S	S	S
Butyl chloride	-	S	-	S	-
Butylene glycol	10 %	S	S	S	S
Butylene glycol	60 %	S	S	S	S
Butylene glycol	100 %	S	S	S	S
Butyraldehyde	-	-	-	S	L
Butyric acid	100 %	L	L	S	L
Calcium arsenate	-	S	S	S	S
Calcium benzoate	-	S	S	S	S
Calcium bisulphide	-	S	S	S	S
Calcium bromate	10 %	S	S	S	S
Calcium bromide	Sat.sol	S	S	S	S
Calcium carbonate	Sat.sol	S	S	S	S
Calcium chlorate	Sat.sol	S	S	S	S
Calcium chloride	Sat.sol	S	S	S	S
Calcium chromate	40 %	S	S	S	S
Calcium cyanide	-	S	S	S	S
Calcium hydrosulphide	Sol	S	S	S	S
Calcium hydroxide	Sat.sol	S	S	S	S
Calcium hypochlorite	Sol	S	S	S	S
Calcium nitrate	Sat.sol	S	S	S	S
Calcium oxide	Sat.sol	S	S	S	S
Calcium perchlorate	1 %	S	-	S	S

Chemical or product	Concentration	LD °C		HD °C	
		20	60	20	60
Calcium permanganate	20 %	S	S	S	S
Calcium persulphate	Sol	S	S	S	S
Calcium sulphate	Sat.sol	S	S	S	S
Calcium sulphide	Dil.sol	-	-	L	L
Camphor oil	-	NS	NS	L	L
Carbon dioxide, dry gas	100 %	-	-	S	S
Carbon dioxide, wet	-	S	S	S	S
Carbon disulphide	100 %	NS	NS	L	NS
Carbon monoxide	100 %	S	S	S	S
Carbon tetrachloride	100 %	NS	NS	L	NS
Carbonic acid		S	S	S	S
Castor oil	Sol	S	S	S	S
Chlorine, water	2 % Sat.sol	L	L	S	S
Chlorine, aqueous	Sat.sol	NS	NS	L	NS
Chlorine, dry gas	100 %	NS	NS	L	NS
Chloroacetic acid	Sol	-	-	S	S
Chlorobenzene	100 %	NS	NS	NS	NS
Chloroethanol	100 %	S	S	S	S
Chloroform	100 %	NS	NS	NS	NS
Chloromethane, gas	100 %	L	-	L	-
Chlorosulphonic acid	100 %	NS	NS	NS	NS
Chloropropene	-	NS	-	L	-
Chrome alum	Sol	S	S	S	S
Chromic acid	Sat.sol	S	S	-	-
Chromic acid	20 %	-	-	S	L
Chromic acid	50 %	-	-	S	L
Chromium VI oxide	Sat.sol	S	S	S	S
Cider	-	S	S	S	S
Citric acid	Sat.sol	S	S	S	S
Citric acid	10 %	S	S	S	S
Citric acid	25 %	S	S	S	S
Coconut oil alcoholic	-	S	S	S	S
Coffee	-	S	S	S	S
Copper (II) chloride	Sat.sol	S	S	S	S
Copper cyanide	Sat.sol	S	S	S	S
Copper (II) fluoride	Sat.sol	S	S	S	S
Copper (II) fluoride	2 %	S	S	S	S
Copper (II) nitrate	Sat.sol	S	S	S	S
Copper (II) sulphate	Sat.sol	S	S	S	S

Chemical or product	Concentration	LD °C		HD °C	
		20	60	20	60
Corn oil	–	S	S	S	S
Cottonseed oil	–	S	S	S	S
Cresylic acid	Sat.sol	–	–	L	–
Crotonaldehyde	Sat.sol	L	–	–	–
Cyclanone	–	S	S	S	S
Cyclohexane	–	NS	NS	NS	NS
Cyclohexanol	Sat.sol	L	NS	–	–
Cyclohexanol	100 %	–	–	S	S
Cyclohexanone	100 %	NS	NS	S	L
Decahydronaphthalene	100 %	L	NS	S	L
Decane	–	NS	NS	L	NS
Decalin	100 %	–	–	S	L
Detergents, synthetic	–	S	S	S	S
Developers (photographic)	Work.conc	–	–	S	S
Dextrin	Sol	S	S	S	S
Dextrose	Sol	S	S	S	S
Diacetone alcohol	–	L	L	L	L
Diazo salts	–	S	S	S	S
Dibutyl amine	–	NS	NS	L	NS
Dibutyl ether	–	NS	NS	L	–
Dibutylphthalate	–	L	L	S	L
Dichlorobenzene	–	NS	NS	NS	NS
Dichloroethylene	–	NS	NS	NS	NS
Dichloropropylene	–	NS	NS	NS	NS
Diesel oil	–	S	NS	S	L
Diethyl ether	100 %	NS	NS	L	–
Diethyl ketone	–	L	NS	L	L
Diethylene glycol	–	S	S	S	S
Diglycolic acid	–	S	S	S	S
Diisobutylketone	100 %	S	L	S	L
Dimethyl amine	100 %	NS	NS	–	–
Dimethyl formamid	–	S	L	S	S
Diethyl phthalate	100 %	L	NS	S	L
Dioxan	100 %	–	–	S	S
Dipentene	–	NS	NS	NS	NS
Disodium phosphate	–	S	S	S	S
Drano, plumbing cleaner	–	S	S	S	S

Chemical or product	Concentration	LD °C		HD °C	
		20	60	20	60
Emulsions, photographic	—	S	S	S	S
Ethandiol	100 %	S	S	S	S
Ethanol	40 %	S	L	S	L
Ethanol	96 %	L	L	—	—
Ethyl acetate	100 %	L	NS	S	NS
Ethyl acrylate	100 %	NS	NS	L	NS
Ethyl alcohol	35 %	S	S	S	S
Ethyl alcohol	100 %	S	S	S	S
Ethyl benzene	—	NS	NS	NS	NS
Ethyl chloride	100 %	NS	NS	NS	NS
Ethylene chloride	100 %	NS	NS	NS	NS
Ethylene diamine	100 %	S	L	S	S
Ethyl ether	—	NS	NS	NS	NS
Ethylene glycol	100 %	S	S	S	S
Ethyl mercaptan	—	NS	NS	NS	NS
Ferric chloride	Sat.sol	S	S	S	S
Ferric nitrate	Sat.sol	S	S	S	S
Ferric sulphate	Sat.sol	S	S	S	S
Ferrous chloride	Sat.sol	S	S	S	S
Ferrous sulphate	Sat.sol	S	S	S	S
Fish solubles	Sol	S	S	S	S
Fluoboric acid	—	S	S	S	S
Fluorine gas	100 %	L	NS	NS	NS
Fluorine gas, dry	100 %	NS	NS	NS	NS
Fluorine gas, wet	100 %	NS	NS	NS	NS
Fluorosilic acid	Conc	S	L	S	L
Fluorosilic acid	40 %	S	S	S	S
Formaldehyde	40 %	S	S	S	S
Formic acid	40 %	S	S	S	S
Formic acid	98 to 100 %	S	S	S	S
Fructose	Sat.sol	S	S	S	S
Fruit pulps	Sol	S	S	S	S
Furfural	100 %	NS	NS	NS	NS
Furfuryl alcohol	100 %	L	NS	S	L
Gallic acid	Sat.sol	S	S	S	S
Gasoline, petrol	—	L	NS	L	L
Gelatine	—	S	S	S	S

Chemical or product	Concentration	LD °C		HD °C	
		20	60	20	60
Glucose	Sat.sol	S	S	S	S
Glycerine	100 %	S	S	S	S
Glycerol	100 %	S	S	S	S
Glycolic acid	30 %	S	L	-	-
Glycolic acid	Sol	-	-	S	S
n-Heptane	100 %	NS	NS	L	NS
Hexachlorobenzene	-	S	S	S	L
Hexachlorophene	-	NS	NS	L	L
Hexamethylenetriamine	40 %	S	-	S	-
Hexane	-	S	L	S	L
Hexanol, tertiary	-	S	S	S	S
Hydrobromic acid	50 %	S	S	S	S
Hydrobromic acid	Up to 100 %	S	S	S	S
Hydrochloric acid	Up to 36 %	S	S	S	S
Hydrochloric acid	Conc	S	S	S	S
Hydrochlorous acid	Conc	S	S	S	S
Hydrocyanic acid	10 %	S	S	S	S
Hydrocyanic acid	Sat.sol	S	S	S	S
Hydrofluoric acid	40 %	S	S	S	S
Hydrofluoric acid	60 %	S	L	S	L
Hydrogen	100 %	S	S	S	S
Hydrogen chloride	Dry gas	S	S	S	S
Hydrogen peroxide	30 %	S	L	S	S
Hydrogen peroxide	90 %	S	NS	S	NS
Hydrogen sulphide gas	100 %	S	S	S	S
Hydroquinone	Sat.sol	S	S	-	-
Hydroxylamine	up to 12 %	S	S	S	S
Inks	-	S	S	S	S
Iodine (in potassium sol)	-	L	NS	NS	NS
Iodine (in alcohol)	-	NS	NS	NS	NS
Iron (II) chloride	Sat.sol	S	S	S	S
Iron (II) sulphate	Sat.sol	S	S	S	S
Iron (III) chloride	Sat.sol	S	S	S	S
Iron (III) nitrate	Sol	S	S	S	S
Iron (III) sulphate	Sat.sol	S	S	S	S
Iso octane	100 %	S	NS	S	L
Iso pentane	-	NS	NS	NS	NS

Chemical or product	Concentration	LD °C		HD °C	
		20	60	20	60
Isopropanol	–	S	S	S	S
Isopropyl amine	–	NS	NS	NS	NS
Isopropyl ether	100 %	L	NS	S	NS
Kerosene	–	NS	NS	NS	NS
Lactic acid	10 %	S	S	S	S
Lactic acid	28 %	S	S	S	S
Lactic acid	up to 100 %	S	S	S	S
Latex	–	S	S	S	S
Lead acetate	Dil.sol	S	S	S	S
Lead acetate	Sat.sol	S	S	S	S
Lead arsenate	–	S	S	S	S
Lubricating oil	–	S	S	S	S
Lysol	–	NS	NS	L	NS
Magnesium carbonate	Sat.sol	S	S	S	S
Magnesium chloride	Sat.sol	S	S	S	S
Magnesium hydroxide	Sat.sol	S	S	S	S
Magnesium nitrate	Sat.sol	S	S	S	S
Magnesium sulphate	Sat.sol	S	S	S	S
Maleic acid	Sat.sol	S	S	S	S
Mercury	–	S	S	S	S
Mercury (I) nitrate	Sol	S	S	S	S
Mercury (II) chloride	Sat.sol	S	S	S	S
Mercury (II) cyanide	Sat.sol	S	S	S	S
Mercury	100 %	S	S	S	S
Methanol	100 %	S	L	S	S
Methyl alcohol	100 %	S	L	S	S
Methyl benzoic acid	Sat.sol	NS	NS	L	–
Methyl bromide	100 %	NS	NS	NS	NS
Methyl chloride	100 %	NS	NS	NS	NS
Methylcyclohexane	–	L	NS	L	NS
Methyl ethyl ketone	100 %	–	–	S	L
Methylene chloride	–	NS	NS	NS	NS
Methoxybutanol	100 %	S	L	S	L
Milk	–	S	S	S	S
Milk of Magnesia	–	S	L	S	L
Mineral oils	–	L	NS	S	L

Chemical or product	Concentration	LD °C		HD °C	
		20	60	20	60
Molasses	Work.conc	S	S	S	S
Motor oil	-	S	L	S	S
Naphtha	-	L	NS	L	NS
Naphtahalene	-	NS	NS	L	-
Nickel chloride	Sat.sol	S	S	S	S
Nickel nitrate	Sat.sol	S	S	S	S
Nickel sulphate	Sat.sol	S	S	S	-
Nicotine	Dil.sol	S	S	S	S
Nicotinic acid	Dil.sol	L	L	S	-
Nitric acid	25 %	S	S	S	S
Nitric acid	50 %	S	L	S	L
Nitric acid	70 %	S	L	S	L
Nitric acid	95 %	NS	NS	NS	NS
Nitric acid	100 %	NS	NS	NS	NS
Nitrobenzene	100 %	NS	NS	NS	NS
Nitroethane	100 %	S	NS	S	NS
Nitromethane	100 %	S	-	S	-
Nitrotoluene	-	NS	NS	NS	NS
n-Octane	-	S	S	S	S
Octyl alcohol	-	S	NS	S	NS
Oil and fats	-	L	NS	S	L
Oleic acid	100 %	L	NS	S	S
Oleum (H2SO4 + 10 % SO3)	-	NS	NS	NS	NS
Oleum (H2SO4 + 50 % SO3)	-	NS	NS	NS	NS
Olive oil	-	S	NS	S	NS
Orthophosphoric acid	50 %	S	S	S	S
Orthophosphoric acid	95 %	S	L	S	L
Oxalic acid	Sat.sol	S	S	S	S
Oxygen	100 %	S	-	S	L
Ozone	100 %	NS	NS	L	NS
Paraffin oil	-	S	L	S	S
n-Pentane	-	NS	NS	NS	NS
Pentane-2	-	NS	NS	NS	NS
Perchloric acid	20 %	S	S	S	S
Perchloric acid	50 %	S	L	S	L
Perchloric acid	70 %	S	NS	S	NS

Chemical or product	Concentration	LD °C		HD °C	
		20	60	20	60
Perchloroethylene	—	NS	NS	NS	NS
Phenol	Sol	L	NS	S	S
Phosphine	100 %	S	S	S	S
Phosphoric acid	up to 25 %	S	S	S	S
Phosphoric acid	25 to 50 %	S	S	S	S
Phosphoric (III) chloride	100 %	S	L	S	L
Phosphorous (II) chloride	100 %	—	—	S	L
Phosphorous pentoxide	100 %	S	S	S	S
Phosphorous trichloride	100 %	S	L	S	L
Photographic solutions	—	S	S	S	S
Phtalic acid	50 %	S	S	S	S
Picric acid	Sat.sol	S	L	S	—
Plating solutions	—	S	S	S	S
Potassium acetate	—	S	S	S	S
Potassium aluminium sulphate	Sat.sol	S	S	S	S
Potassium benzoate	—	S	S	S	S
Potassium bicarbonate	Sat.sol	S	S	S	S
Potassium borate	Sat.sol	S	S	S	S
Potassium bromate	Sat.sol	S	S	S	S
Potassium bromide	Sat.sol	S	S	S	S
Potassium carbonate	Sat.sol	S	S	S	S
Potassium chlorate	Sat.sol	S	S	S	S
Potassium chloride	Sat.sol	S	S	S	S
Potassium chromate	Sat.sol	S	S	S	S
Potassium cyanide	Sol	S	S	S	S
Potassium dichromate	Sat.sol	S	S	S	S
Potassium fluoride	Sat.sol	S	S	S	S
Potassium hexacyanoferrate (III)	Sat.sol	S	S	S	S
Potassium hexacyanoferrate (II)	Sat.sol	S	S	S	S
Potassium hexafluorosilicate	Sat.sol	S	S	S	S
Potassium hydrogen carbonate	Sat.sol	S	S	S	S
Potassium hydrogen sulphate	Sat.sol	S	S	S	S
Potassium hydrogen sulphide	Sol	—	—	S	S
Potassium hydroxide	10 %	S	S	S	S
Potassium hydroxide	Sol	S	S	S	S
Potassium hypochlorite	Sol	S	L	S	L
Potassium iodate	10 %	S	S	S	S
Potassium iodide	Sat.sol	S	S	S	S
Potassium nitrate	Sat.sol	S	S	S	S

Chemical or product	Concentration	LD °C		HD °C	
		20	60	20	60
Potassium orthophosphate	Sat.sol	S	S	S	S
Potassium oxalate	Sat.sol	S	S	S	S
Potassium perchlorate	Sat.sol	S	S	S	S
Potassium permanganate	20 %	S	S	S	S
Potassium persulphate	Sat.sol	S	S	S	S
Potassium phosphate	Sat.sol	S	S	S	S
Potassium sulphate	Sat.sol	S	S	S	S
Potassium sulphide	Sol	S	S	S	S
Potassium sulphite	Sat.sol	S	S	-	-
Potassium thiocyanate	Sat.sol	S	S	S	S
Potassium thiosulphate	Sat.sol	S	S	S	S
Propargul alcohol	-	S	S	S	S
n-Propyl alcohol	-	S	S	S	S
Propionic acid	50 %	-	-	S	S
Propionic acid	100 %	-	-	S	L
Propylene dichloride	100 %	NS	NS	NS	NS
Propylene glycol	-	S	S	S	S
Pyridine	100 %	-	-	S	L
Quinol (hydroquinone)	Sat.sol	S	S	S	S
Resorcinol	Sat.sol	S	S	S	S
Salicylic acid	Sat.sol	S	S	S	S
Sea water	-	S	S	S	S
Selenic acid	-	S	S	S	S
Silicon oil	-	S	S	S	S
Silver acetate	Sat.sol	S	S	S	S
Silver cyanide	Sat.sol	S	S	S	S
Silver nitrate	Sat.sol	S	S	-	-
Soap solution	100 %	S	S	S	S
Sodium acetate	Sat.sol	S	S	-	-
Sodium antimonate	Sat.sol	S	S	S	S
Sodium arsenite	Sat.sol	S	S	S	S
Sodium benzoate	Sat.sol	S	S	S	S
Sodium bicarbonate	Sat.sol	S	S	S	S
Sodium bisulphate	Sat.sol	S	S	S	S
Sodium bisulphite	Sat.sol	S	S	S	S
Sodium borate	-	S	S	S	S
Sodium bromide	Sat.sol	S	S	S	S
Sodium carbonate	Sat.sol	S	S	S	S

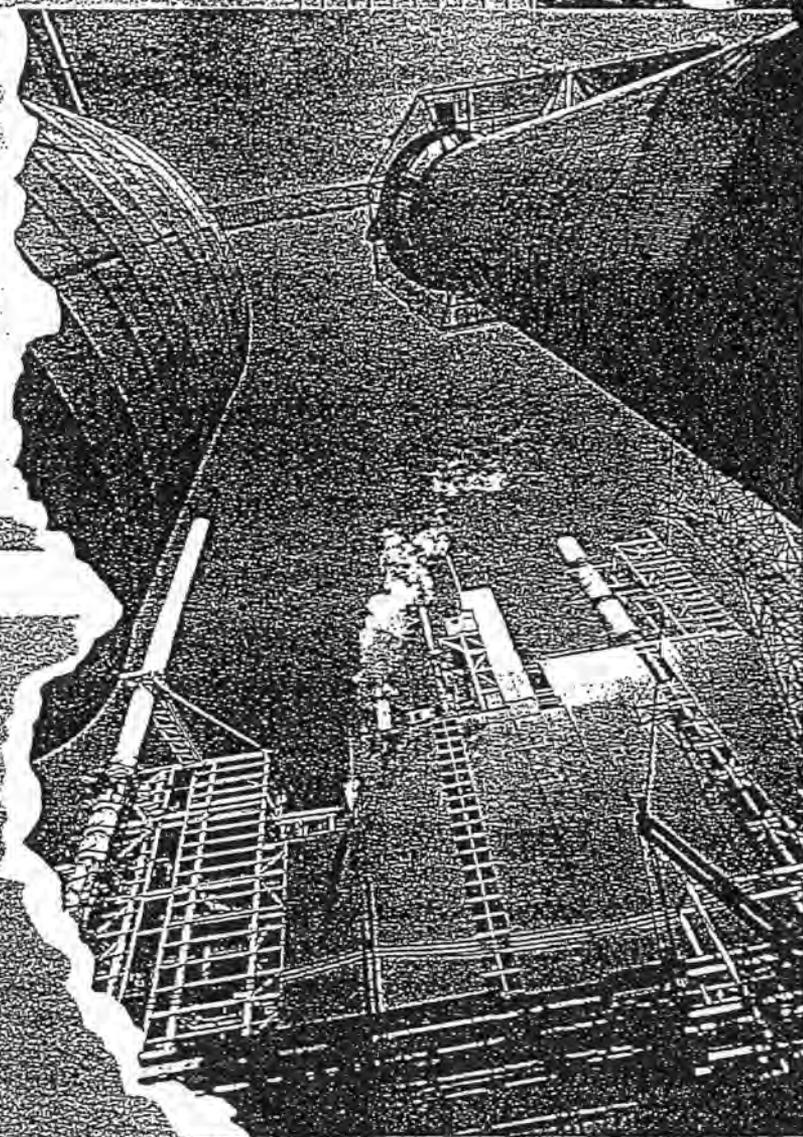
Chemical or product	Concentration	LD °C		HD °C	
		20	60	20	60
Sodium chlorate	Sat.sol	S	S	S	S
Sodium chloride	Sat.sol	S	S	S	S
Sodium chlorite	Sat.sol	L	-	-	-
Sodium cyanide	Sat.sol	S	S	S	S
Sodium dichromate	Sat.sol	S	S	S	S
Sodium fluoride	Sat.sol	S	S	S	S
Sodium hexacyanoferrate (III)	Sat.sol	-	-	S	S
Sodium hexacyanoferrate (II)	Sat.sol	-	-	S	S
Sodium hexafluorosilicate	Sat.sol	S	S	S	S
Sodium hydrogen carbonate	Sat.sol	S	S	S	S
Sodium hydrogen sulphate	Sat.sol	S	S	S	S
Sodium hydrogen sulphite	Sol	S	S	S	S
Sodium hydroxide	40 %	S	S	S	S
Sodium hydroxide	Sol	-	-	S	S
Sodium hypochloride	-	L	NS	S	S
Sodium hypochlorite	15 %	-	-	S	S
	available Cl	-	-	S	S
Sodium iodate	10 %	S	S	S	S
Sodium iodide	Sat.sol	S	S	S	S
Sodium nitrate	Sat.sol	S	S	S	S
Sodium nitrite	Sat.sol	S	S	S	S
Sodium orthophosphate	Sat.sol	S	S	S	S
Sodium oxalate	Sat.sol	S	S	S	S
Sodium phosphate	Sat.sol	S	S	S	S
Sodium silicate	Sol	S	S	S	S
Sodium sulphate	Sat.sol	S	S	S	S
Sodium sulphide	Sat.sol	S	S	S	S
Sodium sulphite	Sat.sol	S	S	S	S
Sodium thiocyanate	Sat.sol	S	S	S	S
Stannic chloride	Sat.sol	S	S	S	S
Stannous chloride	Sat.sol	S	S	S	S
Starch solution	Sat.sol	S	S	S	S
Stearic acid	Sat.sol	S	L	S	-
Styrene	Sol	L	NS	L	NS
Sulphur dioxide, dry	100 %	S	S	S	S
Sulphur trioxide	100 %	NS	NS	NS	NS
Sulphur acid	10 to 50 %	S	S	S	S
Sulphuric acid	10 %	S	S	S	S
Sulphuric acid	50 %	S	S	S	S

Chemical or product	Concentration	LD °C		HD °C	
		20	60	20	60
Sulphuric acid	70 %	S	L	S	L
Sulphuric acid	80 %	S	NS	S	NS
Sulphuric acid	98 %	L	NS	S	NS
Sulphuric acid	Fuming	NS	NS	NS	NS
Sulphurous acid	30 %	S	S	S	S
Sulphurous acid	Sol	S	S	S	S
Tallow	-	S	L	S	L
Tannic acid	Sol	S	S	S	S
Tartaric acid	Sat.sol	S	S	S	S
Tartaric acid	Sol	-	-	S	S
Tetrachloroethylene	100 %	NS	NS	NS	NS
Tetrachloromethane	100 %	NS	NS	L	NS
Tetradecane	-	NS	NS	NS	NS
Tetrahydrofuran	-	NS	NS	NS	NS
Tetrahydronaphthalene	100 %	L	NS	S	L
Thionyl chloride	100 %	NS	NS	NS	NS
Tin (II) chloride	Sat.sol	S	S	S	S
Tin (IV) chloride	Sol	S	S	S	S
Tin (IV) chloride	Sat.sol	-	-	S	S
Titanium tetrachloride	Sat.sol	NS	NS	NS	NS
Toluene	100 %	NS	NS	L	NS
Tribromomethane	-	NS	NS	NS	NS
Trichloroacetaldehyde	-	S	-	S	-
Trichlorobenzene	-	NS	NS	-	-
Trichloroethylene	100 %	NS	NS	NS	NS
Triethanolamine	100 %	S	-	S	-
Triethanolamine	Sol	-	-	S	L
Triethylene glycol	-	S	S	S	S
Trisodium phosphate	Sat.sol	S	S	-	-
Turpentine	-	NS	NS	NS	NS
Urea	up to 30 %	S	S	S	S
Urea	Sol	S	S	S	S
Urine	-	S	S	S	S
Vanilla extract	-	S	S	S	S
Vaseline	-	S	L	S	S
Vegetables oils	-	S	L	S	S
Vinegar	-	S	S	S	S
Water	-	S	S	S	S
Wetting agents	-	S	S	S	S
Wines and spirits	-	S	S	S	S
Chemical or product	Concentration	LD °C		HD °C	
		20	60	20	60

Xylene	100 %	NS	NS	L	NS
Yeast	Sol	S	S	S	S
Zinc bromide	Sat.sol	S	S	S	S
Zinc carbonate	Sat.sol	-	-	S	S
Zinc chloride	Sat.sol	S	S	S	S
Zinc oxide	Sat.sol	S	S	S	S
Zinc stearate	-	S	S	S	S
Zinc sulphate	Sat.sol	S	S	S	S
o-Zylene		NS	NS	NS	NS
p-Zylene	-	NS	NS	NS	NS

CONTAINMENT SOLUTIONS FOR INDUSTRIAL WASTE

Dike raising
Sludge caps
Sludge ponds
Secondary
containment
Landfill linings
Landfill caps
Floating covers



NOC

HIGH DENSITY POLYETHYLENE (HDPE) GEOMEMBRANE

Over the past five years, the geomembrane industry has experienced numerous changes. Factors such as the increased concern for the environment; new products in the marketplace; and the push for tighter governmental control over the environment have all played a significant role in revolutionizing the geosynthetic industry.

Today, the most widely used geomembrane in the waste management industry is High Density Polyethylene (HDPE). HDPE offers superior performance by maintaining the highest standards of durability.

FEATURES AND BENEFITS

National Seal Company's HDPE geomembrane is manufactured on a computer controlled, flat sheet extruder using virgin, first quality, high molecular weight polyethylene. This process guarantees a material thickness of $\pm 5\%$ from target, the most stringent quality control available in the industry. NSC also guarantees the minimum average thickness of our liner will be greater than or equal to the nominal thickness. HDPE is available in 40 (1.0mm), 50 (1.25mm), 60 (1.5mm), 80 (2.0mm), and 100 (2.5mm) mil thicknesses.

★ Chemical Resistance - Often the chemical resistance of the liner is the most critical aspect of the design process. HDPE is the most chemically resistant of all geomembranes. Typical landfill leachates pose no threat to a liner made of HDPE.

Low Permeability - The low permeability of HDPE provides assurance that groundwater will not penetrate the liner; rainwater will not infiltrate a cap; and methane gas will not migrate away from the gas venting system.

Ultraviolet Resistance - HDPE has excellent resistance to ultraviolet degradation. NSC adds carbon black which provides UV protection. Plasticizers are never used in NSC's geomembranes so there is never a concern about volatilization of the plasticizer which can be caused by UV exposure.

APPLICATIONS:

Landfill (primary and secondary containment)	Retention ponds for mining applications
Landfill caps	Wastewater treatment facilities
Lagoon liners	Potable water reservoirs
Pond liners	Tank linings
Floating covers	Canal linings
Secondary containment for above ground storage tanks	Heap leach pads

HDPE GEOMEMBRANE PHYSICAL PROPERTIES

60 mil

The properties on this page are not part of NSC's Manufacturing Quality Control program and are not included on the material certifications. Seam testing is the responsibility of the installer and/or CQA personnel.

PROPERTIES	METHOD	UNITS	MINIMUM ¹	TYPICAL
Multi-Axial Tensile Elongation	GRI, GM-4	percent	20.0	28.0
Critical Cone Height	GRI, GM-3, NSC mod.	cm	1.0	1.5
Wide Width Tensile	ASTM D 4885			
Stress at Yield		psi	2000	2110
Strain at Yield		%	15.0	20.0
Brittleness Temp. by Impact ²	ASTM D 746	°C	-75	<-90
Coef. of Linear Thermal Exp. ²	ASTM D 696	°C ⁻¹	1.5 x 10 ⁻⁴	1.2 x 10 ⁻⁴
ESCR, Bent Strip	ASTM D 1693	hours	1500	>10,000
Hydrostatic Resistance	ASTM D 751	psi	450	510
Modulus of Elasticity	ASTM D 638	psi	80,000	135,000
Ozone Resistance	ASTM D 1149, 168 hrs	P/F	P	P
Permeability ²	ASTM E 96	cm/sec * Pa	2.3x10 ⁻¹⁴	8.1 x 10 ⁻¹⁵
Puncture Resistance	FTMS 101, method 2065	ppi	1300	1700
		lbs	78	105
Soil Burial Resistance ²	ASTM D 3083, NSF mod.	% change	10	0
Tensile Impact	ASTM D 1822	ft lbs/in ²	250	420
Volatile Loss ²	ASTM D 1203, A	percent	0.10	0.06
Water Absorption ²	ASTM D 570, 23°C	percent	0.10	0.04
Water Vapor Transmission ²	ASTM E 96	g/day * m ²	0.024	0.009

SEAM PROPERTIES	METHOD	UNITS	MINIMUM ¹	TYPICAL
Shear Strength	ASTM D 4437, NSF mod.	psi	2000	2700
		ppi	120	166
Peel Strength	ASTM D 4437, NSF mod.	psi	1500	1870
(hot wedge fusion)		ppi	90	115
Peel Strength	ASTM D 4437, NSF mod.	psi	1300	1590
(fillet extrusion)		ppi	78	98

STANDARD ROLL DIMENSIONS

Length	1110 feet	Area	16,650 ft ²
Width	15 feet	Weight	5,000 lbs

This information contained herein has been compiled by National Seal Company and is, to the best of our knowledge, true and accurate. All suggestions and recommendations are offered without guarantee. Final determination of suitability for use based on any information provided, is the sole responsibility of the user. There is no implied or expressed warranty of merchantability or fitness of the product for the contemplated use.

NSC reserves the right to update the information contained herein in accordance with technological advances in the material properties.

6H-0893

NSC

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HDPE GEOMEMBRANE QUALITY CONTROL SPECIFICATIONS

60 mil

National Seal Company's High Density Polyethylene (HDPE) Geomembranes are produced from virgin, first quality, high molecular weight resins and are manufactured specifically for containment in hydraulic structures. NSC HDPE geomembranes have been formulated to be chemically resistant, free of leachable additives and resistant to ultraviolet degradation.

The following properties are tested as a part of NSC's quality control program. Certified test results for properties on this page are available upon request. Refer to NSC's Quality Control Manual for exact test methods and frequencies.

All properties meet or exceed NSF Standard Number 54.

RESIN PROPERTIES	METHOD	UNITS	MINIMUM ¹	TYPICAL
Melt Flow Index ²	ASTM D 1238	g/10 min	0.50	0.25
Oxidative Induction Time	ASTM D 3895, Al pan, 200°C, 1 atm O ₂	minutes	100	120

SHEET PROPERTIES	METHOD	UNITS	MINIMUM ¹	TYPICAL
Thickness	ASTM D 751, NSF mod.			
Average		mils	60.0	61.5
Individual		mils	57.0	59.7
Density	ASTM D 1505	g/cm ³	0.940	0.948
Carbon Black Content	ASTM D 1603	percent	2.0-3.0	2.35
Carbon Black Dispersion	ASTM D 3015, NSF mod.	rating	A1, A2, B1	A1
Tensile Properties	ASTM D 638			
Stress at Yield		psi	2200	2550
		ppi	132	157
Stress at Break		psi	3800	4850
		ppi	228	298
Strain at Yield	1.3" gage length (NSF)	percent	13.0	16.9
Strain at Break	2.0" gage or extensometer	percent	700	890
	2.5" gage length (NSF)	percent	560	710
Dimensional Stability ²	ASTM D 1204, NSF mod.	percent	1.5	0.4
Tear Resistance	ASTM D 1004	ppi	750	860
		lbs	45	53
Puncture Resistance	ASTM D 4833	ppi	1800	2130
		lbs	108	131
Constant Load ESCR, Single Point	GRI, GM-5a	hours	200	>400

¹ This value represents the minimum acceptable test value for a roll as tested according to NSC's Manufacturing Quality Control Manual. Individual test specimen values are not addressed in this specification except thickness.

² Indicates Maximum Value



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How long will my liner last?

| What is the remaining service life of my HDPE geomembrane?

By Ian D. Peggs, P.E., P.Eng., Ph.D.

Introduction

In his keynote lecture at the GeoAmericas-2008 conference last March, Dr. Robert Koerner (et al., 2008) of the Geosynthetic Institute (GSI) reported the ongoing Geosynthetic Research Institute (GRI) work to make the first real stab at assessing the service lives of high-density polyethylene (HDPE), linear low-density polyethylene (LLDPE), reinforced PE, ethylene propylene diene terpolymer (EPDM), and flexible polypropylene (fPP) exposed geomembranes.

The selected environment simulated that of Texas, USA, in sunny ambient temperatures between ~7°C (45°F) and 35°C (95°F). Of course, an exposed black HDPE geomembrane in the sun will achieve much higher temperatures, probably in excess of 80°C (176°F).

I do not know what the temperature would be at 150-300mm above the liner (for those still specifying this parameter), but it is quite immaterial. The only temperature of concern is the actual geomembrane temperature.

The lifetimes are shown in **Table 1**, but it must be recognized that these data are for specific manufactured products with specific formulations. The “greater than” notation indicates that laboratory exposures (incubations) are still on-going, not

that some samples have failed after the indicated time period. The PE-R-1 material is a thin LLDPE, so it might be expected to be the first to reach the defined end of life; the half-life—the time to loss of 50% of uniaxial tensile properties.

It is interesting to note that HDPE-1 and LLDPE-1 are proceeding apace, but it would be expected that the LLDPE-1 would reach its half-life earlier than HDPE-1. However, this does not automatically follow. With adequate additive formulations, perhaps LLDPE could be left exposed and demonstrate more weathering resistance than some HDPEs. This demonstrates the fact that all PEs, whether HD or LLD, are not identical—they can have different long-term performances dependent on the PE resin used and the formulation of the stabilizer package. However, such differences are not evident in the conventional mechanical properties such as tensile strength/elongation, puncture and tear resistances, and so on.

The two fPPs are performing well. However, there had also been an fPP-1, one of the first PP geomembranes that did not perform well. This was due to a totally inappropriate stabilizer formulation. That particular product lasted 1.5 years in service. In

Final Inspection continued on page 44

Type	Specification	Predicted Lifetime in Texas, USA
HDPE-1	GRI-GM13	>28 years (Incubation ongoing)
LLDPEE-1	GRI-GM17	>28 years (Incubation ongoing)
EPDM-1	GRI-GM21	>20 years (Incubation ongoing)
PE-R-1	GRI-GM22	≈17 years (reached halflife)
fPP-2	GRI-GM18 (temp. susp.)	>27 years (Incubation ongoing)
fPP-3	GRI-GM18 (temp. susp.)	>17 years (Incubation ongoing)

Table 1 | Estimated exposed geomembrane lifetimes

| Ian Peggs is president of I-CORP International Inc. and is a member of *Geosynthetics* magazine's Editorial Advisory Committee.

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the QUV weatherometer, it lasted 1,800 light hours at 70°C (158°F). Therefore, the lab/field correlation is that 1,000 QUV light hours is equivalent to a 0.83yr service life under those specific environmental conditions.

At another location in Texas, Korrner/GRI found 1,000hr of QUV exposure was equivalent to 1.1 year actual field exposure. Consequently, for Texas exposures GRI is using a correlation of 1000hr QUV exposure as equivalent to 1yr of in-service exposure. Clearly, the correlation would be different in less sunny and colder environments.

The failed fPP-1 liner was replaced with a correctly stabilized fPP that, subsequently, performed well.

So how can we evaluate the condition of our exposed liners in a simple and practical manner to ensure they will continue to provide adequate service lifetimes and to get sufficient warning of impending expiration?

For each installation, a baseline needs to be established, and changes from that baseline need to be monitored.

A liner lifetime evaluation program

Rather than be taken by surprise when a liner fails or simply expires, it should be possible to monitor the condition of the liner to obtain a few years of notice for impending expiration. One can then plan for a timely replacement without the potential for accidental environmen-

values that generally significantly exceed the specification.

A final option for the baseline would be to use the values at the time of the first liner assessment.

The first liner condition assessment would consist of a site visit during which a general visual examination would be done together with a mechanical probing of the edges of welds. A visual examination would include the black/gray shades of different panels that might indicate low carbon contents.

A closer examination should be done using a loupe (small magnifier) on suspect areas such as wrinkle peaks, the tops and edges of multiple extrusion weld beads, and the apex-down creases of round die-manufactured sheet.

The last detail is significant because the combination of oxidizing surface and exposed surface tension when the liner contracts at low temperatures and the crease is pulled flat can be one of the first locations to crack. The apex-up creases do not fail at the same time because the oxidized exposed surface is under compression (or less tension) when the crease is flattened out.

Appropriate samples for detailed laboratory testing will be removed.

It may be appropriate to do a water lance electrical integrity survey on the exposed sideslopes, but this would only be effective on single liners, and on double liners with a composite primary liner, a conductive geomembrane, or a geocomposite with a conductive geotextile on top.

A sampling and testing regime

A liner lifetime evaluation program should be simple, meaningful, and cost-effective.

While it will initially require expert polymer materials science/engineering input to analyze the test data and to define the critical parameters, it should ultimately be possible to use an expert system to automatically make predictions using the input test data.

Small samples will be taken from deep in the anchor trench and from appropriate

... it should be possible to monitor the condition of the liner to obtain a few years of notice for impending expiration.

While estimated correlations might be made for other locations using historical weather station sunshine and temperature data, there is no question that the best remaining lifetime assessments will be obtained using samples removed from the field installation of interest.

A lifetime in excess of 28yr, demonstrated for a recently-made HDPE geomembrane, is comparable to the present actual service periods of as long as 30-35yr. However, actual lifetimes of as low as ~15yr have also been experienced.

Do service lifetimes now exceeding 30yr mean that we might expect to see another round of stress cracking failures as exposed liners finally oxidize sufficiently on the surface to initiate stress cracking?

This would be frustrating after resolving the early 1980s problems with stress cracking failures at welds and stone protrusions when the liners contracted at low temperatures, but it is the way end-of-life will become apparent. And will that be soon or in another 5-20 years? It would be useful to know.

tal damage and undesirable publicity. A program of periodic liner-condition assessment is proposed.

For baseline data, it would be useful to have some archive material to test, but that is not usually available. Manufacturers often discard retained samples after about 5 years. Perhaps facility owners should be encouraged to keep retained samples at room temperature and out of sunlight. The next best thing is to use material from the anchor trench or elsewhere that has not experienced extremes in temperature and that has not been exposed to UV radiation or to expansion/contraction stresses.

Less satisfactory options are to use the original NSF 54 specifications, the manufacturer's specifications, or the GRI-GM13 specifications at the appropriate time of liner manufacturing. The concern with using these specifications is that while aged material may meet them, there is no indication of whether the measured values have significantly decreased from the actual as-manufactured

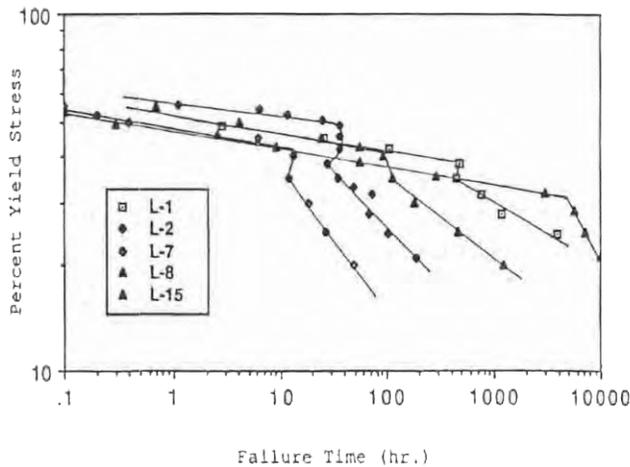


Figure 1 | Standard stress rupture curves for five HDPE geomembranes (Hsuan, et al. 1992)

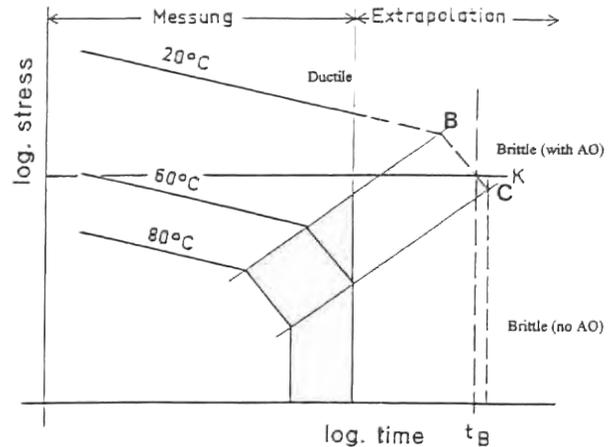


Figure 2 | Stress rupture curves showing third stage (Brittle no AO) oxidized limit. (Gaubé, et al. 1985)

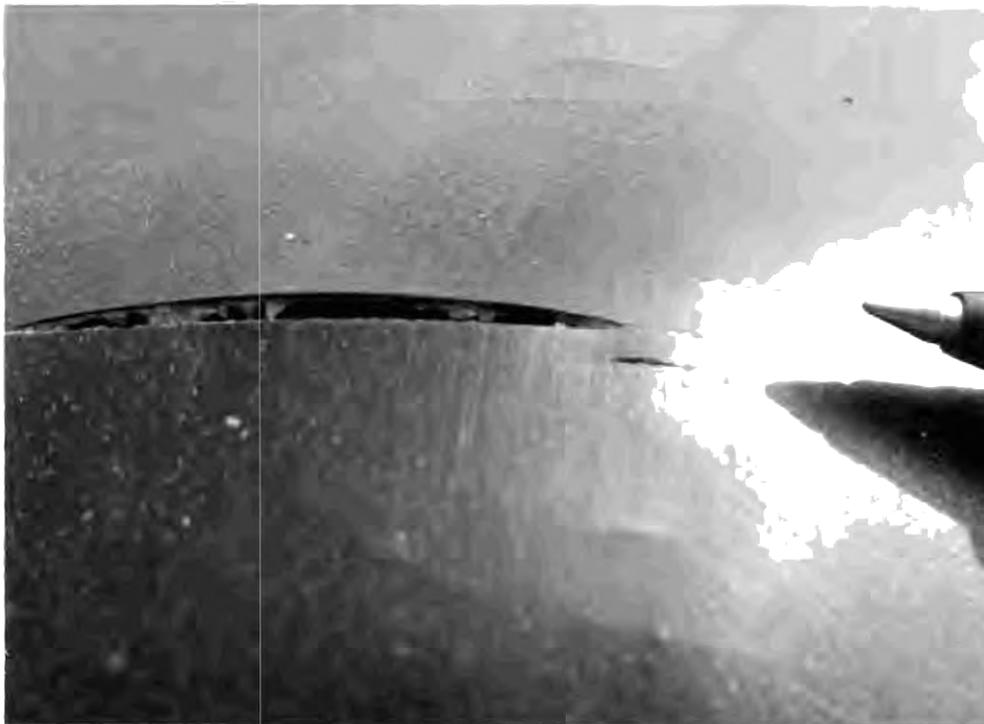


Figure 3 | Stress crack initiated by extruder die line at stone protrusion

The exposed samples will be tested as follows:

- Carbon content (ASTM D1603)
- Carbon dispersion (ASTM D5596)
- Single-point SCR on molded plaque (ASTM D5397)
- Light microscopy of exposed surface, through-thickness cross sections, and thin microsections (~15 μm thick) as necessary
- HP-OIT on 0.5-mm-thick exposed surface layers from basic sheet and from sheet at edge of extruded weld bead (ASTM D5885), preferably at a double-weld bead
- FTIR-ATR on exposed surface to determine CI
- Oven aging/HP-OIT on 0.5mm surface layer (GRI-GM13)
- UV resistance/HP-OIT on 0.5 mm surface layer (GRI-GM13)

Carbon content is done to ensure adequate basic UV protection. Carbon dispersion is done to ensure uniform surface UV protection and to evaluate agglomerates that might act as initiation sites for stress cracking.

HP-OIT is used to assess the remaining amount of stabilizer additives, both in the liner panels and in the sheet adjacent to an extrusion weld. Most stress cracking is observed at the edges of extrusion

exposed locations. Potential sites for future sample removal by the facility owner for future testing will be identified and marked by the expert during the first site visit.

The baseline sample(s) will be tested as follows:

- Single-point stress cracking resistance (SCR) on a molded plaque by ASTM D5397

- High-pressure oxidative induction time (HP-OIT) by ASTM D5885
- Fourier transform infrared spectroscopy (FTIR-ATR) on upper surface to determine carbonyl index (CI) on nonarchive samples only
- Oven aging/HP-OIT (GRI-GM13)
- UV resistance/HP-OIT (GRI-GM13)

weld beads in the lower sheet, so it is important to monitor this location.

While standard OIT (ASTM D3895 at 200°C) better assesses the relevant stabilizers effective at processing (melting) and welding temperatures, the relevant changes in effective stabilizer content during continued service, including in the weld zone, will be provided by measurement of HP-OIT. There will be no future high temperature transient where knowledge of S-OIT will be useful. It is expected that the liner adjacent to the weld bead will be more deficient in stabilizer than the panel itself. Therefore, S-OIT is not considered in this program.

Note that HP-OIT is measured on a thin surface layer because the surface layer may be oxidized while the body of the geomembrane may not. If material

from the full thickness of the geomembrane is used it could show a significant value of OIT, implying that there is still stabilizer present and that oxidation is far from occurring. However, the surface layer could be fully oxidized with stress cracks already initiated and propagating. A crack will then propagate more easily through unoxidized material than would initiation and propagation occur in unoxidized material.

The fact that the HP-OIT meets a certain specification value in the as-manufactured condition provides no guarantee that thermo- and photo-oxidation protection will be provided for a long time. Stabilizers might be consumed quickly or slowly while providing protection. They may also be consumed quickly to begin with, then more slowly, or vice versa.

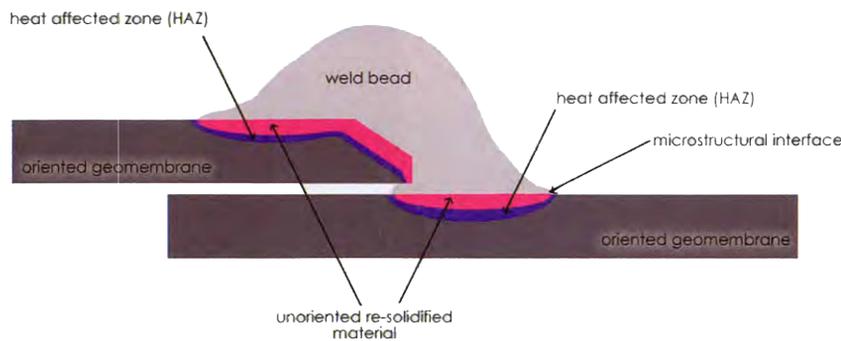


Figure 4 | Schematic of microstructure at extrusion weld

Hence, the need for continuing oven (thermal) aging and UV resistance tests. These two parameters, assessed by measuring retained HP- OIT, are critical to the assessment of remaining service life.

Oven (thermal) aging and UV resistance tests performed in this program will provide an extremely valuable data base that relates laboratory testing to in-service performance and that will further aid in more accurately projecting in-service performance from laboratory testing results.

Special considerations

Because we do not know, by OIT measurements alone, whether the surface layer is or is not oxidized (unless OIT is zero), and since we do not yet know at what level of OIT loss there might be an oxidized surface layer (the database has not yet been generated), FTIR directly on the surface of the geomembrane is performed using the attenuated total reflectance (ATR) technique to deny or confirm the presence of oxidation products (carbonyl groups).

Following the practice of Broutman, et al. (1989) and Duvall (2002) on HDPE pipes, if the ratio of the carbonyl peak at wave number 1760 cm^{-1} and the C-H stretching (PE) peak at wave number 1410 cm^{-1} is more than 0.10, there is a sufficiently oxidized surface layer that

stress cracking might be initiated. For those familiar with the two slope stress rupture curve (Figure 1) where the brittle stress cracking region is the steeper segment below the knee, there is a third vertical part of the curve (Figure 2) where the material is fully oxidized and fracture occurs at the slightest stress. This is what will happen at the end of service life. But first note the times to initiation of stress cracking (the knees in the curves) in Figure 1—they range from ~10/hr to

~5,000/hr—clearly confirming that all HDPEs are not the same. Some are far more durable than others.

At the end of service life, at some level of OIT, there will be a critically oxidized surface layer that when stressed, such as at low temperatures by an upwards protruding stone, or by flexing due to wind uplift, will initiate a stress crack on the surface that will propagate downward through the geomembrane, as shown by the crack in Figure 3.

This crack, initiated at a stress concentrating surface die mark, occurred when the liner contracted at low temperatures, and tightened over an upwardly protruding stone. The straight morphology of the crack, and the ductile break at the bottom surface as the stress in the remaining ligament rose above the knee in the stress rupture curve, are typical of a stress crack. Note the shorter stress cracks initiated along other nearby die marks.

Stress cracks are preferentially initiated along the edges of welds because the adjacent geomembrane has been more depleted of stabilizers during the high temperature welding process. Thus, under further oxidizing service conditions, it will become the first location to

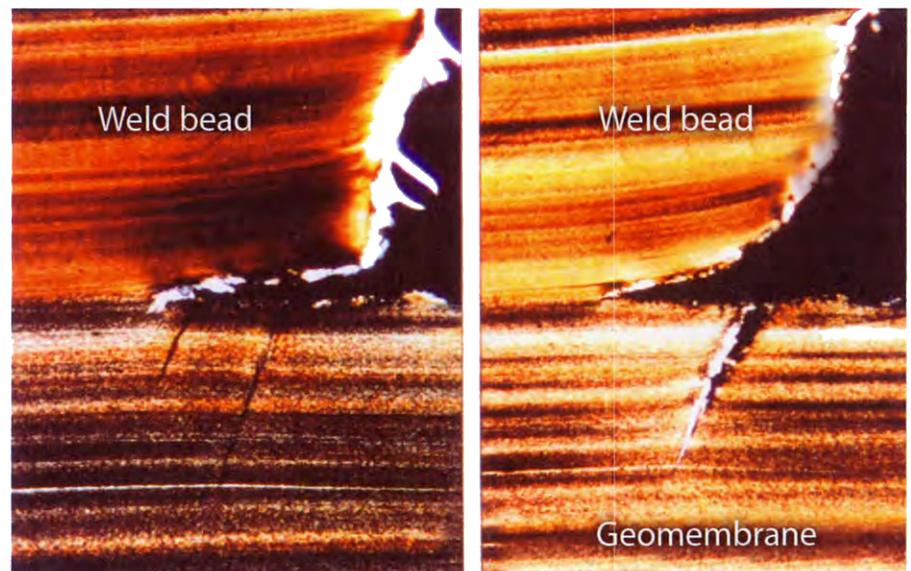


Figure 5 | Typical off-normal angle of precursor crazes (left) and stress crack (right) at edge of extrusion weld.

Type	Specification	Predicted Lifetime in Texas, USA
Side wall exposed	54	5
Side wall concrete side	81	71
Lower launder exposed	16	3
Lower launder concrete side	145	1

Table 2 | S-OIT values on solution and concrete liner surfaces (Peggs, 2008).

be oxidized to the critical level at which stress cracks will be initiated under any applied stress. In addition, the geometrical notches at grinding gouges and at the edges of the bead increase local stresses to critical levels for SC to occur.

I also believe that an internal microstructural flaw exists between the originally oriented geomembrane structure and the pool of more isotropic melted and resolidified material at the edge of the weld zone, as shown schematically in **Figure 4**. Most stress cracks occur at an off-normal angle at the edge of the weld bead that may be related to the angle of this molten-pool to oriented-structure interface (**Figure 5**). It is also known that stress increases the extraction of stabilizers from polyolefin materials.

With all of these agencies acting synergistically, it is not surprising that stress cracking often first occurs adjacent to extrusion welds.

Looking ahead

With the first field assessment test results available to us, and the extent of changes from the baseline sample known, removal of a second set of samples by the facility owner (at locations previously identified and marked by the initial surveyor), will be planned for a future time, probably in 2 or 3 years.

Why 2 or 3 years? In an extreme chemical environment, extensive reductions in

S-OIT of studded HDPE concrete protection liners in mine solvent extraction facilities using kerosene/aromatic hydrocarbon/sulfuric acid process solutions at 55°C (131°F) have been observed on the solution and concrete sides of the liner (**Table 2**) within 1 year (Peggs 2008). But it is unlikely that such rapid decreases will be observed in air-exposed material.

With this second set of field samples, and with three sets of data points, practically reliable extrapolations of remaining lifetime can start to be made.

It is expected that a few years of notice for impending failures will be possible.

The key point to note in making these condition assessments is that, while all HDPE geomembranes have very similar conventional index properties, they can have widely variable photo-oxidation, thermal-oxidation, and stress-cracking resistances. Therefore, some HDPEs are more durable than others.

Thus, while one HDPE geomembrane manufactured in 1990 failed after 15 years in 2005, another HDPE geomembrane made in 1990 from a different HDPE resin (or more correctly a medium-density polyethylene [MDPE] resin), and with a better stabilizer additive package, could still have a remaining lifetime of 5, 20, or 30 years.

So, keep a close eye on those exposed liners and we'll learn a great deal more about liner performance and get notice of

the end of service lifetime. And if owners can retain some archive material from new installations, so much the better.

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**APPLICATION FOR PERMIT
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**VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 6: GEOSYNTHETICS APPLICATIONS AND
COMPATIBILITY DOCUMENTATION**

**ATTACHMENT III.6.B
GEOTEXTILES REFERENCE DOCUMENTATION**

Technical Note No. 7

Chemical Resistance of Amoco Polypropylene Geotextiles

Amoco woven and nonwoven geotextiles are manufactured from polypropylene with ultra violet stabilizing additives. The excellent chemical resistance of Amoco polypropylene geotextiles is one of the qualities which has established Amoco as a leading producer of geotextiles for use in the waste containment industry. This technical note addresses the chemical resistance of polypropylene with a focus on recent testing programs which have clearly demonstrated the durability of Amoco fabrics in a variety of chemical environments.

Are polypropylene geotextiles durable in the chemical environment of landfill leachates?

Yes. Of the polymers used to manufacture geotextiles, polypropylene exhibits the greatest resistance to chemical attack. In fact, polypropylene is the polymer of choice for such commonly used products as landfill liners, synthetic grass for athletic fields, outdoor carpeting, battery cases, bleach bottles, antifreeze jugs, washing machine agitators, and thousands of other commonly used items that are routinely exposed to chemical environments. Polypropylene is stable within a pH range of 2 to 13, making one of the most stable polymers.

Polypropylene geotextiles have been found to be durable in a wide range of chemical environments (Bell, et. al., 1980; Haxo, 1978, 1983; Pucetas, et.al., 1991; Tisinger, et. al., 1989). Research has found both woven and nonwoven polypropylene geotextiles to be non-biodegradable and resistant to commonly encountered soil-bound chemicals, landfill leachates, mildew, and insects.

How is the chemical resistance of polypropylene geotextiles determined?

Numerous laboratory test programs have subjected polypropylene to severe chemical environ-

ments such as solutions of organic solvents, oils, organic acids, and inorganic acids. The laboratory tests are generally performed in accordance with ASTM D 543, "Standard Test Method for Resistance of Plastics to Chemical Reagents." These test programs have found polypropylene to exhibit superb chemical resistance.

In the ASTM D 543 procedure, the specimens are immersed in a concentrated chemical solution at a specified temperature for a specified exposure period. This test method exposes the polypropylene to extremely harsh conditions which are considerably more severe than those encountered in most civil engineering applications.

The chemical compatibility of geotextiles with leachates is determined by EPA Test Method 9090 (EPA 9090), "*Compatibility Test for Wastes and Membrane Liners*." This was the laboratory method used in the Amoco geotextile test programs reported in this technical note. Geotextile samples are immersed in a constant temperature leachate bath for four months. At the end of each month samples of the fabric are removed and subjected to physical testing. Changes in properties may indicate chemically imposed degradation.

Have Amoco geotextiles been proven to be chemically resistant?

Four laboratory testing programs have been performed to evaluate the chemical compatibility of Amoco geotextiles with landfill leachates. The tests exposed both Amoco woven and nonwoven products to hazardous and municipal waste leachates.

In all testing programs there was no indication of geotextile degradation due to exposure to landfill leachates. The test results are summarized in the remainder of this technical note.

Hazardous waste leachate

A laboratory testing program was performed in 1989 to evaluate the chemical compatibility of Amoco geotextiles with a hazardous waste leachate. The program included EPA 9090 testing of 4 oz/yd² and 8 oz/yd² nonwoven specimens. The testing exposed the geotextiles to leachate in both the laboratory and in a leachate collection sump at a hazardous waste landfill.

Test evaluation incorporated detailed microstructural analyses which are not typically incorporated into chemical resistance testing programs. Methods included differential scanning calorimetry, thermal gravimetric analysis, and infrared spectrophotometry. These analyses were performed to identify any changes in the microstructure of the geotextile due to immersion in the leachate.

The results of this testing program found the geotextile microstructure remained intact, stable, and unchanged (Tisinger, et. al., 1989).

Municipal waste leachate

The chemical resistance of Amoco geotextiles to municipal solid waste leachate was evaluated in three laboratory testing programs. The first program, completed in 1990, included EPA 9090 testing of 16 oz/yd² nonwoven geotextile specimens. The second test program, performed in 1992, tested specimens of 8 oz/yd² nonwoven geotextile. The third program, completed in 1993, evaluated the chemical resistance of a high strength woven geotextile. The testing programs evaluated changes in physical properties of the specimens, including specimen dimensions, thickness, grab tensile strength and elongation, puncture resistance, burst strength, and tear strength. In all cases there were no measurable changes in physical properties of the specimens after exposure to the leachate.

Are the results of these tests applicable to Amoco geotextiles which have not been similarly tested?

Yes. All Amoco geotextiles are equally resistant to chemical degradation because they are all manufactured using the same polymer and additives. This conclusion is supported by the test results, which demonstrated no difference in chemical resistance for different types of Amoco geotextiles. The information in this technical note, therefore, is considered to be applicable to all Amoco geotextiles regardless of weight, thickness, or strength.

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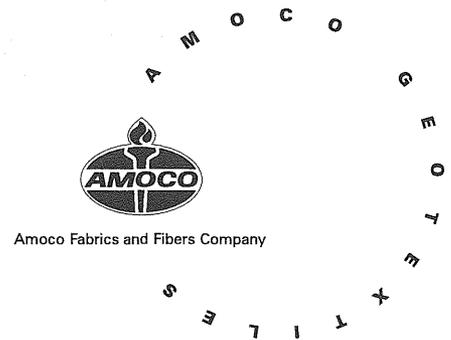
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Technical Note No. 14



Geotextile Polymers for Waste Applications

What types of polymers are used to manufacture geotextiles?

Virtually all geotextile fibers are made from either polypropylene or polyester polymers.

Are these polymers used in a 100% pure form?

The manufacture of geosynthetics usually includes the addition of stabilizers and other additives that are blended with the base polymer. The additives constitute a minor fraction of the polymer mixture.

Additives are used primarily to counteract the effects of oxidation, to which many synthetic polymers are sensitive. Oxidation can cause a reduction in material properties such as strength and elasticity. The main sources of oxidation are heat/temperature (thermal oxidation) and ultra violet (UV) radiation from sunlight (photo-oxidation). Manufacturers of geosynthetics add a variety of proprietary additives during production to make the polymers more stable against thermal and UV degradation (see Amoco Technical Note No. 9).

Should the designer specify polypropylene or polyester for geotextiles to be used in waste applications?

The type of polymer used in the fabrication of the geotextile is not a relevant design parameter. The specifications should be developed to focus on the required physical properties of the geotextile relative to strength, hydraulic performance, and chemical compatibility and durability. These elements are addressed in detail in the Amoco Waste-Related Geotextile Guide Specifications.

Does the type of base polymer affect the chemical resistance of geotextiles used in landfills?

Geotextiles in landfills are exposed to leachates, which are generally dilute solutions of chemicals. The geotextile must be resistant to degrading in this chemical environment. Chemical resistance of geotextiles to leachates is evaluated in the laboratory using EPA Test Method 9090 (EPA 9090). The results of such testing on polypropylene and polyester have proved both polymers to be relatively inert and durable in various chemical environments of hazardous and nonhazardous waste landfills (refer to Amoco Technical Note No. 7).

Of the polymers used to manufacture geotextiles, polypropylene exhibits the greatest resistance to chemical attack. Polypropylene is inert to most chemicals except for some highly concentrated solvents. Geotextiles are not expected to be exposed to such solvents in waste applications, where the associated leachates typically contain only trace to very low concentrations of solvent constituents.

Polyester exhibits comparable chemical compatibility. However, unlike polypropylene, polyester is subject to hydrolysis in aqueous environments such as landfill leachates. Hydrolysis is a process in which water-based solvents or water alone causes the polymer chains to break. This can result in a reduction in the mechanical properties of the polymer. Despite this characteristic, the results of EPA 9090 testing on polyester do not show an impact from hydrolysis.

What effect does polymer type have on the UV resistance of geotextiles used in landfills?

There are only slight differences in the UV stability of various geotextile polymers. From a construction perspective, these differences have no impact on the selection of geotextiles for landfill applications. Regardless of the polymer type, it is important to limit exposure of the geotextile to potentially damaging UV radiation.

In landfill applications, geotextiles are usually covered by soil layers and waste soon after construction. Their exposure to UV radiation therefore generally occurs only during construction. Regardless of polymer type, exposure of the fabrics to sunlight during installation should be limited in accordance with the project specifications (see Amoco Waste-Related Geotextile Guide Specifications).

On some landfill side slopes, the geotextile might be left exposed for an extended time before being covered with soil. In these cases, the geotextile must be protected from UV radiation by alternative methods, regardless of whether the fabric is manufactured of polypropylene or polyester. Alternatives include covering the geotextile with a sacrificial geotextile layer or opaque plastic sheet. The sacrificial layer would be removed prior to placing soil cover.

Has the performance of Amoco geotextiles in landfill applications been verified?

Yes. In fact, the excellent chemical resistance of Amoco polypropylene geotextiles is one of the qualities that has established Amoco as a leading supplier of fabrics to the waste containment industry.

Laboratory testing programs have been performed specifically to evaluate the chemical compatibility of Amoco polypropylene geotextiles with landfill leachates. In all test cases there were no measurable changes in the physical properties of the Amoco geotextiles after exposure to leachates. Also, unlike polyester, polypropylene does not undergo hydrolysis. Amoco Technical Note No. 7 provides detailed information regarding the chemical compatibility test conditions, procedures, and results.

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**VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 6: GEOSYNTHETICS APPLICATIONS AND
COMPATIBILITY DOCUMENTATION**

**ATTACHMENT III.6.C
GEONET REFERENCE DOCUMENTATION**

EVALUATION ON STRESS CRACKING RESISTANCES OF VARIOUS HDPE DRAINAGE GEONETS

M.S. Mok¹, E. Blond², J. Mlynarek³ and H. Y. Jeon⁴

ABSTRACT: Specimens from each geonet were placed under various compressive loads in a vessel containing a solution of 10% surface-active agent and 90% water at a temperature of 50°C. Then the surface morphology study of the specimen was performed after 500 hours test duration. The results show that all of these geonets did not appear any kind of stress cracking in the condition of 400 kPa, which is a typical landfill's loading condition. However, in the case of bi-planar geonet there were some deposits on the surface of geonet's strand and it is expected that this phenomena is due to the results of chemical clogging. On the other hand, in the case of the tri-planar and circular type bi-planar geonets, it maintained very clean flow channels until the end of the test. For high normal pressure some environmental stress cracks were detected for the circular type bi-planar geonet. The results show that the resistance to the environmental stress cracking is related to its polymer density, crystallinity and also rigidity not its mechanical properties.

KEYWORDS: geonet, compressive loads, surface morphology, stress cracking, chemical clogging, flow channels

INTRODUCTION

Land filling, by all indications, will continue to be the predominant method of solid waste disposal. As the use of high density polyethylene (HDPE) geonets increase in landfill applications, it is required to evaluate their long-term properties in several chemical conditions. (Ward and Brown 1990; Carlson 1993)

Typically, the high crystallinity of polyethylene geonets provides an excellent chemical resistance to harsh chemical leachate, however can be problematic with regard to environmental stress cracking. (Qian and Brown 1993; Thomas 1998) Under low stresses in the circumstance of room temperature polyethylenes will fracture by slow crack growth. This mode of failure limits the lifetime of polyethylenes used in critical applications as drainage materials, lining under landfills. (Lagaron, Pastor, Kip 1999; Bobsein 1999)

Geomembranes and geonets are used as a barrier and drainage component in this system, respectively. With addition of carbon black which is an anti-oxidation material HDPE geomembranes and geonets are normally used in hazardous landfill system as a barrier and drainage respectively.

Many researchers and a lot of work about environmental stress cracking resistance for the geomembranes were done and many beneficial reports have already

been published. (Peggs and Kannien 1995; Thomas and Deschepper 1993) However a few research results on the environmental stress cracking resistance for the geonet drainage material were performed. Therefore, in this study the resistance to environmental stress cracking (ESCR) was examined mainly in morphological issues for various geonets (bi-planar, tri-planar and circular type of bi-planar geonet) under condition of various normal pressures.

SPECIMEN & TEST METHODS

Total three types of geonets were test in this study. Sample A has 5.6 mm mean value of thickness and two layers which means bi-planar geonet. The cross sectional shape of strand of Sample A is more likely to a square. Sample B has average of 8.6 mm thickness and has 3 layers (tri-planar). Sample C is also bi-planar geonet however has circular type cross sectional shape and thicker than sample A. The raw material of all these samples is high density polyethylene (HDPE). Typical specifications of the samples are provided in Table 1.

Fig. 1 shows these samples. Short-term compressive deformation test was performed using the procedures set forth in Standard Test Method for Determining Short-term Compression Behavior of Geosynthetics (ASTM

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D6364) to evaluate basic mechanical properties of samples. Specimen is positioned between two rigid steel platens and compressed at a constant rate of 1.0 mm/min. To control an accurate temperature of specimen of 23°C heating platens were manufactured and its heating is 14°C/min. Also special test equipment for ESCR under compression was manufactured and this equipment is shown Fig. 2.

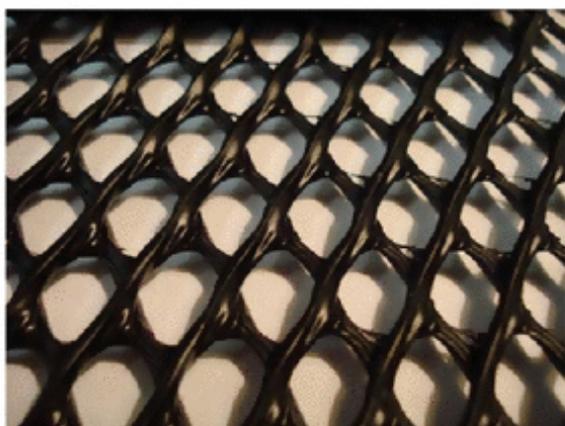
The specimens were immersed in a solution of 90% water and 10% I-gepal CO630 at a temperature of 50°C. The solution level was checked daily and de-ionized water used to keep the bath at a constant level.

And the solution was replaced every 2 weeks. 200, 400 and 700 kPa for sample A, 600, 1,000 and 1,200 kPa for sample B and 400, 600 and 800 kPa for C of load were subjected as compressive load using 6:1 arm lever loading system within considering their compressive strengths.

The immersion duration was 500 hours and during and after the test apparent observation and microscopic morphology was evaluated for the specimen.

Table 1 Typical specification of the samples

Property	Test method	Unit	Sample		
			A	B	C
Thickness	ASTM D5199	mm	5.6	8.6	8.2
Mass per unit area	ASTM D5261	g/m ²	920	1700	2300
Carbon black	ASTM D4218	%	2.3	2.2	2.3
Density	ASTM D1505	g/cm ³	0.942	0.944	0.940
Crystallinity	ASTM D2910	%	56	55	61



(a) Sample A



(b) Sample B



(c) Sample C

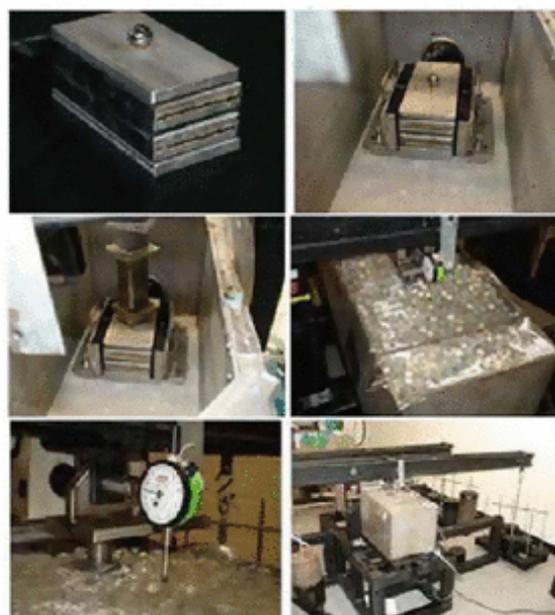


Fig. 2 Compressive environmental stress cracking test equipment

RESULTS & DISCUSSION

Considering the compressive strength and strain properties, the sample C has the stiffest behavior in these three Samples. Initial 5% elastic modulus is much higher than other samples. From this behavior of Sample C it is expected that sample C has rigid structure and has high crystallinity of over 60%. Table 1 confirms this phenomenon. In the other hand Sample A and C have more flexible behavior and low initial elastic modulus.

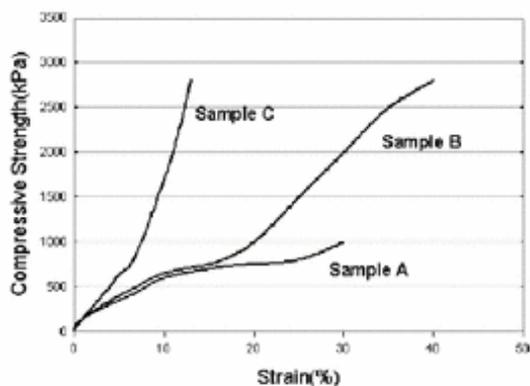


Fig. 3 Short-term compression test results

Figs. 4–9 exhibit the results of apparent observations and microscopic morphologies. Some kind of chemical clogging due to the I-gepal solution is expected for the Sample A because of its flow channel and thickness. This chemical clogging for the Sample A was confirmed by the apparent observation. Fig. 4 shows the results of apparent observations for Sample A. In this figure many deposits on the surface of the specimens were detected during and end of the test and it seems that these deposits which were induced from the chemical solution may occur clogging and therefore affect geonet's in-plane flow capacity. Also there is no chemical clogging on the surface of the specimen for Sample B and this fact was confirmed by apparent observation (Fig. 5).

Considering flowing pattern of the I-gepal solution through out the specimen, the I-gepal has zig-zag flow pattern and this courses some frictions with strands of sample A, therefore the chance of clogging is higher than the Sample B which has straight flow pattern. Also thin thickness compared to other samples can increase chance of any clogging. For the Sample C, the initial creep deformation was very low which means the initial modulus is higher than the other samples and therefore high modulus indicate more rigid than others. High rigidity has brittle failure pattern rather than ductile failure and this can induce a stress crack during the compressive creep test. Also it seems that the chemical act a stress cracking accelerator.

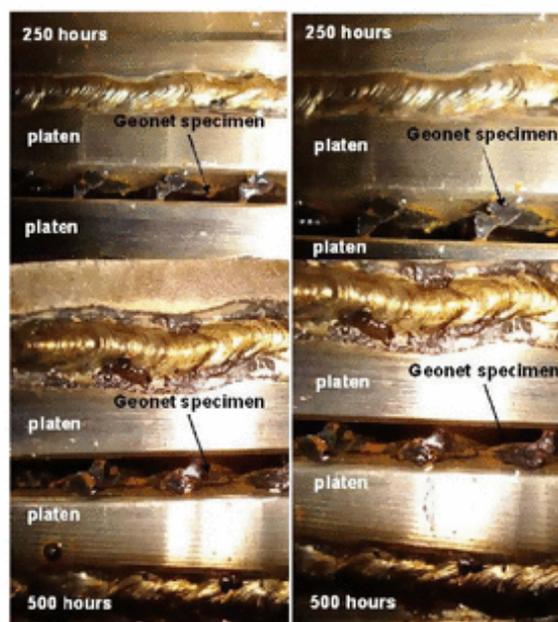


Fig. 4 Apparent observation during and end of the test for sample A (200kPa)

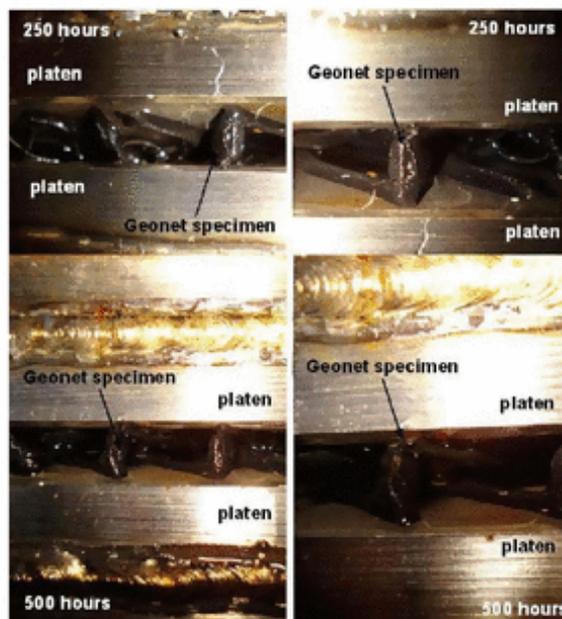


Fig. 5 Apparent observation during and end of the test for sample B (700 kPa)

Figs. 6–9 confirm this environmental stress cracking phenomenon. From these exhibitions it is clear that Sample A and Sample B which have relatively more flexible HDPE strand than Sample C didn't experience any kind of environmental stress cracking. For the Sample C which is more rigid and has high crystallinity (Table 1) likely has to chance of stress cracking. The microscopic morphologies indicate that the extent of

environmental stress cracking observed in the Sample C is related to its flexibility and crystallinity. And from the morphologies it seems that the stress cracks occurred at the junction point of the strands first and then propagate to strands with increasing normal pressure.

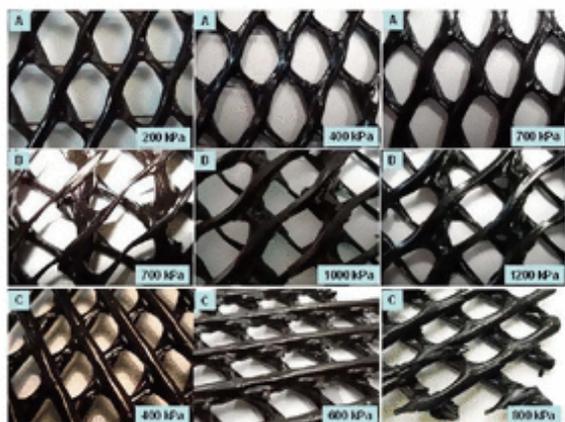


Fig. 6 Apparent observations end of the test for samples under various normal pressures



Fig. 7 Microscopic morphologies of Sample A after the test for various normal pressures



Fig. 8 Microscopic morphologies of Sample B after the test for various normal pressures



Fig. 9 Microscopic morphologies of Sample C after the test for various normal pressures

CONCLUSIONS

In this study long-term (500 hours) environmental stress cracking resistance for various geonets under various normal pressures were evaluated. The conclusions are as follows:

1. ESCR property is one of the most critical parameters for evaluating long-term chemical resistance of HDPE geonets which used in hazardous landfill systems.
2. Traditional bi-planar geonets which have square type strand and tri-planar geonet have very strong chemical and stress cracking resistance even high normal pressure.
3. Cylindrical type bi-planar geonets is more rigid material than other samples and it is very weak to environmental stress cracking with increasing normal pressure

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**APPLICATION FOR PERMIT
SUNDANCE WEST**

**VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 6: GEOSYNTHETICS APPLICATIONS AND
COMPATIBILITY DOCUMENTATION**

**ATTACHMENT III.6.D
GEOSYNTHETIC CLAY LINER REFERENCE DOCUMENTATION**



THE EFFECTS OF LEACHATE ON THE HYDRAULIC CONDUCTIVITY OF BENTOMAT®

Compatibility testing was performed to determine the effects of solid waste landfill leachate on the permeability of Bentomat over a prescribed time period. Testing was performed in accordance with United States Environmental Protection Agency (USEPA) Method 9100, as provided in SW846.

Hydration of specimens was conducted using de-aired tap water for approximately 48 hours. Saturation was also conducted using de-aired tap water until a minimum B value of 0.95 was achieved. Following hydration and saturation, baseline hydraulic conductivity was performed using water. After the baseline hydraulic conductivity was established, the permeant was switched to leachate. Testing continued for an additional 30 days to allow a sufficient number of pore volumes to permeate the specimen to establish a hydraulic conductivity with leachate.

Results show that the hydraulic conductivity of Bentomat ^{was} unaffected when permeated with this leachate.

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TR-101A

FINAL REPORT
LABORATORY TESTING OF BENTOMAT

Prepared for

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31 July 1991

2. TEST PROCEDURES

2.1 Task 1: EPA 9100 Compatibility Testing

Compatibility testing on the Bentomat was performed to measure the effect of leachate on the hydraulic conductivity of the mat product over a prescribed period of time. Testing was performed in accordance with the United States Environmental Protection Agency (USEPA) Method 9100 SW-846, Revision 1, 1987. The test conditions for Task 1 were as follows:

- Testing was conducted using flexible-wall triaxial permeameters, as shown in Photograph 2.1-1.
- Three replicate samples of the Bentomat were tested.
- Each sample was trimmed to a diameter of 2.8 in. (70 mm) and assembled in the following test configuration (from bottom to top): porous stone/filter paper/sand layer/Bentomat/sand layer/filter paper/porous stone.
- Hydration and saturation of the samples using de-aired tap water was conducted at an effective stress of 2.0 psi (14 kPa) for a time period of approximately 48 hours. Saturation was defined as a minimum Skempton's B-parameter of 0.95.
- Consolidation of the saturated test samples was performed at an effective stress of 5.0 psi (35 kPa). Pore-water displacement was monitored until primary consolidation was complete.
- To determine the baseline hydraulic conductivity, the samples were permeated using de-aired tap water. The average hydraulic gradient used for baseline permeation was approximately 50. For this testing program, initial hydration and saturation was

conducted using de-aired tap water. Hydration with leachate may or may not yield different results.

- After establishing the baseline hydraulic conductivity, the permeant was switched to the leachate. Because of the slow permeation rates and the objective to increase the volume of leachate in contact with the Bentomat, the sand layer was replaced on all samples by an Amoco 4516 geotextile after approximately three weeks of testing. Permeation of the samples with the leachate continued for an additional 30 days. The hydraulic conductivity of the sample was monitored and reported daily during this period.
- Permeation of the test specimens with the leachate was initially conducted at an average hydraulic gradient of approximately 50. In order to increase flow through the Bentomat during the prescribed time period, the average hydraulic gradient was increased to approximately 160.
- Because the final hydrated thickness of the Bentomat is unknown until the completion of testing and for comparison of the test data, the hydraulic conductivity was calculated using 0.4 in. (1.0 cm) for the Bentomat. These values were used in all calculations of hydraulic conductivity in Tasks 1 through 7.

TABLE 3.1-1

EPA 9100 COMPATIBILITY TESTING
BENTOMAT SPECIMEN CONDITIONS

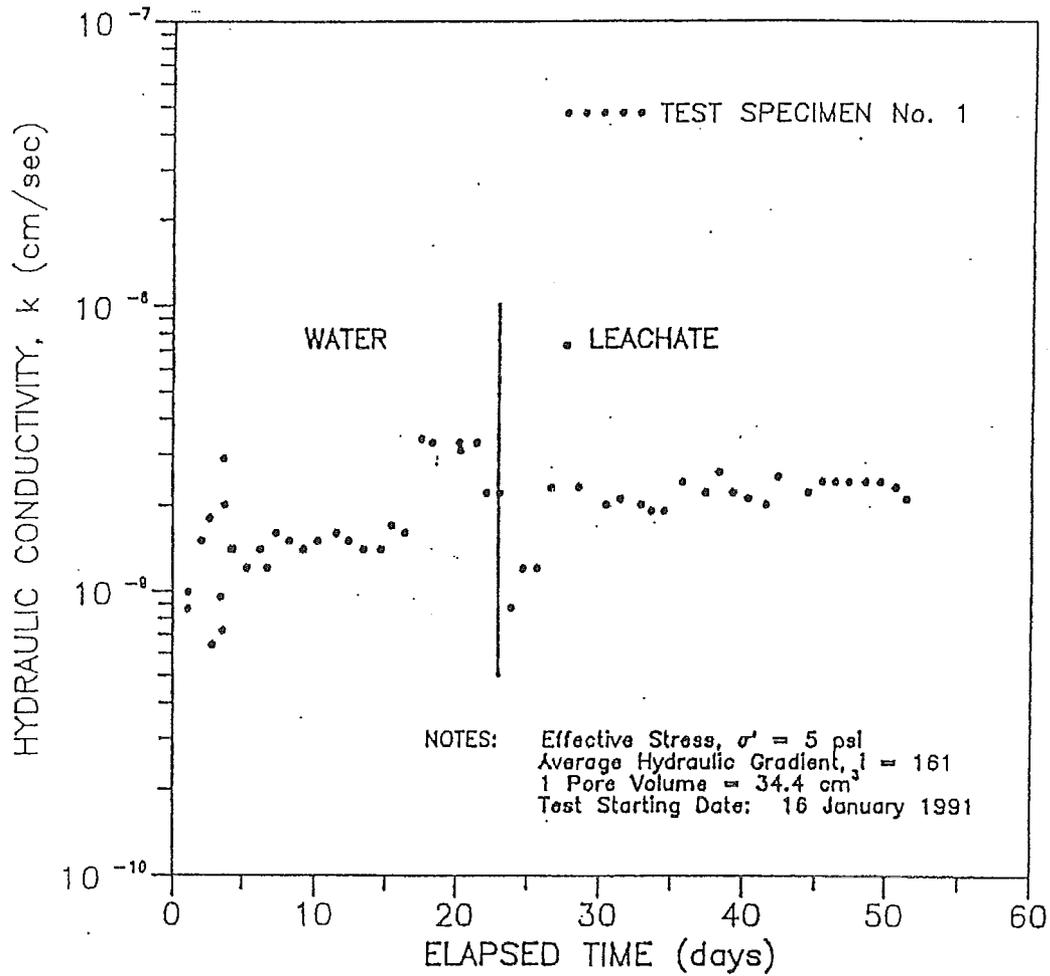
American Colloid Company

Parameters	Specimen No. 1		Specimen No. 2		Specimen No. 3	
	Initial	Final	Initial	Final	Initial	Final
Thickness, in.	0.29	0.39	0.33	0.43	0.28	0.36
Diameter, in.	3.01	3.14	3.19	3.30	3.11	3.18
¹ Dry Mass, g	30.8	24.4	38.3	31.4	34.4	26.1
² Mass/Area, lb/ft ²	1.37	1.00	1.54	1.16	1.44	1.05
Water Content, %	18.8	170.1	15.7	169.4	10.9	167.4

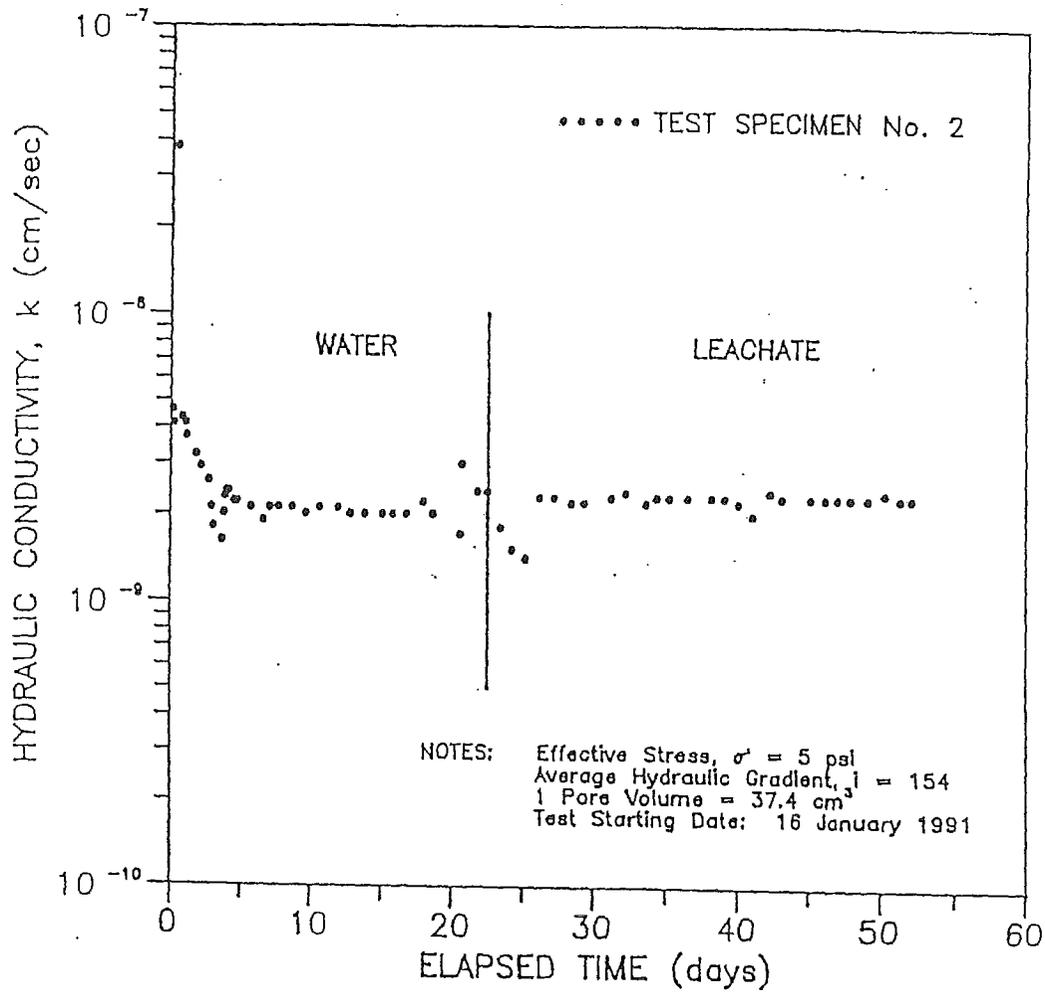
Notes: ¹ The dry mass includes the dry weight of the bentonite and the geotextiles bonded to the specimen.

² The mass/area is determined using the dry mass of the material normalized with respect to the cross-sectional area of the test specimen before drying.

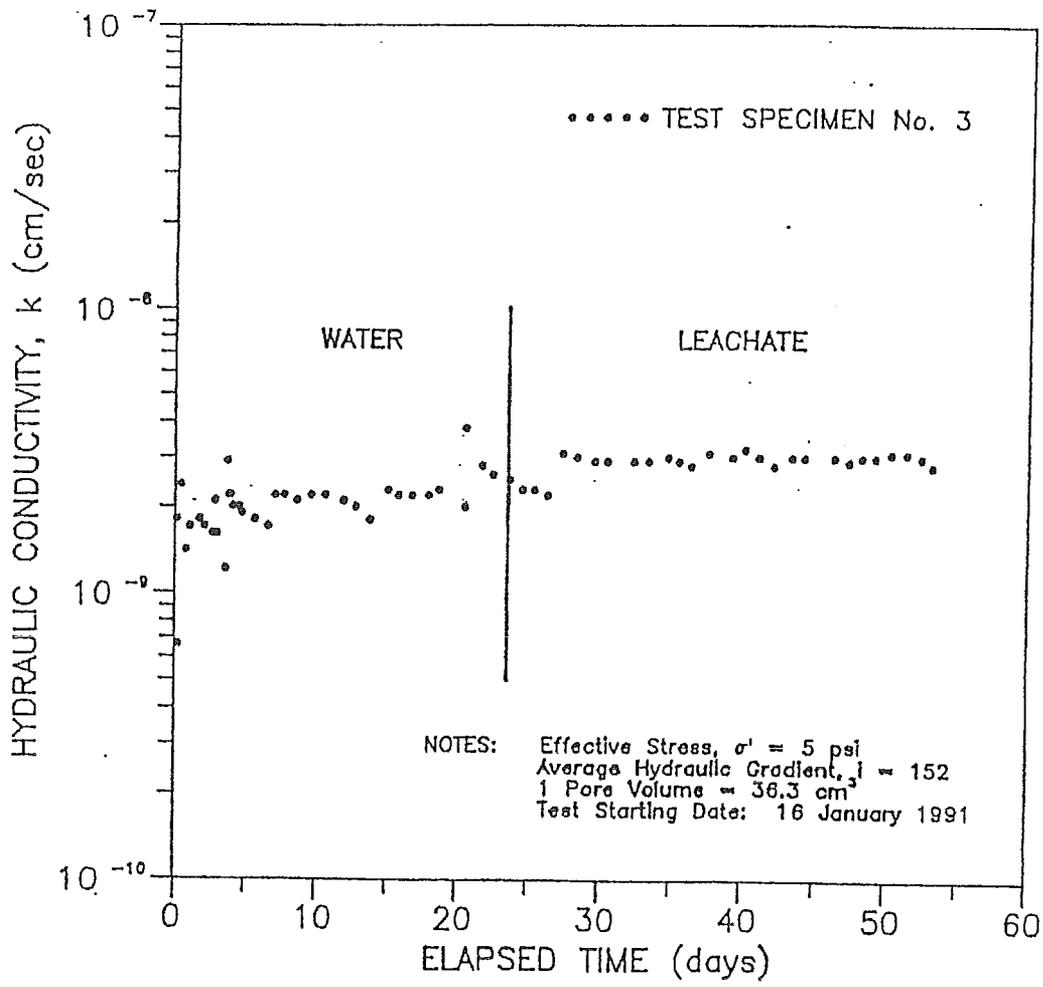
EPA 9100 COMPATIBILITY TESTING
BENTOMAT SAMPLE #ELO05



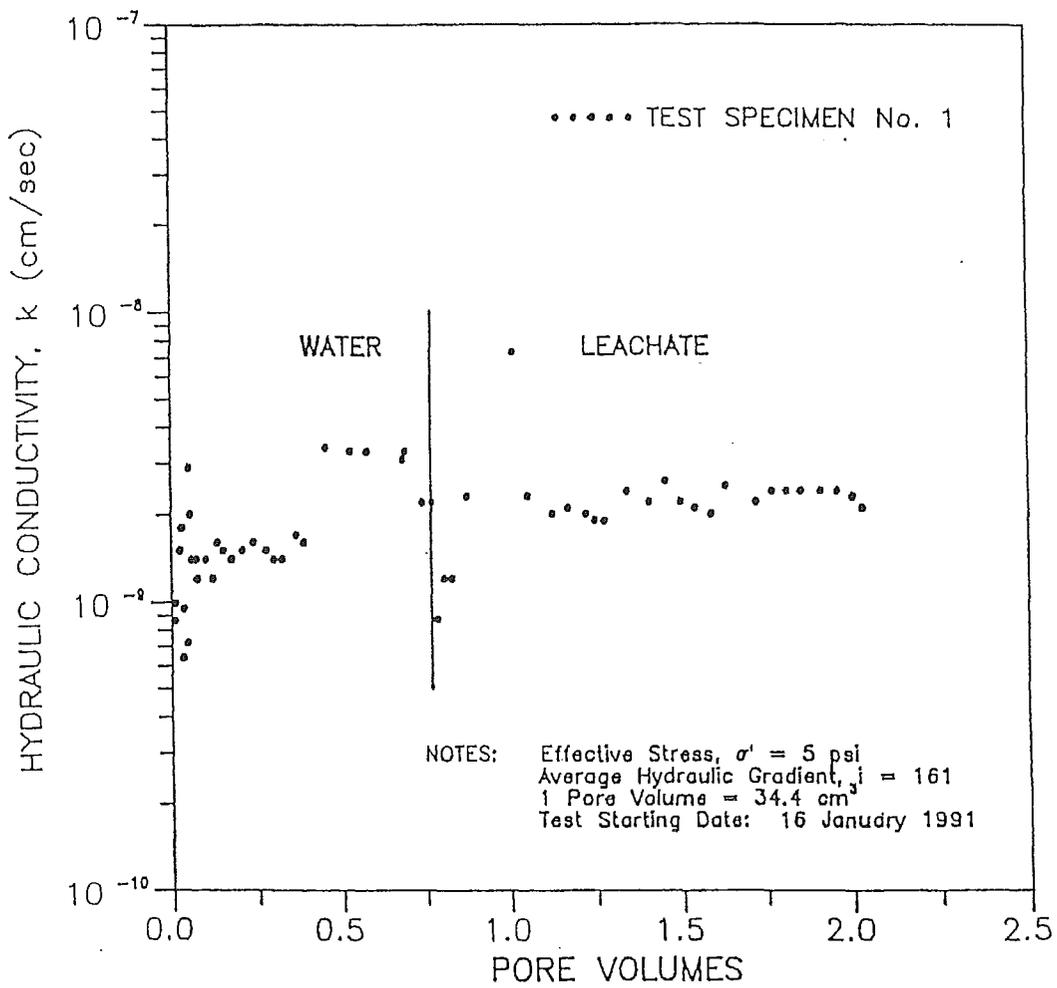
EPA 9100 COMPATIBILITY TESTING
BENTOMAT SAMPLE #E005



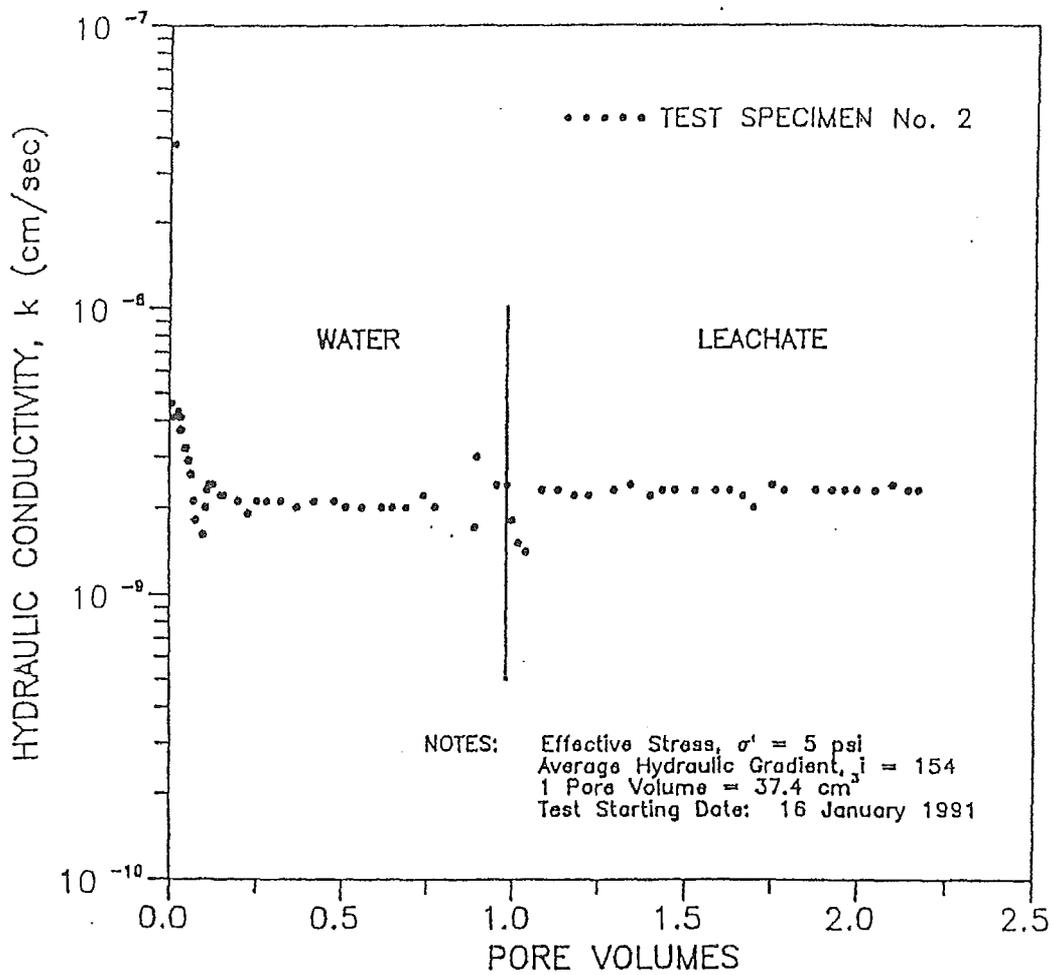
EPA 9100 COMPATIBILITY TESTING BENTOMAT SAMPLE #ELO05



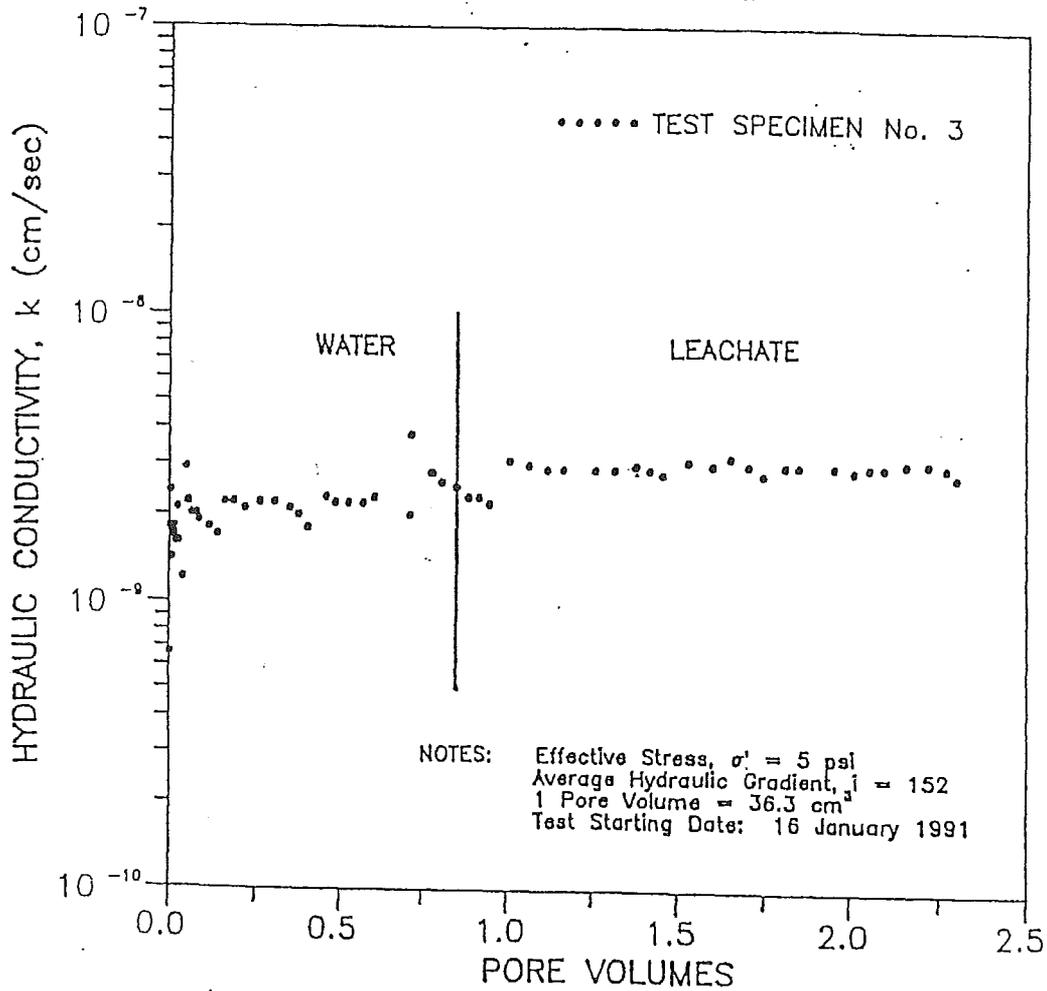
EPA 9100 COMPATIBILITY TESTING
BENTOMAT SAMPLE #ELO05



EPA 9100 COMPATIBILITY TESTING
BENTOMAT SAMPLE #ELO05



EPA 9100 COMPATIBILITY TESTING BENTOMAT SAMPLE #ELO05



3.1 Task 1: EPA 9100 Compatibility Testing

3.1.1 Test Results

The physical conditions of the three Bentomat specimens, measured before and after the tests, are summarized in Table 3.1-1. Graphical presentations of the hydraulic conductivity as a function of elapsed time are presented in Figures 3.1-1, 2, and 3. Graphical presentations of the hydraulic conductivity as a function of the volume of liquid passed through the specimens (i.e., pore volumes) are presented in Figures 3.1-4, 5, and 6.

3.1.2 Observations

Because of the low hydraulic conductivity of the bentonite mat, and in order to maximize the volume of leachate through the mat, the sand layer in each test was replaced by an Amoco 4516 geotextile during that test. This generally occurred shortly before the permeant was switched from water to leachate. In many cases the data indicated erratic behavior for a short time after the switch, but the hydraulic conductivities eventually became consistent.

All specimens were initially permeated at a hydraulic gradient of 50. The resulting hydraulic conductivity measurements were somewhat variable. The hydraulic gradient was subsequently increased to 160 after approximately five days of testing. The test results tended to stabilize after the gradient increase. The average hydraulic gradients that were used for the remainder of each test after the initial increase gradient is indicated on each figure.

In all cases, the data presented in the tables show that each specimen swelled in thickness and in diameter, and that each specimen experienced an apparent loss of mass. The effluent water however, was not visibly cloudy in any of the tests.

In each figure, a transition from water to leachate is indicated. The variability in the test results near this transition is likely the result of disturbance due to leachate injection and removal of the sand layer. Within a short period of time, the test results stabilized.

BENCH-SCALE HYDRAULIC CONDUCTIVITY TESTS
OF BENTONITIC BLANKET MATERIALS
FOR LINER AND COVER SYSTEMS

by

PAULA ESTORNELL, B.S.C.E.

THESIS

Presented to the Faculty of the Graduate School of
The University of Texas at Austin
in Partial Fulfillment
of the Degree of
MASTER OF SCIENCE IN ENGINEERING

THE UNIVERSITY OF TEXAS AT AUSTIN

August, 1991

aid in maintaining a 6- to 9-in-wide overlap during installation.

2.1.2 Available Laboratory Test Data of the Hydraulic Properties of Bentomat®

2.1.2.1 Bentomat® Permeation with Water

J & L Testing Company (1990) conducted flexible-wall hydraulic conductivity tests on 6-in (150-mm) diameter samples of Bentomat® containing either untreated granular bentonite ("CS" grade) or high-contaminant-resistant bentonite ("SS" grade). Test conditions and results are summarized in Table 2.2. The duration of the tests was not reported. Figure 2.2 presents the relationship between hydraulic conductivity and maximum effective stress. Hydraulic conductivities ranged from 6×10^{-10} cm/s to 6×10^{-9} cm/s.

2.1.2.2 Bentomat® Permeation with Chemical Leachates

GeoSyntec Consultants (1991a) performed compatibility tests on Bentomat® in flexible-wall permeameters in order to measure the effect of landfill leachate on the alternative barrier material. Three 2.8-in (70-mm) diameter replicate samples were permeated first with de-aired water (under an effective stress of 2.0 psi (14 kPa) and a hydraulic gradient of about 50) and then with leachate (under an effective stress of

Table 2.2 Summary of Results of Hydraulic Conductivity Tests on Bentomat® (J&L Testing Company, 1990)

<u>Grade of Bentonite</u>	<u>Stress (psi)</u>			<u>Maximum Effective</u>	<u>Hydraulic Conductivity (cm/s)</u>
	<u>Cell</u>	<u>Headwater</u>	<u>Tailwater</u>		
High-Contaminant-Resistant ("SS")	50	42.2	41.8	8.2	2.1×10^{-9}
	50	44.6	39.4	10.6	7.5×10^{-10}
	50	47.2	36.8	13.2	5.8×10^{-10}
Untreated Granular Bentonite ("CS")	50	42.2	41.8	8.2	5.6×10^{-9}
	50	44.6	39.4	10.6	1.1×10^{-9}
	50	47.2	36.8	13.2	9.8×10^{-10}

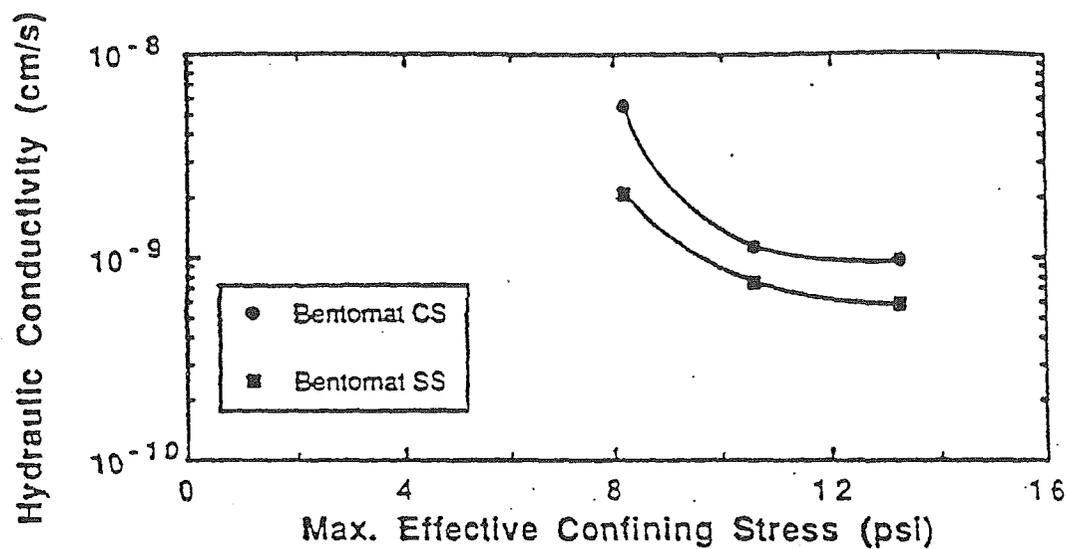


Fig. 2.2 Results of Flexible-Wall Hydraulic Conductivity Tests on Bentomat® (J&L Testing Company, 1990)

5.0 psi (35 kPa) and an average hydraulic gradient of approximately 160). The steady-state hydraulic conductivity, after two months of testing and 2.3 pore volumes of flow, was approximately 2×10^{-9} cm/s using the de-aired water and approximately 2.5×10^{-9} cm/s using the landfill leachate. The results seem to indicate that Bentomat® samples that have been hydrated first with de-aired water will have very little increase in hydraulic conductivity after the introduction of landfill leachate.

2.1.2.3 Effects of Desiccation on Bentomat®

GeoSyntec Consultants (1991a) conducted a flexible-wall hydraulic conductivity test on a 2.8-in (70-mm) sample of Bentomat® that had undergone 4 desiccation cycles. Each cycle involved first permeating the sample with de-aired water (using an effective stress of 5.0 psi (34 kPa) and an average hydraulic gradient of approximately 25) then desiccating the sample for two weeks in a 40°C (104°F) oven. This procedure was repeated 4 times. The steady-state hydraulic conductivity, measured after each cycle, ranged sporadically between 1×10^{-9} cm/s and 3×10^{-9} cm/s. The results show little effect of desiccation on the hydraulic conductivity of Bentomat®.

2.2.2 Available Laboratory Test Data on the Hydraulic Properties of Claymax®

2.2.2.1 Claymax® Permeation with Water

Literature published by the James Clem Corporation lists 2×10^{-10} cm/s as the hydraulic conductivity of Claymax® permeated with de-aired water. A summary of published measurements of the hydraulic conductivity of Claymax® to water is given in Table 2.4. Results are plotted in Fig. 2.5 in terms of hydraulic conductivity versus effective confining stress. The results show that the hydraulic conductivity to water varies from just under about 1×10^{-8} cm/s at low effective stress to just above 1×10^{-10} cm/s at high effective stress.

2.2.2.2 Claymax® Permeation with Various Liquid and Chemical Leachates

The information available concerning hydraulic conductivity of Claymax® permeated with liquids other than water is summarized in Table 2.5. All of the test specimens that were hydrated with water and then permeated with chemicals maintained a hydraulic conductivity $\leq 1 \times 10^{-8}$ cm/s, even for compounds such as diesel fuel and heptane that would normally be very aggressive to soil liner materials. Brown, Thomas, and Green (1984), for example, found that the

Table 2.4 Results of Hydraulic Conductivity Tests on Claymax® Permeated with Water

Source of Information	Permeameter	Backpressure Saturation?	Permeant Water	Diameter of Sample (in.)	Effective Stress (psf)	Hydraulic Conductivity (cm/s)
Clem Corp. Literature	- -	- -	Deaired Water	- -	- -	2×10^{-10}
Chen-Northern (1988)	Flex. Wall	Yes	- -	2.5	3.5	2×10^{-9}
GeoServices (1988a)	Flex. Wall	Yes	Deaired Tap Water	2.8	29	4×10^{-10}
GeoServices (1989c)	Flex. Wall	Yes	Deaired Tap Water	2.8	30	8×10^{-10}
GeoServices (1989c)	Flex. Wall	Yes	Deaired Tap Water	2.8	30	8×10^{-10}
GeoServices (1989c)	Flex. Wall	Yes	Deaired Tap Water	2.8	30	3×10^{-10}
GeoServices (1989c)	Flex. Wall	Yes	Deaired Tap Water	2.8	30	7×10^{-10}
Shan (1990)	Flex. Wall	No	Distilled Water	4.0	2	2×10^{-9}
Shan (1990)	Flex. Wall	No	Tap Water	4.0	2	2×10^{-9}
Shan (1990)	Flex. Wall	No	Distilled Water	4.0	5	1×10^{-9}
Shan (1990)	Flex. Wall	No	Tap Water	4.0	5	8×10^{-10}
Shan (1990)	Flex. Wall	No	Distilled Water	4.0	10	6×10^{-10}
Shan (1990)	Flex. Wall	No	Distilled Water	4.0	20	3×10^{-10}
Shan (Unpub.)	Flex. Wall	Yes	Tap Water	1.2	2	2×10^{-9}
GeoServices (1990b)	Flex. Wall	Yes	Deaired Water	- -	30	3×10^{-10}
GeoSyntec (1990a)	Flex. Wall	Yes	Deaired Water	- -	1.0	2×10^{-9}
GeoSyntec (1990a)	Flex. Wall	Yes	Deaired Water	- -	1.5	4×10^{-9}

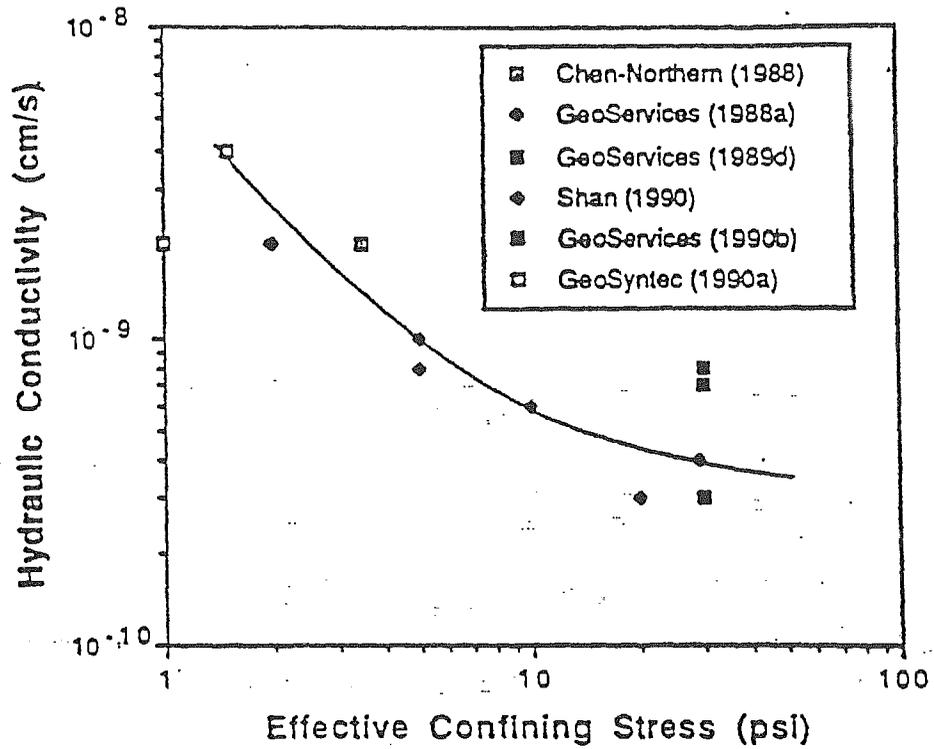


Fig. 2.5 Results of Hydraulic Conductivity Tests on Claymax® Permeated with Water

Table 2.5 Hydraulic Conductivity of Claymax® Permeated with Various Liquids

Source of Information	Permeant Liquid	Hydrallon Liquid	Pore Volumes of Flow	Effective Stress (psf)	Hydraulic Conductivity (cm/s)
STS Consultants (1988b)	Sewage Leachate	Sewage Leachate	--	--	8×10^{-10}
STS Consultants (1988c)	Paper Pulp Sludge	Paper Pulp Sludge	--	--	2×10^{-10}
GeoServices (1988b)	Simulated Seawater	Simulated Seawater	--	30	2×10^{-10}
STS Consultants (1989a)	Landfill Leachate	Landfill Leachate	--	--	4×10^{-10}
STS Consultants (1989b)	Ash-Fill Leachate	Ash-Fill Leachate	--	--	1×10^{-10}
GeoServices (1989c)	Diesel Fuel	Water	1.5	30	9×10^{-10}
GeoServices (1989c)	Jet Fuel	Water	2.5	30	9×10^{-10}
GeoServices (1989c)	Unleaded Gasoline	Water	1.6	30	3×10^{-10}
Shan (1990)	50% (Vol) Methanol	Water	2.2	5	9×10^{-10}
Shan (1990)	Heptane	Water	0.2	5	1×10^{-10}
Shan (1990)	Sulfuric Acid	Water	3.1	5	6×10^{-11}
Shan (1990)	0.01 N CaSO ₄	Water	2.2	5	1×10^{-9}
Shan (1990)	0.5 N CaCl ₂	Water	2.4	5	8×10^{-9}
Shan (Unpublished)	50% (Vol) Methanol	50% Methanol	4	5	5×10^{-6}
Shan (Unpublished)	Methanol	Methanol	5.4	5	3×10^{-5}
Shan (Unpublished)	Heptane	Heptane	4.3	5	5×10^{-5}
GeoServices (1990a)	Methyl Tertiary Butyl Ether	Deaired Water	1.6	30	7×10^{-10}
Klohn Leonoff (1990)	Solution from Goldmine	Solution from Goldmine	1.8	17.4	2×10^{-10}
GeoSyntec (1991b)	Landfill Leachate	Deaired Water	1.7	5	3×10^{-9}

hydraulic conductivity of a compacted, micaceous soil was 1 to 4 orders of magnitude higher to kerosene, diesel fuel, and gasoline than it was to water. The inconsistency of results reported in Table 2.5 to the research conducted by Brown and his co-workers may be related to either a small cumulative pore volumes of flow in the tests on Claymax® or application of a high compressive stress to the test specimens. The cumulative pore volumes of flow of permeant liquid was not reported in many of the test referenced in Table 2.5; in many cases, there was probably an insufficient quantity of flow to determine the full effects of the permeant liquids. In some tests, a large effective confining stress was used. Broderick and Daniel (1990) found that one compacted clay was vulnerable to significant alterations in hydraulic conductivity when compressive stresses were $\leq 5 - 10$ psi (34 - 69 kPa) but did not undergo an increase in hydraulic conductivity when the specimens were permeated with compressive stresses larger than 5 to 10 psi (34 to 69 kPa). Brown and his co-workers applied no compressive stress to their test specimens.

Tests on specimens of Claymax® that were hydrated with the same liquid as the eventual permeant liquid (rather than water) showed mixed results. For leachates, a paper pulp sludge, and simulated seawater, the hydraulic conductivity was found to be $< 1 \times 10^{-9}$ cm/s. However, the significance of

these results is questionable because the duration of the tests was short, the cumulative pore volumes of flow was not reported, and the applied compressive stress was not reported. In as-yet unpublished tests by Shan, markedly different results were obtained when Claymax® was not prehydrated with water. Shan found that when dry Claymax® was permeated directly with a 50% mixture of water and methanol, with pure methanol, or with heptane, the bentonite did not hydrate even after several pore volumes of flow, and the hydraulic conductivity did not drop below 1×10^{-6} cm/s. Shan used a compressive stress of 5 psi (34 kPa). Thus, with concentrated organic liquids, the conditions of hydration appear to play an important role in determining the ability of the bentonitic blanket to resist the deleterious action of organic chemicals. The bentonite appears to be more chemically resistant if hydrated with fresh water before exposure to concentrated organic chemicals.

2.2.2.3 Effects of Desiccation on Claymax®

The effects of desiccation were investigated by GeoServices (1989d). Three hydrated samples of Claymax® were placed in a temperature- and humidity-controlled chamber. The chambers operated on a timed cycle to simulate day and night conditions. The temperature and humidity during

thick HDPE geomembrane, was the material tested during this study.

2.3.2 Available Laboratory Test Data of the Hydraulic Properties of Paraseal and Gundseal

2.3.2.1 Paraseal Permeation with Water

Pittsburgh Testing Laboratory (1985) conducted a hydraulic conductivity test on a 2.5-in (64-mm) diameter sample of Paraseal. A 15-ft (4.6-m) head of water was applied to the sample, which was soaked for 5 days prior to permeation. A single, falling-head test was performed, which yielded a hydraulic conductivity reported to be 4×10^{-10} cm/s. Further details of the test procedures are not available. However, because the direction of flow was apparently through the HDPE membrane, the test may have provided a measure of sidewall leakage rather than flow through the material.

2.3.2.2 Gundseal Permeation with Chemical Leachates

The hydraulic conductivity of Gundseal permeated with landfill leachate was measured by GeoSyntec Consultants (1991c). A grid of 0.12-in (3-mm) diameter holes on 0.3 in (0.75 cm) centers were drilled into the Gundseal test samples in order to effectively test the bentonite portion of the Gundseal product. Three 2.8-in (70-mm) diameter samples

were placed in flexible-wall permeameters and subjected to an effective stress of 5.0 psi (35 kPa). The test specimens were permeated, first with de-aired water then with leachate. The average hydraulic gradient applied during permeation with de-aired water was 50. The hydraulic gradient was increased to 230 during permeation with the leachate in order to increase flow through the Gundseal. The average hydraulic conductivity of the punctured Gundseal specimens was 1×10^{-9} cm/s for both the de-aired water and the leachate after approximately 1.2 pore volumes of flow. The hydraulic conductivity of the prehydrated bentonite appeared unaffected by the introduction of the leachate.

2.3.2.3 Effects of Desiccation on Gundseal

GeoSyntec Consultants (1991c) measured the hydraulic conductivity of a sample of Gundseal that had undergone 4 desiccation cycles. The 2.8-in (70-mm) diameter sample was punctured with small holes in the same grid pattern as the samples described previously. The test sample was permeated with de-aired water in a flexible-wall permeameter under an effective stress of 5.0 psi (34 kPa) and an average hydraulic gradient of 215 in order to determine hydraulic conductivity. The sample was removed from the permeameter, subjected to a 0.4 psi (3 kPa) confining stress, and placed in an oven for two

2.5 Summary of Hydraulic Properties of Bentomat[®], Claymax[®], and Paraseal/Gundseal

Table 2.10 is an abridged summary of the hydraulic conductivity data of Bentomat[®], Claymax[®], and Paraseal/Gundseal. The table includes results from tests conducted by GeoSyntec (1991a,b,c), GeoSyntec (1990b), and Shan (1990). Results from hydraulic conductivity tests conducted by other laboratories have not been included in Table 2.10 in order to present the information in a simplified and concise form.

Table 2.10 Summary of Hydraulic Conductivity Tests on Bentomat®, Claymax®, and Parasoal/Gundseal

Sample	Bentomat®		Claymax®		Parasoal/Gundseal	
	Reference Stress (psf)	Hydraulic Conductivity (cm/s)	Reference Stress (psf)	Hydraulic Conductivity (cm/s)	Reference Stress (psf)	Hydraulic Conductivity (cm/s)
Sample Permeated with Deaired Water	GeoSyntec (1991a) 2.0	2.0×10^{-9}	GeoSyntec (1991b) 2.0	1.8×10^{-9}	GeoSyntec (1991c) 5.0	1×10^{-9}
★ Sample Permeated with Landfill Leachate	GeoSyntec (1991a) 5.0	2.5×10^{-9}	GeoSyntec (1991b) 5.0	2.8×10^{-9}	GeoSyntec (1991c) 5.0	1×10^{-9}
	GeoSyntec (1991a) 5.0	1.0×10^{-9} to 3.0×10^{-9}	Shan (1990) 2.0	2.0×10^{-9}	GeoSyntec (1991c) 8.0	5.0×10^{-10} to 2.0×10^{-9}
Freeze-Thaw Sample	GeoSyntec (1991a) 5.0	1.0×10^{-9} to 6.0×10^{-9}	Shan (1990) 2.0	2.2×10^{-9}	GeoSyntec (1991c) 5.0	1.0×10^{-9}
	GeoSyntec (1991a) 5.0	1.3×10^{-4}	Shan (1990)(1) 2.0	5.0×10^{-9}	GeoSyntec (1991c) 5.0	1.0×10^{-3}
	GeoSyntec (1991a) 5.0	1.7×10^{-4}	Shan (1990)(1) 2.0	5.0×10^{-9}	GeoSyntec (1991c) 5.0	1.0×10^{-3}
Composite Sample	GeoSyntec (1991a) 5.0	3.0×10^{-5}	Shan (1990) 2.0	4.0×10^{-9}	GeoSyntec (1991c) 5.0	1.0×10^{-3}
	GeoSyntec (1991a) 5.0	3.0×10^{-9}	Shan (1990) 2.0	4.0×10^{-9}	GeoSyntec (1991c) 5.0	2.0×10^{-9}
Overlapped Seam Sample	GeoSyntec (1991a) 5.0	6.0×10^{-7} to 2.0×10^{-5}	GeoSyntec (1990b) 1.0	2.0×10^{-9}	GeoSyntec (1991c) 5.0	6.0×10^{-8}
	GeoSyntec (1991a) 5.0	2.0×10^{-5}	GeoSyntec (1990b) 1.0	2.0×10^{-9}	GeoSyntec (1991c) 5.0	6.0×10^{-8}

(1) The damaged Claymax® sample tested by Shan (1990) was punctured with 3 - 1 inch diameter holes.

Report

Project

HYDRAULIC CONDUCTIVITY AND
COMPATIBILITY TESTING OF CLAYMAX
BALTIMORE COUNTY LANDFILL PROJECT
TOWNSON, MARYLAND

Client

CLEM ENVIRONMENTAL CORPORATION
444 NORTH MICHIGAN AVENUE, SUITE 1610
CHICAGO, IL 60611

Project # 25868-XH

Date MAY 11, 1989



STS Consultants Ltd.
Consulting Engineers
111 Plimston Road

HYDRAULIC CONDUCTIVITY AND COMPATIBILITY TESTING OF CLAYMAX
BALTIMORE COUNTY LANDFILL PROJECT
TOWNSON, MARYLAND

SCOPE OF SERVICES

STS was to perform two hydraulic conductivity tests on sections of Claymax liner material in conjunction with a six inch sand layer utilizing leachates as the hydration medium and the permeants. The Claymax specimens were supplied to STS by Clem Environmental and the leachate specimens were obtained from L.A. Solamen, Inc. All testing materials were delivered to our Northbrook Testing Facility.

Test Equipment

The equipment used in the compatibility study was a triaxial compression permeameter. This equipment incorporates the use of a flexible membrane, preventing sidewall seepage. back pressure to facilitate specimen saturation small diameter burettes making measurement of small volumes of collected permeant possible and the system is closed preventing the permeant from being exposed to the surrounding air.

Specimen Construction

Each of the specimens, utilized throughout the testing program, consisted of an approximately six inch cylindrical column of silica sand on top of which a circular section of Claymax was placed. The orientation of the Claymax to the sand provided for permeant flow initiated through the sand followed by the Claymax section. The directional flow of the permeant. is similar to those conditions found in the field applications.

Clem Environmental Corporation
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May 11, 1989

Once the specimens were assembled, a flexible rubber membrane was used to encase the specimens while sealed in the triaxial permeameter chamber.

Test Procedures

After its initial construction and placement in a triaxial compression permeameter each of the specimens is backpressure saturated. To aide in specimen saturation, carbon dioxide gas was allowed to flow freely through the test specimen, inundating the voids in the sand and dry Claymax. The use of this carbon dioxide gas has been accepted as a procedure to aide in specimen saturation. The carbon dioxide gas will go into solution more readily than normal atmospheric air. Once it was determined that the carbon dioxide gas had completely inundated the voids of the test specimen, the permeants were allowed to free flow through the test specimen first saturating the silica sand and then the Claymax section. For this study, the leachates were utilized both as a set hydrating medium and as the actual permeant for the hydraulic conductivity determination.

Two leachates were used during the study. The first was labeled Parkton Landfill and the second labeled as Eastern Sanitary Landfill. It is the understanding of STS Consultants that the two leachates were a municipal landfill leachate and contained such things as heavy metals, phenals, cyanide, copper, phosphorus and other substances.

Once the leachate had fully hydrated the test specimen, the specimen was allowed to stand for a 24 hour hydration period. Following the hydration period, the backpressure saturation techniques were implemented to complete the saturation procedures. This was accomplished by simultaneously increasing the cell and back pressures in increments while maintaining a pressure differential of 0.125 kilograms per square centimeter (KSC). Pressures were incrementally increased until obtaining testing pressures of 4.125 KSC cell pressure and 4.00 KSC back pressure.

Clem Environmental Corporation
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Specimen saturation was considered complete when a Skempton's Pore Pressure B-parameter of 0.95 or greater was obtained. The "B" parameter is simply a ratio of an increase in pore water pressure to a simultaneous increase in confining pressure. When full specimen saturation was determined, permeant flow was initiated through the bottom of the test specimen, allowed to flow through the top of the test specimen and collect in a calibrated burette. The test was performed utilizing two separate gradients. The initial gradient consisted of an application of a hydraulic head of one foot. The second gradient was applied as a hydraulic head equivalent to 35 feet.

During the entire test, permeant volume versus time measurements were recorded and the hydraulic conductivity of the test specimen at the two gradients was determined. The test was allowed to continue until it had been determined that a minimum of three pore volumes of pore fluid had passed through the test specimen. Once this had occurred and steady state flow had been established, the test was terminated.

Laboratory Test Results

As a result of the testing as outlined above, the Claymax section utilizing the Parkton Landfill Leachate, as the permeant, obtained hydraulic conductivity values of 2×10^{-10} centimeters per second (cm/sec) for a hydraulic head of one foot and 4×10^{-10} cm/sec for a hydraulic head of 35 feet. The Claymax section exposed to the Eastern Sanitary Landfill leachate obtain hydraulic conductivity values of 3×10^{-10} cm/sec utilizing a hydraulic head of 1 foot and 4×10^{-10} cm/sec utilizing a hydraulic head of 35 feet. A summary of specific specimen characteristics and final hydraulic conductivity values is attached to this report.



STS Consultants Ltd.

STS PROJECT NO. 25868-XH

PROJECT Baltimore County

Landfill Project

DATE 4-24-89

SUMMARY OF HYDRAULIC CONDUCTIVITY TESTS

	Parkton Landfill	Eastern Sanitary Landfill
Permeant		
Sample No.	1	2
Classification	Claymax with 6" Silica Sand	Claymax with 6" Silica Sand
Unit Weight (pcf)	51.6	62.5
Water Content (%)	Dry	Dry
Diameter (cm)	7.028	7.026
Length (cm)	0.568	0.616
Saturation B Value	0.97	0.99
Hydraulic Conductivity k (cm/sec)	1 ft. 2×10^{-10} 35 ft. 4×10^{-10}	1 ft. 3×10^{-10} 35 ft. 4×10^{-10}



BALTIMORE COUNTY
WASTEWATER MONITORING AND ANALYSIS DIVISION
INDUSTRIAL DISCHARGE CONTROL PROGRAM

Rev: 12/87

Dennis F. Rasmussen
County Executive

SAMPLING/ANALYSIS FORM

Sample No.: 9 01110

Industry Name: EASTERN SANITARY LANDFILL Facility No.: _____
Address: Days Cove Road
Telephone: _____ Requested by: P. Phillips
Sampling Site Location: Leachate pit
Special Instructions: STD 5, metals, Total alkalinity & Chlorides

FIELD

Date and Time of Sampling: Start 1/18/89 10:20 a.m. Finish _____
Sampled by: P. Phillips, T.E. Ryan
Type of Sample: Grab
Sampler Settings: N/A
Sample Characteristics: 1 quart; dark gray; 1 quart; dark brown
Preservatives Added: Cooled with ice
Comments and Observations: _____
Delivered to Lab by: PP, TER Date: 1/18/89 Time: 11:50 a.m.

LABORATORY

Sample received by: WP Date: 1/18/89 Time: 11:50 a.m.
Characteristics of Note: _____
(Origin of Seed: Polysand)

ANALYTICAL RESULTS

Code	BDL	Parameter	Conc. (mg/L)	Code	BDL	Parameter	Conc. (mg/L)
		pH	6.3	3011	0.05	Ni (Nickel)	BDL
		BOD	122 mg/L	3015	0.01	Zn (Zinc)	0.05 mg/L
		COD	148 mg/L	3130		Phenols	
		TSS	125 mg/L	3013	0.01	Silver	BDL
5012		FOG - A&V					
5013		FOG - Petv		*		GRAB pH	
2026		P (Phosphorus)	2.52 mg/L				
3006	0.01	Cd (Cadmium)	BDL			Total Fe	3.88 mg/L
3007	0.05	Cr (Chromium)	BDL			Total alkalinity	350 mg/L
3008	0.02	Cu (Copper)	0.04 mg/L			Chloride	80 mg/L
4		Cn (Cyanide)					
3009	0.10	Pb (Lead)	0.36 mg/L				



BALTIMORE COUNTY
WASTEWATER MONITORING AND ANALYSIS DIVISION
INDUSTRIAL DISCHARGE CONTROL PROGRAM

Rev: 12/87

Dennis F. Rasmussen
County Executive

SAMPLING/ANALYSIS FORM

Sample No.: 9 02104

Industry Name: PARKTON Facility No.: _____
Address: _____
Telephone: _____ Requested by: R. Much
Sampling Site Location: Call #3
Special Instructions: pH, BOD, COD, TSS, Alkalinity, Chloride, Metals

FIELD

Date and Time of Sampling: Start 2/9/89 Finish _____
Sampled by: R. Much, R. Kramer
Type of Sample: Grab
Sampler Settings: _____
Sample Characteristics: _____
Preservatives Added: _____
Comments and Observations: _____
Delivered to Lab by: BK, RM Date: 2/9/89 Time: 2:20 P.M.

LABORATORY

Sample received by: WP Date: 2/9/89 Time: 2:20 P.M.
Characteristics of Note: _____

(Origin of Seed: Polyseed)

ANALYTICAL RESULTS

Code	BDL	Parameter	Conc. (mg/L)	Code	BDL	Parameter	Conc. (mg/L)
		pH	<u>6.1</u>	3011	0.05	Ni (Nickel)	<u>1.44 mg/L</u>
		BOD	<u>38,888 mg/L</u>	3015	0.01	Zn (Zinc)	<u>5.45 mg/L</u>
		COD	<u>60,831 mg/L</u>	3130		Phenols	
		TSS	<u>691 mg/L</u>	3013	0.01	Silver	<u>0.03 mg/L</u>
<u>012</u>		FOG - A&V					
<u>013</u>		FOG - Petr		*		GRAB pH	
<u>026</u>		P (Phosphorus)	<u>Interference</u>				
<u>006</u>	0.01	Cd (Cadmium)	<u>0.10 mg/L</u>			Total Fe	<u>736.00 mg/L</u>
<u>007</u>	0.05	Cr (Chromium)	<u>0.22 mg/L</u>			Total alkalinity	<u>15,000 mg/L</u>
<u>008</u>	0.02	Cu (Copper)	<u>0.17 mg/L</u>			Chloride	<u>1,500 mg/L</u>
<u>002</u>		Cn (Cyanide)					
<u>009</u>	0.10	Pb (Lead)	<u>0.60 mg/L</u>				

**APPLICATION FOR PERMIT
SUNDANCE WEST**

**VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 6: GEOSYNTHETICS APPLICATIONS AND
COMPATIBILITY DOCUMENTATION**

**ATTACHMENT III.6.E
HDPE PIPE REFERENCE DOCUMENTATION**

Chemical Resistance of Plastics and Elastomers Used in Pipeline Construction

1. Introduction

It is now inconceivable to construct pipelines without the use of plastics. Pipes made from plastics are used not only for drinking water, water for general use and waste water, but also for the conveyance of aggressive liquids and gases. Expensive pipe materials such as lined metal, ceramic or glass, have been largely superseded by plastic pipes. It is, however, important that the most suitable plastic material is selected for each application. This "Chemical Resistance List" serves as a useful guide in this respect. The list is periodically revised to include the latest findings. It contains all plastics and elastomers in the George Fischer product range which can come into direct contact with the media.

The information is based on experiments, immersion and, when available, on data from tests which include temperature and pressure as stress factors. The results achieved in immersion experiments cannot be applied without reservation to pipes under stress, i.e. internal pressure, as the factor "stress corrosion cracking" is not taken into consideration. In certain cases it can be of advantage to test the suitability under the planned working conditions. The tests referred to have been carried out partly by George Fischer and partly by the International Standardization Organization (ISO) or national standards organizations.

Pure chemicals were used for the tests. If a mixture of chemicals is to be conveyed in practice this may affect the chemical resistance of the plastic. It is possible in special cases to carry out appropriate tests with the specific mixture. Suitable test equipment is available at George Fischer for this purpose, which we regard as part of our service to the customer. It goes without saying that we are willing to give individual advice at any time. In this connection it is worth mentioning that George Fischer already possesses information concerning the behavior towards plastics of a number of chemicals or mixtures of chemicals which are

not yet included in this list. The "Chemical Resistance List" gives valuable assistance in the planning of plastic pipelines. Please refer to the following instructions, which are important for the application and evaluation of this list.

2. Instructions for the Use of the Chemical Resistance List

2.1 General

As stated in the introduction, the "Chemical Resistance List" is only intended as a guide. Changes in the composition of the medium or special working conditions could lead to deviations. If there is any doubt, it is advisable to test the behavior of the material under the specific working conditions, by means of a pilot installation. No guarantees can be given in respect of the information contained in this booklet. The data shown is based upon information available at the time of printing, but it may, however, be revised from time to time in the light of subsequent research and experience.

2.2 Classification

The customary classifications: **resistant, conditionally resistant and not recommended** are depicted by the signs: +, O, and -, which allow simple presentation and application. These classifications are defined as:

Resistant: +

Within the acceptable limits of pressure and temperature the material is unaffected or only insignificantly affected.

Conditionally Resistant: O

The medium can attack the material or cause swelling. Restrictions must be made in regard to pressure and/or temperature, taking the expected service life into account. The service life of the installation can be noticeably shortened. Further consultation with George Fischer is recommended.

Not recommended: -

The material cannot be used with the medium at all, or only under special conditions.

2.3 Pipe Joints

2.3.1 Solvent Cement Joints (PVC)

Solvent cement joints made with standard PVC cement and primer systems are generally as resistant as the PVC material itself. The following chemicals are, however, an exception:

- Sulphuric acid H_2SO_4 in concentrations above 70 percent
- Hydrochloric acid HCl in concentrations above 25 percent
- Nitric acid HNO_3 in concentrations above 20 percent

Hydrofluoric acid in any concentration In conjunction with the above media the solvent cement joining is classified as "conditionally resistant". Previously recommended solvent cement (Dytex, by Henkel, Germany) used for pipe and fittings to carry concentrated acids, can no longer be brought into the United States because of its methylene chloride solvent system being classified as a carcinogen. There is no known domestically available substitute. Special consideration should be given to the possible attack of the cemented joints by these concentrated acids.

2.3.2 Fusion Joints

In the case of PE, PP, and PVDF (ISYGEF®) heat fusion joints have practically the same chemical resistance as the respective material. In conjunction with media which could cause stress cracking, the fused joints can be subjected to an increased risk due to residual stress from the joining process.

2.4 Sealing Materials

Depending upon the working conditions and the stress involved, the life span of the sealing materials can differ from that of the pipeline material. Seals in PTFE, which are not included in this list, are resistant to all the chemicals indicated. The greater permeability of PTFE should, however, be considered. Under certain working conditions, for example when conveying highly aggressive media such as hydrochloric acid, this material characteristic must be taken into account.

2.5 General Summary and Limits of Application

The following table includes all the materials contained in the George Fischer product range, and their abbreviations. The summary gives preliminary information regarding the general behavior of the materials and the temperature limits.

2.6 Standards

This list has been compiled with reference to the following ISO standards: ISO/TR 7473

Unplasticized polyvinyl chloride pipes and fittings – Chemical resistance with respect to fluids.

ISO/TR 7474

High density polyethylene pipes and fittings – Chemical resistance with respect to fluids to be conveyed.

ISO/TR 7471

Polypropylene (PP) pipes and fittings – Chemical resistance with respect to fluids.

ISO TR 10358

Plastic pipes and fittings – Combined chemical resistance classification table. DVS 2205 Part I

Calculations for thermoplastic containers and appliances.

DIN 8080 Supplement 1 «Pipes of chlorinated polyvinyl chloride (PVC-C), PVC-C 250 – Chemical Resistance».

Material	Abbreviation	Remarks	Maximum Permissible Temperature [Water] °C	
			Constant	Short Term
Polyvinyl Chloride	PVC	Resistant to most solutions of acids, alkalis and salts and to organic compounds miscible with water. Not resistant to aromatic and chlorinated hydrocarbons	60°	60°
Chlorinated Polyvinyl Chloride	CPVC	Can be used similarly to PVC but at higher temperatures. Consult factory for specific applications.	90°	110°
High-density Polyethylene	PE 50	Resistant to hydrous solutions of acids, alkalis and salts as well as to a large number of organic solvents. Unsuitable for concentrated oxidizing acids.	60°	80°
Polypropylene, heat stabilized	PP	Chemical resistance similar to that of PE but suitable for higher temperatures	90°	110°
Polyvinylidene Fluoride	PVDF (SYGFLF*)	Resistant to acids, solutions of salts, aliphatic, aromatic and chlorinated hydrocarbons, alcohols and halogens. Conditionally suitable for ketones, esters, organic bases and all-alkine solutions	140°	150°
Polybutylene-1	PB	Similar to PE 50, but can be used up to 90°C	90°	100°
Polyoxymethylene	POM	Resistant to most solvents and hydrous alkalis. Unsuitable for acids	60°	80°
Polytetrafluoroethylene (e.g. Teflon®)	PTFF	Resistant to all chemicals in this list	250°	300°
Nitrile Rubber	NBR	Good resistance to oil and petrol. Unsuitable for oxidizing media	90°	120°
Butyl Rubber Ethylene Propylene Rubber	BR EPDM	Good resistance to ozone and weather. Especially suitable for aggressive chemicals. Unsuitable for oils and fats	90°	120°
Chloroprene Rubber (e.g. Neoprene®)	CR	Chemical resistance very similar to that of PVC-U and between that of Nitrile and Butyl Rubber	80°	110°
Fluorine Rubber (e.g. Viton®)	FPM	Has best chemical resistance to solvents of all elastomers	150°	200°
Chlorine Sulphonyl Polyethylene (e.g. Hypalon®)	CSM	Chemical resistance similar to that of EPDM	100°	140°

*Registered trade name

The abbreviations listed below are found throughout the listings and have the following definition:

- Q/E (Quellung/Erweichung) = swelling/softening
 D/P (Diffusion/Permeation) = diffusion/permeation
 SpRB (Spannungsrisssbildung) = environmental stress cracking

(Courtesy George Fischer Engineering Handbook)

Aggressive Media				Chemical Resistance															
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF/IS/GEFI	EPDM	FFM	NBR	CR	CSM				
Acetaldehyde	CH ₃ -CHO (C ₂ H ₄ O)	21	technically pure	20	-	-	-	O+	·	·	·	·	·	·	·	·			
				40	-	-	-	O+	·	·	·	·	·	·	·	·	·		
				60	-	-	-	O+	·	·	·	·	·	·	·	·	·	·	
				80	-	-	-	O+	·	·	·	·	·	·	·	·	·	·	·
				100	-	-	-	O+	·	·	·	·	·	·	·	·	·	·	·
Acetaldehyde			40%, aqueous solution	20	-	O	-	O+	·	·	·	·	·	·	·	·			
				40	-	O	-	O+	·	·	·	·	·	·	·	·	·		
				60	-	O	-	O+	·	·	·	·	·	·	·	·	·	·	
				80	-	O	-	O+	·	·	·	·	·	·	·	·	·	·	
				100	-	O	-	O+	·	·	·	·	·	·	·	·	·	·	
Acetic acid (SpRB)	CH ₃ COOH	118	technically pure, glacial	20	-	O	-	O+	·	·	·	·	·	·	·	·			
				40	-	O	-	O+	·	·	·	·	·	·	·	·	·		
				60	-	O	-	O+	·	·	·	·	·	·	·	·	·	·	
				80	-	O	-	O+	·	·	·	·	·	·	·	·	·	·	
				100	-	O	-	O+	·	·	·	·	·	·	·	·	·	·	
Acetic acid (SpRB)	CH ₃ COOH		10%, aqueous	20	+	+	+	+	+	+	+	+	+	+	+	+			
				40	+	+	+	+	+	+	+	+	+	+	+	+	+		
				60	O	+	+	+	+	+	+	+	+	+	+	+	+	+	
				80	O	+	+	+	+	+	+	+	+	+	+	+	+	+	
				100	O	+	+	+	+	+	+	+	+	+	+	+	+	+	
Acetic acid (SpRB)			50%, aqueous	20	+	+	·	+	+	+	+	+	·	·	·	·			
				40	+	+	·	+	+	+	+	+	·	·	·	·	·		
				60	O	+	·	+	+	+	+	+	·	·	·	·	·		
				80	O	+	·	+	+	+	+	·	·	·	·	·	·		
				100	O	+	·	+	+	+	·	·	·	·	·	·	·		
Acetic acid (SpRB)	CH ₃ COOH		60%	20	+	·	·	+	+	+	+	+	·	·	·	·			
				40	+	·	·	+	+	+	+	+	·	·	·	·			
				60	+	·	·	+	+	+	+	+	·	·	·	·			
				80	+	·	·	+	+	+	+	·	·	·	·	·			
				100	+	·	·	+	+	+	+	·	·	·	·	·			
Acetic acid (SpRB)		118	98%	20	-	-	-	+	+	+	·	·	·	·	·				
				40	-	-	-	+	+	+	·	·	·	·	·				
				60	-	-	-	+	+	+	·	·	·	·	·				
				80	-	-	-	+	+	+	·	·	·	·	·				
				100	-	-	-	+	+	+	·	·	·	·	·				
Acetic acid anhydride (SpRB)	(CH ₃ CO) ₂ O	139	technically pure	20	-	-	-	+	+	·	·	·	·	·	·				
				40	-	-	-	+	+	·	·	·	·	·	·				
				60	-	-	-	+	+	·	·	·	·	·	·				
				80	-	-	-	+	+	·	·	·	·	·	·				
				100	-	-	-	+	+	·	·	·	·	·	·				

(Courtesy George Fischer Engineering Handbook)

Aggressive Medio				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (S/G/EF)	EPDM	FFM	NBR	CR	CSM
Acetic acid isobutyl ester	$(CH_2)_2-CH(CH_2)_2-CO_2H$		technically pure	20 40 60 80 100 120 140						-					
Acetone	$CH_3-CO-CH_3$	56	technically pure	20 40 60 80 100 120 140	-	-		+++	+++		+++				OO
Acetone			up to 10%, aqueous	20 40 60 80 100 120 140	-	-	O	+++	+++	OOO	+++	OO		OO	OO
Acetonitrile	CH_3CN	81.6	100%	20 40 60 80 100 120 140	-	-									
Acetophenone	$CH_3-CO-C_6H_5$		100 %	20 40 60 80 100 120 140	-	-					+				
Acrylic acid methyl ester	$CH_2=CHCOOCH_3$	80.3	technically pure	20 40 60 80 100 120 140	-	-			+		O				
Acrylic ester	$CH_2=CH-COO CH_2CH_3$	100	technically pure	20 40 60 80 100 120 140	-	-					O			O	+
Acrylonitrile	$CH_2=CH-CN$	77	technically pure	20 40 60 80 100 120 140	-	-		+	+		+	OO		+	OO
								+	+		+	OO		+	OO

(Courtesy George Fischer Engineering Handbook)

Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (S/G/EF)	EPDM	FPM	NBR	CR	CSM
Adipic acid	HOOC-(CH ₂) ₄ -COOH	fp 153	saturated, aqueous	20	+	+	-	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	
				60	+	+	+	+	+	+	+	+	+	+	
				80	+	+	+	+	+	+	+	+	+	+	
				100	+	+	+	+	+	+	+	+	+	+	
				120	+	+	+	+	+	+	+	+	+	+	
Aluni	see Potassium/ aluminium sulphate		approx. 40% ethyl alcohol	20	+	O	-	+	+	+	+	+	+	+	+
				40	+	O	-	+	+	+	+	+	+	+	
				60	+	O	-	+	+	+	+	+	+	+	
				80	+	O	-	+	+	+	+	+	+	+	
				100	+	O	-	+	+	+	+	+	+	+	
				120	+	O	-	+	+	+	+	+	+	+	
Allyl alcohol	H ₂ C=CH-CH ₂ -OH	97	96%	20	O	O	-	+	+	+	O	O	O	O	+
				40	O	O	-	+	+	+	O	O	O	O	+
				60	O	O	-	+	+	+	O	O	O	O	+
				80	O	O	-	+	+	+	O	O	O	O	+
				100	O	O	-	+	+	+	O	O	O	O	+
				120	O	O	-	+	+	+	O	O	O	O	+
Aluminium chloride	AlCl ₃		10%, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	
				60	+	+	+	+	+	+	+	+	+	+	
				80	+	+	+	+	+	+	+	+	+	+	
				100	+	+	+	+	+	+	+	+	+	+	
				120	+	+	+	+	+	+	+	+	+	+	
Aluminium chloride	AlCl ₃	115	saturated	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	
				60	+	+	+	+	+	+	+	+	+	+	
				80	+	+	+	+	+	+	+	+	+	+	
				100	+	+	+	+	+	+	+	+	+	+	
				120	+	+	+	+	+	+	+	+	+	+	
Aluminium fluoride	AlF ₃		saturated	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	
				60	+	+	+	+	+	+	+	+	+	+	
				80	+	+	+	+	+	+	+	+	+	+	
				100	+	+	+	+	+	+	+	+	+	+	
				120	+	+	+	+	+	+	+	+	+	+	
Aluminium hydroxide	Al(OH) ₃		Suspension	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	
				60	+	+	+	+	+	+	+	+	+	+	
				80	+	+	+	+	+	+	+	+	+	+	
				100	+	+	+	+	+	+	+	+	+	+	
				120	+	+	+	+	+	+	+	+	+	+	
Aluminium nitrate	Al(NO ₃) ₃		saturated	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	
				60	+	+	+	+	+	+	+	+	+	+	
				80	+	+	+	+	+	+	+	+	+	+	
				100	+	+	+	+	+	+	+	+	+	+	
				120	+	+	+	+	+	+	+	+	+	+	

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PPH	PVDF (SYGEFI)	EPDM	FPM	NBR	CR	CSM
Aluminium sulphate	$Al_2(SO_4)_3$		10%, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	O	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Aluminium sulphate			cold saturated, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Ammonia (SprBI)	NH_3	-33	gaseous, technically pure	20	+	+	-	+	+	+	+	O	+	+	+
				40	+	+	-	+	+	+	+	O	+	+	+
				60	+	+	-	+	+	+	+	O	+	+	+
				80	+	+	-	+	+	+	+	O	+	+	+
				100	+	+	-	+	+	+	+	O	+	+	+
				120	+	+	-	+	+	+	+	O	+	+	+
				140	+	+	-	+	+	+	+	O	+	+	+
Ammonium acetate	CH_3COONH_4		aqueous, all	20	O	+	O	+	+	+	+	+	O	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Ammonium aluminium sulfate				20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Ammonium bromide				20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Ammonium carbonate	$NH_4)_2CO_3$		50%, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Ammonium chloride	NH_4Cl	115	aqueous, cold saturated	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	O	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+

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Aggressive Media				Chemical Resistance													
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (ST/GEFF)	EPDM	FRM	NBR	CR	CSM		
Ammonium citrate				20	+												
				40	+												
				60	+												
				80	+												
				100													
				140													
Ammonium dicromate	$(\text{NH}_4)_2 \text{Cr}_2 \text{O}_7$		saturated	20		++											
				40		+++											
				60		++											
				80		+											
				100													
				140													
Ammonium dihydrogenphosphate				20	+			++	++								
				40	+			++	+++								
				60	+					++							
				80						+							
				100													
				140													
Ammonium fluoride	NH_4F			20	+	+		++	++	++							
				40	+			++	+++	++							
				60	+					++	+++	++					
				80						+	+++	+++					
				100							+	+++	+++				
				140													
Ammonium formiate				20						+							
				40						++							
				60						++							
				80						++							
				100						+							
				140													
Ammonium hexafluorosulfate				20						+							
				40						++							
				60						++							
				80						++							
				100						+							
				140													
Ammonium hydrogen fluoride	NH_4HF_2		50%, aqueous	20	+	+	+	+	+	+	+	+					
				40	+	+		+	+	+							
				60	O	+		+	+	+							
				80													
				100													
				140													
Ammonium hydrogencarbonate				20	+			+	++								
				40	+			+	+++								
				60	+			+	+++								
				80					+	+++							
				100													
				140													

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PPH	PVDF (SYGEEI)	EPDM	FPM	NBR	CR	CSM
					Ammonium hydrogenphosphate				20	+					
					40	+									
					60	+									
					80	+									
					100										
					120										
					140										
Ammonium hydrogensulfite					20										
					40										
					60										
					80										
					100										
					120										
					140										
Ammonium hydroxide	NH ₄ OH		aqueous, cold saturated		20	+	-	+							
					60	O		O	+						
					80										
					100										
					120										
					140										
Ammonium nitrate	NH ₄ NO ₃	112	aqueous, saturated		20	+	+	+							
					40	+	+	+							
					60	+	+	O	+						
					80	+	+		+						
					100				+						
					120				+						
					140				+						
Ammonium oxalate	H ₄ NOOC-COONH ₄				20										
					40						+				
					60										
					80										
					100										
					120										
					140										
Ammonium persulphate	INH ₄ 2S ₂ O ₈				20		+								
					40		+								
					60										
					80		+								
					100										
					120										
					140										
Ammonium phosphate	INH ₄ 3PO ₄		saturated		20	+	+	+							
					40	+	+	+							
					60	+	+	+							
					80			+							
					100			+							
					120										
					140										
Ammonium sulphate	INH ₄ 2SO ₄		aqueous, saturated		20	+	+	+							
					40	+	+	+							
					60	+	+	+							
					80			+							
					100			+							
					120			+							
					140										

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGFEI)	EPDM	FRM	NBR	CR	CSM
					Ammonium sulphide	INH_4S		aqueous, all	20	+					
				40	+										
				60	0										
				80	+										
				100	+										
				120	+										
				140	+										
Ammonium tetrafluoroborate				20											
				40											
				60											
				80											
				100											
				120											
				140											
Ammonium thiocyanate	NH_4SCN		saturated	20											
				40											
				60											
				80											
				100											
				120											
				140											
Amyl acetate	$\text{CH}_3(\text{CH}_2)_4\text{COOCH}_3$	141	technically pure	20	-	-	-				0	-	-	-	-
				40	-	-	-				0	-	-	-	-
				60	-	-	-				0	-	-	-	-
				80	-	-	-				0	-	-	-	-
				100	-	-	-				0	-	-	-	-
				120	-	-	-				0	-	-	-	-
				140	-	-	-				0	-	-	-	-
Amyl alcohol (SpRBI)	$\text{CH}_3(\text{CH}_2)_3\text{CH}_2\text{-OH}$	137	technically pure	20	+	+	+	+	+	+	+	0	+	+	+
				40	+	+	+	+	+	+	+	0	+	+	+
				60	+	+	+	+	+	+	+	0	+	+	+
				80	0	+	+	+	+	+	+	0	+	+	+
				100	+	+	+	+	+	+	+	0	+	+	+
				120	+	+	+	+	+	+	+	0	+	+	+
				140	+	+	+	+	+	+	+	0	+	+	+
Aniline	$\text{C}_6\text{H}_5\text{NH}_2$	182	technically pure	20	-	-	-	0	0	+	-	0	-	-	-
				40	-	-	-	0	0	+	-	0	-	-	-
				60	-	-	-	0	0	+	-	0	-	-	-
				80	-	-	-	0	0	+	-	0	-	-	-
				100	-	-	-	0	0	+	-	0	-	-	-
				120	-	-	-	0	0	+	-	0	-	-	-
				140	-	-	-	0	0	+	-	0	-	-	-
Aniline hydrochloride	$\text{C}_6\text{H}_7\text{N+HCl}$	245	aqueous, saturated	20	+	+	+	+	+	+	+	0	0	+	+
				40	0	+	+	+	+	+	+	0	0	+	+
				60	+	+	+	+	+	+	+	0	0	+	+
				80	+	+	+	+	+	+	+	0	0	+	+
				100	+	+	+	+	+	+	+	0	0	+	+
				120	+	+	+	+	+	+	+	0	0	+	+
				140	+	+	+	+	+	+	+	0	0	+	+
Antimony thiocyanate				20											
				40											
				60											
				80											
				100											
				120											
				140											

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PPH	PVDF (SYGFEI)	EPDM	FFM	NBR	CR	CSM
					Antimony trichloride (SpRBI)	SbCl ₃		90%, aqueous	20	+	+	-			
				40	+			+++							
				60	+			+++							
				80				+++							
				100				+++							
				120				+++							
				140				+++							
Aqua regia (SpRBI)	HNO ₃ +HCl			20	+	+	-			○	-	○	-	-	○
				40	○										
				60											
				80											
				100											
				120											
				140											
Arsenic acid	H ₃ AsO ₄		80%, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	○	+	+	+	+	+	+	+	+	+	+
				60		+	+	+	+	+	+	+	+	+	+
				80		+	+	+	+	+	+	+	+	+	+
				100		+	+	+	+	+	+	+	○	+	+
				120		+	+	+	+	+	+	+	+	+	+
				140		+	+	+	+	+	+	+	+	+	+
Barium carbonate	BaCO ₃			20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Barium chloride	BaCl ₂		saturated	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Barium hydroxide	Ba(OH) ₂	102	aqueous, saturated	20	+	+	+	+	+	-	+	+	+	+	○
				40	+	+	+	+	+		+	+	+	+	+
				60	○	+	+	+	+		+	+	+	+	+
				80		+	+	+	+		+	+	+	+	+
				100		+	+	+	+		+	+	+	+	+
				120		+	+	+	+		+	+	+	+	+
				140		+	+	+	+		+	+	+	+	+
Barium salts			aqueous, all	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Barium sulfate	BaSO ₄			20	+			+	+	+	+	+	+	+	+
				40	+			+	+	+	+	+	+	+	+
				60	+			+	+	+	+	+	+	+	+
				80				+	+	+	+	+	+	+	+
				100				+	+	+	+	+	+	+	+
				120				+	+	+	+	+	+	+	+
				140				+	+	+	+	+	+	+	+

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PPH	PVDF (STGEFI)	EPDM	FM	NBR	CR	CSM
					Barium sulfide	BaS		suspension	20	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+			
				60	+	+	+	+	+	+	+	+			
				80	+	+	+	+	+	+	+	+			
				100	+	+	+	+	+	+	+	+			
				120	+	+	+	+	+	+	+	+			
				140	+	+	+	+	+	+	+	+			
Battery acid	see Sulphuric acid 40%														
Beef tallow emulsion, sulphonated (SpRB)			usual commercial	20	+	o	+	+	+	+	-	+	+	+	+
				40											
				60											
				80											
				100											
				120											
				140											
Beer			usual commercial	20	+	+	+	+	+	+		+	+	+	+
				40	+	+	+	+	+	+					
				60	+	+	+	+	+	+					
				80	+	+	+	+	+	+					
				100	+	+	+	+	+	+					
				120	+	+	+	+	+	+					
				140	+	+	+	+	+	+					
Benzaldehyde	C ₆ H ₅ -CHO	180	saturated, aqueous	20	-	-	-	+	+	o	+	+	+	o	-
				40											
				60				+							
				80											
				100											
				120											
				140											
Benzene	C ₆ H ₆	80	technically pure	20	-	-	-	o	o	o	+	+	o	-	-
				40											
				60				o	o	o					
				80											
				100											
				120											
				140											
Benzenesulfonic acid	C ₆ H ₅ SO ₃ H		technically pure	20						+		+			
				40											
				60											
				80											
				100											
				120											
				140											
Benzoic acid	C ₆ H ₅ -COOH	Fp., 122	aqueous, all	20	+	+	+	+	+	+	+	+	-	-	-
				40	o	+	+	+	+	+	+	+			
				60			+	+	+	+	+	+			
				80		o	+	+	+	+	+	+			
				100			+	+	+	+	+	+			
				120				+	+	+	+	+			
				140					+	+	+	+			
Benzoyl chloride	C ₆ H ₅ CHCl ₂		technically pure	20						+					
				40											
				60											
				80											
				100						o					
				120											
				140											

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SIGGFI)	EPDM	FPM	NBR	CR	CSM
					Benzyl alcohol (SpRBI)	$C_6H_5-CH_2-OH$	206	technically pure	20	O	-	-	O + +	O + +	O + +
				40											
				60											
				80											
				100											
				120											
				140											
Beryllium chloride				20						+					
				40											
				60											
				80											
				100											
				120											
				140											
Beryllium sulfate				20						+		+			
				40								+			
				60											
				80											
				100											
				120											
				140											
Borax	$Na_2B_4O_7$		aqueous, all	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	O	+	+	+	+	+	+	+	+	+	O
				80	+	+	+	+	+	+	+	+	+	+	
				100											
				120											
				140											
Boric acid	H_3BO_3		all, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	O	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100											
				120											
				140											
Brine, containing chlorine				20	+	+	-	+	O	+	O	+	O	O	O
				40	+	+									
				60	+	+									
				80	+	+				O					
				100											
				120											
				140											
Brombenzene	C_6H_5Br			20	-	-				+		+			
				40											
				60											
				80											
				100											
				120											
				140											
Bromine, liquid	Br_2	59	technically pure	20	-	-	-	-	-	+	.	+	-	-	-
				40											
				60											
				80											
				100											
				120						O					
				140											

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Aggressive Media					Chemical Resistance										
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGFEI)	EPDM	FRM	NBR	CR	CSM
					Bromine, vapours	Br ₂		high	20	-	-	-	-	-	+
				40	-	-	-	-	-	+	-	+	-	-	-
				60	-	-	-	-	-	+	-	+	-	-	-
				80	-	-	-	-	-	+	-	+	-	-	-
				100	-	-	-	-	-	+	-	+	-	-	-
				120	-	-	-	-	-	+	-	+	-	-	-
				140	-	-	-	-	-	+	-	+	-	-	-
Bromine water	Br ₂ O		saturated, aqueous	20	+	o	-	-	-	+	-	+	-	-	-
				40	+	o	-	-	-	+	-	+	-	-	-
				60	+	o	-	-	-	+	-	+	-	-	-
				80	+	o	-	-	-	+	-	+	-	-	-
				100	+	o	-	-	-	+	-	+	-	-	-
				120	+	o	-	-	-	+	-	+	-	-	-
				140	+	o	-	-	-	+	-	+	-	-	-
Butadiene (Q/E)	H ₂ C=CH-CH=CH ₂	-4	technically pure	20	+	+	-	+	+	+	-	o	-	+	o
				40	+	+	-	+	+	+	-	o	-	+	o
				60	+	+	-	+	+	+	-	o	-	+	o
				80	+	+	-	+	+	+	-	o	-	+	o
				100	+	+	-	+	+	+	-	o	-	+	o
				120	+	+	-	+	+	+	-	o	-	+	o
				140	+	+	-	+	+	+	-	o	-	+	o
Butane	C ₄ H ₁₀	0	technically pure	20	+	+	+	+	+	+	-	+	+	+	+
				40	+	+	+	+	+	+	-	+	+	+	+
				60	+	+	+	+	+	+	-	+	+	+	+
				80	+	+	+	+	+	+	-	+	+	+	+
				100	+	+	+	+	+	+	-	+	+	+	+
				120	+	+	+	+	+	+	-	+	+	+	+
				140	+	+	+	+	+	+	-	+	+	+	+
Butanediol (SpRB)	HO-(CH ₂) ₄ -OH	230	aqueous, 10%	20	o	+	-	+	+	+	+	+	+	o	+
				40	o	+	-	+	+	+	+	+	+	o	+
				60	o	+	-	+	+	+	+	+	+	o	+
				80	o	+	-	+	+	+	+	+	+	o	+
				100	o	+	-	+	+	+	+	+	+	o	+
				120	o	+	-	+	+	+	+	+	+	o	+
				140	o	+	-	+	+	+	+	+	+	o	+
Butanol (SpRB)	C ₄ H ₉ OH	117	technically pure	20	+	+	-	+	+	+	+	+	+	+	+
				40	+	+	-	+	+	+	+	+	+	+	+
				60	+	+	-	+	+	+	+	+	+	+	+
				80	+	+	-	+	+	+	+	+	+	+	+
				100	+	+	-	+	+	+	+	+	+	+	+
				120	+	+	-	+	+	+	+	+	+	+	+
				140	+	+	-	+	+	+	+	+	+	+	+
Butyl acetate	CH ₃ COOCH ₂ CH ₂ CH ₂ CH ₃	126	technically pure	20	-	-	-	+	o	+	+	o	-	o	o
				40	-	-	-	+	o	+	+	o	-	o	o
				60	-	-	-	+	o	+	+	o	-	o	o
				80	-	-	-	+	o	+	+	o	-	o	o
				100	-	-	-	+	o	+	+	o	-	o	o
				120	-	-	-	+	o	+	+	o	-	o	o
				140	-	-	-	+	o	+	+	o	-	o	o
Butyl phenol, p-tertiary	(CH ₃) ₃ C-C ₆ H ₄ -OH	237	technically pure	20	o	o	-	o	+	+	-	o	-	-	-
				40	o	o	-	o	+	+	-	o	-	-	-
				60	o	o	-	o	+	+	-	o	-	-	-
				80	o	o	-	o	+	+	-	o	-	-	-
				100	o	o	-	o	+	+	-	o	-	-	-
				120	o	o	-	o	+	+	-	o	-	-	-
				140	o	o	-	o	+	+	-	o	-	-	-

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (S/G/EF)	EPDM	FPM	NBR	CK	CSM
					Butylene glycol (SpRB)	HO-CH ₂ -CH=CH-CH ₂ -OH	235	technically pure	20	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	O	+	+	+	+	+	+	+	+	+	+
				80											
				100											
				120											
				140											
Butylene liquid	C ₄ H ₈	51	technically pure	20	+						O	+	+	+	O
				40											
				60											
				80											
				100											
				120											
				140											
Butyric acid (SpRB)	CH ₃ -CH ₂ -CH ₂ -COOH	163	technically pure	20	+	+	-		+	+	O	O	-	O	O
				40											
				60											
				80											
				100											
				120											
				140											
Cadmium bromide	CdBr ₂			20	+	+		+	+		+	+	+	+	+
				40	+	+		+	+		+	+	+	+	+
				60	+	+		+	+		+	+	+	+	+
				80				+	+		+	+	+	+	+
				100											
				120											
				140											
Cadmium chloride	CdCl ₂			20	+	+		+	+		+	+	+	+	+
				40	+	+		+	+		+	+	+	+	+
				60	+	+		+	+		+	+	+	+	+
				80				+	+		+	+	+	+	+
				100											
				120											
				140											
Cadmium cyanide	Cd(CN) ₂			20	+			+	+		+	+	+	+	+
				40	+			+	+		+	+	+	+	+
				60	+			+	+		+	+	+	+	+
				80				+	+		+	+	+	+	+
				100											
				120											
				140											
Cadmium sulfate	CdSO ₄			20	+	+		+	+		+	+	+	+	+
				40	+	+		+	+		+	+	+	+	+
				60	+	+		+	+		+	+	+	+	+
				80	+	+		+	+		+	+	+	+	+
				100											
				120											
				140											
Calcium acetate	(CH ₃ COO) ₂ Ca		saturated	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100											
				120											
				140											

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (S/GEF)	EFDM	FPM	NBR	CR	CSM
Calcium bisulphite	CaHSO ₃ ₂		cold saturated, aqueous	20	+	+	+			+	+				
				40		+	+			+	+	+			
				60		+	+	+			+	+	+		
				80		+	+				+	+	+		
				100		+	+				+	+	+		
Calcium carbonate	CaCO ₃			20	+	+									
				40		+	+								
				60		+	+	+							
				80		+	+								
				100		+	+								
Calcium chlorate	Ca(ClO ₃) ₂			20	+	+									
				40		+	+								
				60		+	+	+							
				80		+	+								
				100		+	+								
Calcium chloride	CaCl ₂	125	saturated, aqueous, all	20	+	+									
				40		+	+								
				60	O	+	+	+							
				80		+	+	+	+						
				100		+	+	+	+	+					
Calcium fluoride	CaF ₂			20	+										
				40		+									
				60		+		+							
				80		+		+							
				100		+		+							
Calcium hydrogencarbonate				20						+					
				40							+				
				60							+				
				80							+				
				100							+				
Calcium hydrosulfide	Ca(SH) ₂			20		+									
				40		+									
				60		+									
				80		+									
				100		+									
Calcium hydrosulfite	CaHSO ₃ ₂		saturated	20						+					
				40							+				
				60							+				
				80							+				
				100							+				

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (S/G/FF)	EPDM	FPM	NBR	CR	CSM
					Calcium hydroxide	Ca(OH) ₂	100	saturated, aqueous	20	+	+	+	+	+	○
				40	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+		+	+	+	+	+
				80		+	+	+	+		+	+	+	+	+
				100							+	+	+	+	+
				120											+
				140											+
Calcium nitrate	Ca(NO ₃) ₂	115	50%, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60							+	+	+	+	+
				80		+		+	+		+	+	+	+	+
				100						+	+	+	+	+	+
				120						+	+	+	+	+	+
				140						+	+	+	+	+	+
Calcium phosphate	CaH ₂ PO ₄ l ₂ CaHPO ₄ Ca ₃ (PO ₄) ₂			20						+					
				40						+					
				60						+					
				80						+					
				100						+					
				120						+					
				140						+					
Calcium sulfide	CaS			20	+				+		+				
				40	+				+						
				60	+				+						
				80					+						
				100					+						
				120					+						
				140					+						
Calcium sulphate	CaSO ₄		suspensions	20	+	+				+	+				
				40	+	+				+	+				
				60	+	+				+	+				
				80		+				+	+				
				100						+	+				
				120						+	+				
				140						+	+				
Calcium sulphite	Ca(HSO ₃) ₂		aqueous, cold saturated	20	+		+	+			+				
				40	+		+	+							
				60	+		+	+							
				80			+	+							
				100			+	+							
				120			+	+							
				140			+	+							
Calcium tungstate				20						+	+				
				40						+	+				
				60						+	+				
				80						+	+				
				100						+	+				
				120						+	+				
				140						+	+				
Calcium bromide	CaBr ₂			20	+	+		+	+		+	+			
				40	+	+		+	+		+	+			
				60	+	+		+	+		+	+			
				80				+	+						
				100				+	+						
				120				+	+						
				140				+	+						

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CFVC	ABS	PE	PP-H	PVDF (SYGFEI)	EPDM	FPM	NBR	CR	CSM
					Calcium lactate	$\text{ICH}_2\text{COO} \cdot \frac{1}{2}\text{Ca}$		saturated	20 40 60 80 100 120 140				++	+++	
Caprolactam	$\text{C}_6\text{H}_{11}\text{NO}$			20 40 60 80 100 120 140											
Caprolactone	$\text{C}_6\text{H}_{10}\text{O}_2$			20 40 60 80 100 120 140											
Carbon dioxide-carbonic acid	CO_2		technically pure, anhydrous	20 40 60 80 100 120 140	++	+++	++	+	++	++	+	++	++	++	++
Carbon disulphide	CS_2	46	technically pure	20 40 60 80 100 120 140	-	-	-	O	O	+		+	-	-	-
Carbon tetrachloride	CCl_4	77	technically pure	20 40 60 80 100 120 140	-	-	-	-	-	+		+	-	-	-
Carbonic acid				20 40 60 80 100 120 140	+++	+++		+	+++	+++	+++	+++	+++		
Caro's acid	see Peroxomonosulfuric acid			20 40 60 80 100 120 140											
Casein				20 40 60 80 100 120 140					+++						

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Aggressive Media					Chemical Resistance																
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (STGFEF)	EPDM	FPM	NBR	CR	CSM						
					20	40	60	80	100	120	140	20	40	60	80	100	120	140	20	40	60
Calcium chloride	CaCl ₂			20						+++											
Calcium hydroxide	CaOH			20						+++											
Caustic potash solution (potassium hydroxide)	KOH	131	50%, aqueous	20	+	+	+	+	+	.											
				40	O	+	+	+	+												
				60																	
				80																	
				100																	
				120																	
				140																	
Caustic soda solution	NaOH		50%, aqueous	20	+	+	+	+	+	O											
				40																	
				60																	
				80																	
				100																	
				120																	
				140																	
Cerium (III) -chloride	CeCl ₃			20						+++											
				40																	
				60																	
				80																	
				100																	
				120																	
				140																	
Chloral hydrate	CCl ₃ CH(OH) ₂	98	technically pure	20	-			+		O											
				40				+													
				60				+													
				80				+													
				100				.													
				120																	
				140																	
Chloric acid (SpRB)	HClO ₃		10%, aqueous	20	+	+	-	+	-	+											
				40	+	+		+		+											
				60	O	+		+		+											
				80																	
				100																	
				120																	
				140																	
Chloric acid (SpRB)	HClO ₃		20%, aqueous	20	+	+	-	O	-	+											
				40	+	+															
				60	O	+															
				80																	
				100																	
				120																	
				140																	

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (S/GFF)	EPDM	FRM	NBR	CR	CSM
					Chlorosulphonic acid	ClSO ₃ H	158	technically pure	20	O	-	-	-	-	O
				40	O	-	-	-	-	O	-	-	-	-	-
				60	O	-	-	-	-	O	-	-	-	-	-
				80	O	-	-	-	-	O	-	-	-	-	-
				100	O	-	-	-	-	O	-	-	-	-	-
				120	O	-	-	-	-	O	-	-	-	-	-
				140	O	-	-	-	-	O	-	-	-	-	-
Chrome alum (chromium potassium sulphate)	K ₂ Cr ₂ O ₇		cold saturated, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Chromic acid (SpRl)	CrO ₃ +H ₂ O		up to 50%, aqueous	20	O	O	-	O	O	+	O	+	-	-	O
				40	O	O	-	O	O	+	O	+	-	-	O
				60	O	O	-	O	O	+	O	+	-	-	O
				80	O	O	-	O	O	+	O	+	-	-	O
				100	O	O	-	O	O	+	O	+	-	-	O
				120	O	O	-	O	O	+	O	+	-	-	O
				140	O	O	-	O	O	+	O	+	-	-	O
Chromic acid (SpRl)			all, aqueous	20	O	O	-	O	O	+		+	-	-	O
				40	O	O	-	O	O	+		+	-	-	O
				60	O	O	-	O	O	+		+	-	-	O
				80	O	O	-	O	O	+		+	-	-	O
				100	O	O	-	O	O	+		+	-	-	O
				120	O	O	-	O	O	+		+	-	-	O
				140	O	O	-	O	O	+		+	-	-	O
Chromic acid + sulphuric acid + water (SpRl)	Cr ₂ O ₃ H ₂ SO ₄ H ₂ O		50 g 15 g 35 g	20	O	+	+	-	-	+	O	+	-	-	O
				40	O	+	+	-	-	+	O	+	-	-	O
				60	O	+	+	-	-	+	O	+	-	-	O
				80	O	+	+	-	-	+	O	+	-	-	O
				100	O	+	+	-	-	+	O	+	-	-	O
				120	O	+	+	-	-	+	O	+	-	-	O
				140	O	+	+	-	-	+	O	+	-	-	O
Chromium (III) -chloride				20	+	+	+			+					
				40	+	+	+			+					
				60	+	+	+			+					
				80	+	+	+			+					
				100	+	+	+			+					
				120	+	+	+			+					
				140	+	+	+			+					
Chromium (III) -fluoride	CrF ₃			20						+					
				40						+					
				60						+					
				80						+					
				100						+					
				120						+					
				140						+					
Chromium (III) -chloride	CrCl ₃			20	+	+	+			+					
				40	+	+	+			+					
				60	+	+	+			+					
				80	+	+	+			+					
				100	+	+	+			+					
				120	+	+	+			+					
				140	+	+	+			+					

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PPH	PVDF (SYGEEF)	EPDM	FPM	NBR	CR	CSM
Chlorine	Cl ₂		moist, 97%, gaseous	20 40 60 80 100 120 140	-	-	-	-	-	-	-	+	-	-	0
Chlorine	Cl ₂		anhydrous, technically pure	20 40 60 80 100 120 140	-	-	-	0	-	+	0	+	-	-	0
Chlorine	Cl ₂		liquid, technically pure	20 40 60 80 100 120 140	-	-	-	-	-	+	-	0	-	-	-
Chlorine water (SpRB)	Cl ₂ H ₂ O		saturated	20 40 60 80 100 120 140	+	+	0	0	0	0	0	0	-	0	-
Chloroacetic acid, mono (SpRB)	ClCH ₂ COOH		50%, aqueous	20 40 60 80 100 120 140	+	-	-	+	+	+	0	-	-	-	0
Chloroacetic acid, mono (SpRB)	ClCH ₂ COOH	188	technically pure	20 40 60 80 100 120 140	+	-	-	+	+	-	0	-	-	-	0
Chlorobenzene	C ₆ H ₅ Cl	132	technically pure	20 40 60 80 100 120 140	-	-	-	0	+	+	-	-	-	-	0
Chloroethanol	ClCH ₂ -CH ₂ OH	129	technically pure	20 40 60 80 100 120 140	-	-	-	+	+	+	0	-	+	-	0

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEEF)	EPDM	FPM	NBR	CR	CSM
Chromium (III) -nitrate	Cr(NO ₃) ₃			20	+	+									
				40	+	+									
				60	+	+									
				80	+	+									
				100	+	+									
				140	+	+									
Chromium (III) -sulfate	Cr ₂ (SO ₄) ₃			20	+	+									
				40	+	+									
				60	+	+									
				80	+	+									
				100	+	+									
				140	+	+									
Cider				20	+	+									
				40	+	+									
				60	+	+									
				80	+	+									
				100	+	+									
				140	+	+									
Citric acid		Fp. +153	10%, aqueous	20	+	+	+	+	+	+					
				40	+	+	+	+	+	+					
				60	O	+	+	+	+	+					
				80		+	+	+	+	+					
				100		+	+	+	+	+					
				140		+	+	+	+	+					
Citric acid				20	+										
				40	+										
				60			+	+	+						
				80			+	+	+						
				100			+	+	+						
				140											
Citric acid up to 10%				20											
				40											
				60											
				80											
				100											
				140											
Coal gas, benzene free				20	+	+	+	+	+						
				40											
				60											
				80											
				100											
				140											
Coconut fat alcohol (SpRBI)			technically pure	20	+	-									
				40	O			O	+	+					
				60											
				80											
				100											
				140											

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Aggressive Media				Chemical Resistance																					
Medium	Formula	Boiling point °C	Concentration	Temperature °C																					
				PVC	CPVC	ABS	PE	PP-H	PVDF (STGEFI)	EPDM	FFM	NBR	CR	CSM											
Compressed air, containing oil (SpRB)				20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
				40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
				60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
				80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
				100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
				120	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				140	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Copper salts	CuCl, CuCl ₂ , CuF ₂ , Cu(NO ₃) ₂ , CuSO ₄ , Cu(CN) ₂		all, aqueous	20	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			
				40	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
				60	O	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
				80	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
				100	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
				120	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Corn oil (SpRB)			technically pure	20	O	O	O	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			
				40	O	O	O	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
				60	O	O	O	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
				80	O	O	O	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
				100	O	O	O	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
				120	O	O	O	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				140	O	O	O	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Cresol	HO-C ₆ H ₄ -CH ₃		cold saturated, aqueous	20	O	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			
				40	O	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
				60	O	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
				80	O	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				100	O	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				120	O	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				140	O	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Crotonic aldehyde	CH ₃ -CH=CH-CHO	102	technically pure	20	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			
				40	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
				60	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
				80	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				100	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				120	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				140	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Cyclohexane (Q/E)	C ₆ H ₁₂	81	technically pure	20	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			
				40	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
				60	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
				80	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				100	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				120	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				140	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Cyclohexanol (SpRB)	C ₆ H ₁₂ O	161	technically pure	20	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
				40	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
				60	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
				80	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Cyclohexanone	C ₆ H ₁₀ O	155	technically pure	20	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			
				40	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
				60	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
				80	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				100	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				120	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				140	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF(S/GFF)	EPDM	FRM	NBR	CR	CSM
Densodrine VV				20	+	+	+	+	+	+					
				40	+	+	+	+	+	+					
				60	+	+	+	+	+	+					
				80	+	+	+	+	+	+					
				100	+	+	+	+	+	+					
				120	+	+	+	+	+	+					
				140	+	+	+	+	+	+					
Detergents (SpRBI)	see washing powder		for usual washing laithers												
Dextrine	$C_6H_{10}O_5)_n$		usual commercial	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Dextrose	siehe Glucose			20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Dibutyl ether	$C_8H_{18}OC_4H_9$	142	technically pure	20	-	-	-	○	○		-	+	+	-	○
				40	-	-	-	○	○		-	+	+	-	○
				60	-	-	-	○	○		-	+	+	-	○
				80	-	-	-	○	○		-	+	+	-	○
				100	-	-	-	○	○		-	+	+	-	○
				120	-	-	-	○	○		-	+	+	-	○
				140	-	-	-	○	○		-	+	+	-	○
Dibutyl phthalate	$C_8H_8(COOC_4H_9)_2$	340	technically pure	20	-	-	-	+	+	+	○	○	-	-	-
				40	-	-	-	○	○	○	○	○	-	-	-
				60	-	-	-	○	○	○	○	○	-	-	-
				80	-	-	-	○	○	○	○	○	-	-	-
				100	-	-	-	○	○	○	○	○	-	-	-
				120	-	-	-	○	○	○	○	○	-	-	-
				140	-	-	-	○	○	○	○	○	-	-	-
Dibutyl sebacate	$C_8H_{18}(COOC_8H_{17})_2$	344	technically pure	20	-	-	-	+	+	+	+	+	-	-	-
				40	-	-	-	+	+	+	+	+	-	-	-
				60	-	-	-	+	+	+	+	+	-	-	-
				80	-	-	-	+	+	+	+	+	-	-	-
				100	-	-	-	+	+	+	+	+	-	-	-
				120	-	-	-	+	+	+	+	+	-	-	-
				140	-	-	-	+	+	+	+	+	-	-	-
Dichlorbenzol	$C_6H_4Cl_2$	180	technically pure	20	-	-	-								
				40	-	-	-								
				60	-	-	-								
				80	-	-	-								
				100	-	-	-								
				120	-	-	-								
				140	-	-	-								
Dichloroacetic acid	$Cl_2CHCOOH$	194	technically pure	20	+	-	-	+	+	+	+	○	-	○	+
				40	○	+	-	○	○	○	+	○	-	○	○
				60	○	+	-	○	○	○	+	○	-	○	○
				80	○	+	-	○	○	○	+	○	-	○	○
				100	○	+	-	○	○	○	+	○	-	○	○
				120	○	+	-	○	○	○	+	○	-	○	○
				140	○	+	-	○	○	○	+	○	-	○	○

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (ST/GEF)	EPDM	FPM	NBR	CR	CSM
					Dichloroacetic acid (SpRB)	<chem>Cl2CHCOOH</chem>		50%, aqueous	20	+	-	-	+	+	+
				40	+	-	-	+	+	+	+	+	-	-	+
				60	O	-	-	+	+	+	+	+	-	-	+
				80				+	+	+	+	+	-	-	+
				100				+	+	+	+	+	-	-	+
				120				+	+	+	+	+	-	-	+
				140				+	+	+	+	+	-	-	+
Dichloroacetic acid methyl ester	<chem>Cl2CHCOOCH3</chem>	143	technically pure	20	-	-	-	+	+	O	+	+	-	-	+
				40				+	+		+	+	-	-	+
				60				+	+		O	+	-	-	+
				80				+	+			+	-	-	+
				100				+	+			+	-	-	+
				120				+	+			+	-	-	+
				140				+	+			+	-	-	+
Dichloroethan	Ethylene chloride			20	-	-	-	-	O	+	-	O	-	-	-
Dichloroethylene	<chem>ClCH=CHCl</chem>	60	technically pure	40											
				60											
				80											
				100											
				120											
				140											
Dichloromethane				20	-	-	-								
				40											
				60											
				80											
				100											
				120											
				140											
Diesel oil (SpRB, Q/EI)				20	+	+	O	+	O	+	-	+	+	O	O
				40	+	+						+	+		
				60				O				+	+		
				80								+	+		
				100								+	+		
				120								+	+		
				140								+	+		
Diethyl ether				20	-	-	-								
				40											
				60											
				80											
				100											
				120											
				140											
Diethylamine	<chem>(C2H5)2NH</chem>	56	technically pure	20	O	-	-	+	+	O	O	-	-	-	-
				40											
				60											
				80											
				100											
				120											
				140											
Diethylene glycol butyl ether				20	-	-	-								
				40											
				60											
				80											
				100											
				120											
				140											

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Aggressive Media				Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PPH	PVDF(S/GEFI)	EFDm	FFM	NBR	CR	CSM	
Diglycolic acid (SPRB)	HOOC-CH ₂ -O-CH ₂ -COOH	Fp* 148	30%, aqueous	20	+	+	+	+	+	+	+	+	+	+	+	
				40	O	+	+	+	+	+	+	+	+	+	+	
				60		+	+	+	+	+	+	+	+	+	+	
				80		+	+	+	+	+	+	+	+	+	+	
				100												
				140												
Di-isobutyl ketone	[(CH ₃) ₂ CHCH ₂] ₂ CO	124	technically pure	20	-	-	-	+	+	+	O	-	-	-	-	
				40												
				60												
				80												
				100												
				140												
Dimethyl formamide	[(CH ₃) ₂ CHNO	153	technically pure	20	-	-	-	+	+	+	O	-	O	+	+	
				40												
				60												
				80												
				100												
				140												
Dimethylamine	[(CH ₃) ₂ NH	7	technically pure	20	O	-	-	+	+	O	O	-	-	-	-	
				40												
				60												
				80												
				100												
				140												
Dimethylphthalate (DMPI)	C ₆ H ₄ (CH ₃) ₂			20	-	-	-	-	-	-	-	-	-	-	-	
				40												
				60												
				80												
				100												
				140												
Dinonylphthalate (DNPI)			technically pure	20	-	-	-	O	+	-	O	+	-	-	-	
				40												
				60												
				80												
				100												
				140												
Diocetylphthalate (SPRB) (DOP)			technically pure	20	-	-	-	O	+	-	O	+	-	-	-	
				40												
				60												
				80												
				100												
				140												
Dioxane	C ₄ H ₈ O ₂	101	technically pure	20	-	-	-	+	+	O	O	O	O	-	-	
				40												
				60												
				80												
				100												
				140												
Drinking water	see water															

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (IS/GEF)	EPDM	FFM	NBR	CR	CSM
Ethanolamine	see Annino ethanol														
Ethyl acetate	CH ₃ COOCH ₂ -CH ₃	77	technically pure	20	-	-	-	-	-	0	+	-	-	-	-
				40	-	-	-	-	-	0	+	-	-	-	-
				60	-	-	-	-	-	0	0	0	-	-	-
				80	-	-	-	-	-	0	0	0	-	-	-
				100	-	-	-	-	-	0	0	0	-	-	-
				140	-	-	-	-	-	0	0	0	-	-	-
Ethyl alcohol + acetic acid (fermentation mixture)			technically pure	20	+	0	-	+	+	+	0	0	0	+	+
				40	+	0	-	+	+	+	0	0	0	+	+
				60	0	+	-	+	+	+	0	0	0	+	+
				80	0	+	-	+	+	+	0	0	0	+	+
				100	0	+	-	+	+	+	0	0	0	+	+
				140	0	+	-	+	+	+	0	0	0	+	+
Ethyl alcohol (Ethnocl ISpRBI)	CH ₃ -CH ₂ -OH	78	technically pure, 96%	20	+	0	-	+	+	+	+	0	0	+	+
				40	+	0	-	+	+	+	+	0	0	+	+
				60	+	0	-	+	+	+	+	0	0	+	+
				80	+	0	-	+	+	+	+	0	0	+	+
				100	+	0	-	+	+	+	+	0	0	+	+
				140	+	0	-	+	+	+	+	0	0	+	+
Ethyl benzene	C ₆ H ₅ -CH ₂ -CH ₃	136	technically pure	20	-	-	-	0	0	0	-	+	-	-	-
				40	-	-	-	0	0	0	-	+	-	-	-
				60	-	-	-	0	0	0	-	+	-	-	-
				80	-	-	-	0	0	0	-	+	-	-	-
				100	-	-	-	0	0	0	-	+	-	-	-
				140	-	-	-	0	0	0	-	+	-	-	-
Ethyl chloride	CH ₃ -CH ₂ Cl	12	technically pure	20	-	-	-	0	0	0	-	0	-	-	-
				40	-	-	-	0	0	0	-	0	-	-	-
				60	-	-	-	0	0	0	-	0	-	-	-
				80	-	-	-	0	0	0	-	0	-	-	-
				100	-	-	-	0	0	0	-	0	-	-	-
				140	-	-	-	0	0	0	-	0	-	-	-
Ethyl ether	CH ₃ CH ₂ -O-CH ₂ CH ₃	35	technically pure	20	-	-	-	+	0	+	-	-	-	-	-
				40	-	-	-	+	0	+	-	-	-	-	-
				60	-	-	-	+	0	+	-	-	-	-	-
				80	-	-	-	+	0	+	-	-	-	-	-
				100	-	-	-	+	0	+	-	-	-	-	-
				140	-	-	-	+	0	+	-	-	-	-	-
Ethylenchloride (1,2-Dichloroethane)				20	-	-	-	-	-	-	-	-	-	-	-
				40	-	-	-	-	-	-	-	-	-	-	-
				60	-	-	-	-	-	-	-	-	-	-	-
				80	-	-	-	-	-	-	-	-	-	-	-
				100	-	-	-	-	-	-	-	-	-	-	-
				140	-	-	-	-	-	-	-	-	-	-	-
Ethylene chloride	ClCH ₂ -CH ₂ Cl	83	technically pure	20	-	-	-	0	0	+	-	+	0	0	-
				40	-	-	-	0	0	+	-	+	0	0	-
				60	-	-	-	0	0	+	-	+	0	0	-
				80	-	-	-	0	0	+	-	+	0	0	-
				100	-	-	-	0	0	+	-	+	0	0	-
				140	-	-	-	0	0	+	-	+	0	0	-

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDY (SYGEFI)	EPDM	FRM	NBR	CR	CSM
Ethylene diamine	H ₂ N-CH ₂ -CH ₂ -NH ₂	117	technically pure	20	O	-	-	+	+	+	+				
				40				+	+	+					
				60				+	+	+					
				80				+	+	+					
				100							+				
				120											
Ethylene glycol (SpRB)	HO-CH ₂ -CH ₂ -OH	198	technically pure	20	+	+	O	-	+	+	+	+			
				40	+	+	+		+	+	+	+			
				60	+	+	+		+	+	+	+	+		
				80	+	+	+		+	+	+	+	+		
				100	+	+	+		+	+	+	+	+		
				120	+	+	+		+	+	+	+	+		
Ethylene glycol	CH ₂ OHCH ₂ OH	198	technically pure	20	+			-	+	+	+	+			
				40	+				+	+	+	+	+		
				60	+				+	+	+	+	+		
				80	+				+	+	+	+	+		
				100	+				+	+	+	+	+		
				120	+				+	+	+	+	+		
Ethylene oxide	CH ₂ -CH ₂	10	technically pure, moist	20	-	-	-	-	O	+	O				
				40											
				60											
				80											
				100											
				120											
Ethylenediaminetetraacetic acid (EDTA)				20					+	+	+				
				40											
				60											
				80											
				100											
				120											
Fatty acids >C ₆ (SpRB)	R-COOH		technically pure	20	+	+		-	+	+	+	+			
				40	+	+	+		+	+	+	+			
				60	+	+	+		O	+	+	+			
				80							+	+			
				100											
				120											
Fatty alcohol sulphates (SpRB)			aqueous	20	+	+	+		+	+	+	+			
				40	O	+	O		+	+	+	+			
				60					+	+	+	+			
				80							+	+			
				100											
				120											
Fertilizers			aqueous	20	O	+	+	+	O	+	+	+			
				40	+	+	+		+	+	+	+			
				60	+	+	+		+	+	+	+			
				80	+	+	+		+	+	+	+			
				100	+	+	+		+	+	+	+			
				120	+	+	+		+	+	+	+			

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEEF)	EPDM	FPM	NBR	CR	CSM
					Fluorine	F ₂		technically pure	20	-	-	-	-	-	-
				40	-	-	-	-	-	-	-	-	-	-	-
				60	-	-	-	-	-	-	-	-	-	-	-
				80	-	-	-	-	-	-	-	-	-	-	-
				100	-	-	-	-	-	-	-	-	-	-	-
				120	-	-	-	-	-	-	-	-	-	-	-
				140	-	-	-	-	-	-	-	-	-	-	-
Fluorosilicic acid (Q/E)	H ₂ SiF ₆		32%, aqueous	20	+	+	+	+	+	+	+	○	○	○	+
				40	+	+	+	+	+	+	+	○	○	○	+
				60	+	+	+	+	+	+	+	○	○	○	+
				80	+	+	+	+	+	+	+	○	○	○	+
				100	+	+	+	+	+	+	+	○	○	○	+
				120	+	+	+	+	+	+	+	○	○	○	+
				140	+	+	+	+	+	+	+	○	○	○	+
Formaldehyde (SpRB)	HCHO		40%, aqueous	20	+	+	+	+	+	+	+	+	○	+	+
				40	+	+	+	+	+	+	+	+	○	+	+
				60	+	+	+	+	+	+	+	+	○	+	+
				80	+	+	+	+	+	+	+	+	○	+	+
				100	+	+	+	+	+	+	+	+	○	+	+
				120	+	+	+	+	+	+	+	+	○	+	+
				140	+	+	+	+	+	+	+	+	○	+	+
Formamide	HCONH ₂	210	technically pure	20	-	-	-	+	+	+	+	○	+	+	+
				40	-	-	-	+	+	+	+	○	+	+	+
				60	-	-	-	+	+	+	+	○	+	+	+
				80	-	-	-	+	+	+	+	○	+	+	+
				100	-	-	-	+	+	+	+	○	+	+	+
				120	-	-	-	+	+	+	+	○	+	+	+
				140	-	-	-	+	+	+	+	○	+	+	+
Formic acid (SpRB)	HCOOH		up to 50%, aqueous	20	+	○	-	+	+	+	+	+	-	+	+
				40	+	○	-	+	+	+	+	+	-	+	+
				60	○	+	+	+	+	+	○	○	+	+	+
				80	○	+	+	+	+	+	○	○	+	+	+
				100	○	+	+	+	+	+	○	○	+	+	+
				120	○	+	+	+	+	+	○	○	+	+	+
				140	○	+	+	+	+	+	○	○	+	+	+
Formic acid (SpRB)	HCOOH	101	technically pure	20	+	○	-	+	+	+	+	+	-	+	+
				40	○	-	-	+	+	+	+	+	-	+	+
				60	-	-	-	+	+	+	+	+	-	+	+
				80	-	-	-	+	+	+	○	+	-	+	+
				100	-	-	-	+	+	+	○	+	-	+	+
				120	-	-	-	+	+	+	○	+	-	+	+
				140	-	-	-	+	+	+	○	+	-	+	+
Formic acid (SpRB)			25%	20	+	+	-	+	+	+	+	+	-	+	+
				40	+	+	-	+	+	+	+	+	-	+	+
				60	+	+	-	+	+	+	+	+	-	+	+
				80	+	+	-	+	+	+	+	+	-	+	+
				100	+	+	-	+	+	+	+	+	-	+	+
				120	+	+	-	+	+	+	+	+	-	+	+
				140	+	+	-	+	+	+	+	+	-	+	+
Freon 113	see trifluoro, trichloroethane	48													
Frigen 12 (D/PI)	see Freon 12	-30	technically pure												

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYG/EF)	EPDM	FFM	NBR	CR	CSM
Fruit juices (SpRBI)				20	+	+	+	+	+	+					
				40	+	+	+	+	+	+					
				60	+	+	+	+	+	+					
				80	+	+	+	+	+	+					
				100	+	+	+	+	+	+					
				140											
Fruit pulp				20	+	+		+	+						
				40				+	+						
				60				+	+						
				80				+	+						
				100				+	+						
				140											
Fuel oil				20	+	+		○	○	+					
				40	○	+									
				60											
				80											
				100											
				140											
Furfuryl alcohol (SpRBI)	C ₃ H ₆ O ₂	171	technically pure	20	-	-	-	+	+	+	○			○	○
				40				+	+	+					
				60				+	+	+	○				
				80				+	+	+					
				100				+	+	+					
				140											
Gasoline (SpRBI)	C ₃ H ₁₂ to C ₁₂ H ₂₆	80-130	free of lead and aromatic compounds	20	+	+	-	+	○	+					○
				40	+	+		+	○	+					
				60	+	+		○		+					
				80				+	+	+					
				100				+	+	+					
				140											
Gelatin			all, aqueous	20	+	+	+	+	+	+					
				40	+	+	+	+	+	+					
				60	+	+	+	+	+	+					
				80				+	+	+					
				100				+	+	+					
				140											
Glucose	C ₆ H ₁₂ O ₆	Fp*, 148	all, aqueous	20	+	+	+	+	+	+					
				40	+	+	+	+	+	+					
				60	○	+	+	+	+	+					
				80	+	+	+	+	+	+					
				100				+	+	+					
				140											
Glycerol	HO-CH ₂ -CH(OH)-CH ₂ -OH	290	technically pure	20	+	+	+	+	+	+					
				40	+	+	+	+	+	+					
				60	+	+	+	+	+	+					
				80	+	+	+	+	+	+					
				100	+	+	+	+	+	+					
				140											

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGFEI)	EPDM	FPM	NBR	CR	CSM
Glycol (SpRB)	$\text{NH}_2\text{-CH}_2\text{-COOH}$	fp.* 233	10%, aqueous	20 40 60 80 100 120 140	+	+	+	+	+	+		+	+	+	+
Glycol	see Ethylene glycol														
Glycolic acid	$\text{HO-CH}_2\text{-COOH}$	fp.* 80	37%, aqueous	20 40 60 80 100 120 140	+	-	+	+	+		+	+	+	+	
Heptane (SpRB)	C_7H_{16}	98	technically pure	20 40 60 80 100 120 140	+	○	-	+	+	+	-	+	+	+	+
Hexane (SpRB)	C_6H_{14}	69	technically pure	20 40 60 80 100 120 140	+	○	-	+	+	+	-	+	+	+	+
Hydrazine hydrate (SpRB)	$\text{H}_2\text{N-NH}_2 \cdot \text{H}_2\text{O}$	113	aqueous	20 40 60 80 100 120 140	+	-	-	+	+	+	+	○	-	-	+
Hydrobromic acid (SpRB)	HBr	124	aqueous, 50%	20 40 60 80 100 120 140	+	+	+	+	+	+	+	○	+	+	+
Hydrochloric acid (Q/E, D/P)	HCl		up to 38%	20 40 60 80 100 120 140	+	+	-	+	○	+	+	+	-	○	+
Hydrochloric acid (Q/E, D/P)	HCl		5%, aqueous	20 40 60 80 100 120 140	+	+	+	+	+	+	+	+	○	○	+

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (S/G/ET)	EPDM	FKM	NBR	CR	CSM
Hydrochloric acid (Q/E, D/PI)	HCl		10%, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	O	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Hydrochloric acid (Q/E, D/PI)	HCl		up to 30%, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	O	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Hydrochloric acid (Q/E, D/PI)	HCl		36%, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	O	+	+	+	+	+	+	+	+	+	+
				60	O	O	O	+	+	+	+	+	+	+	+
				80	O	O	O	+	+	+	+	+	+	+	+
				100	O	O	O	+	+	+	+	+	+	+	+
				140	O	O	O	+	+	+	+	+	+	+	+
Hydrocyanic acid	HCN	26	technically pure	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	O	+	+	+	+	+	+	+	+	+	+
				80	O	+	+	+	+	+	+	+	+	+	+
				100	O	+	+	+	+	+	+	+	+	+	+
				140	O	+	+	+	+	+	+	+	+	+	+
Hydrofluoric acid	HF			20	+	-	-	+	+	+	-	+	-	+	+
				40	O	-	-	+	+	+	-	+	-	+	+
				60	O	-	-	+	+	+	-	+	-	+	+
				80	O	-	-	+	+	+	-	+	-	+	+
				100	O	-	-	+	+	+	-	+	-	+	+
				140	O	-	-	+	+	+	-	+	-	+	+
Hydrogen	H ₂	-253	technically pure	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Hydrogen chloride (Q/E)	HCl	-85	technically pure, gaseous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	O	+	+	+	+	+	+	+	+	+	+
				80	O	+	+	+	+	+	+	+	+	+	+
				100	O	+	+	+	+	+	+	+	+	+	+
				140	O	+	+	+	+	+	+	+	+	+	+
Hydrogen peroxide			70%	20	+	+	+	+	+	O	O	+	+	+	+
				40	+	+	+	+	+	O	O	+	+	+	+
				60	+	+	+	+	+	O	O	+	+	+	+
				80	+	+	+	+	+	O	O	+	+	+	+
				100	+	+	+	+	+	O	O	+	+	+	+
				140	+	+	+	+	+	O	O	+	+	+	+

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (STGFEI)	EPDM	FFM	NBR	CR	CSM
Hydrogen peroxide (SpRBI)	H ₂ O ₂		50%, aqueous	20	+	+	-	+	+	0	0	+			
				40											
				60											
				80											
				100											
Hydrogen peroxide (SpRBI)	H ₂ O ₂		10%, aqueous	20	+	+	-	++	++	0	0	+			
				40											
				60	0										
				80											
				100											
Hydrogen peroxide (SpRBI)	H ₂ O ₂	139	90%, aqueous	20	+		-	+	-	0	0	+			0
				40											
				60											
				80											
				100											
Hydrogen peroxide (SpRBI)	H ₂ O ₂	105	30%, aqueous	20	+	+	-	+	+	0	0	+			
				40											
				60											
				80											
				100											
Hydrogen sulphide	H ₂ S		technically pure	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	
				60	+	+	+	+	+	+	+	+	+	+	
				80	+	+	+	+	+	+	+	+	+	+	
				100	+	+	+	+	+	+	+	+	+	+	
Hydrogen sulphide	H ₂ S		saturated, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	
				60	0	+	+	+	+	+	+	+	+	+	
				80											
				100											
Hydroquinone	C ₆ H ₄ (OH) ₂		saturated	20	+	+		+	+		+				
				40	+	+		+	+						
				60				+	+						
				80				+	+						
				100											
Hydroxylamine sulfate	see Sodium dithione			20	+			+			+				
				40	+			+							
				60	+			+							
				80											
				100											

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGFEI)	EPDM	FPM	NBR	CR	CSM
Hydroxylamine sulphate	$(NH_2OH)_2SO_4$		all, aqueous	20	+	+	-	++	++		+				
				40	+	+		++	++						
				60	+	+		++	++						
				80	+	+		++	++						
				100	+	+		++	++						
				120	+	+		++	++						
				140	+	+		++	++						
Iodine-potassium iodide solution (Iugof's solution)				20	+	-	-			+		+			
				40	+										
				60	+										
				80	+										
				100	+										
				120	+										
				140	+										
Iodine	I_2	185	100%	20	-	-	-			+		+			
				40	-	-	-								
				60	-	-	-								
				80	-	-	-								
				100	-	-	-								
				120	-	-	-								
				140	-	-	-								
Iron III -chloride			saturated	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Iron III -chloride	$FeCl_2$		saturated	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Iron III -nitrate	$Fe(NO_3)_2$		saturated	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Iron III -chloride	$FeCl_3$		saturated	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Iron III -chloride			saturated	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PPH	PVDF (VDFE)	EPDM	FPM	NBR	CR	CSM
					Iron (III) -chloridsulfate		saturated	20	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Iron (III) -nitrate		saturated	20	+	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Iron (III) -nitrate	Fe(NO ₃) ₃	saturated	20	+	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Iron (III) -sulfate	Fe ₂ (SO ₄) ₃	saturated	20	+	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Iron (III) -sulfate		saturated	20	+	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Iron (III) -nitrate	Fe(NO ₃) ₃	saturated	20	+	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Iron (III) -sulfate	FeSO ₄	saturated	20	+	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Iron (III) -sulfate		saturated	20	+	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYG/EF)	EPDM	FRM	NBR	CR	CSM
					Iron salts			all, aqueous	20	+	+	+			
				40	+	+	+								
				60	O	+	+								
				80	+	+	+								
				100											
				120											
				140											
Isooctane (SpRB)	$(CH_3)_2C-CH_2-CH(CH_3)_2$	99	technically pure	20	+										
				40											
				60											
				80											
				100											
				120											
				140											
Isophorone (SpRB)	$C_{14}H_{28}O$		technically pure	20											
				40											
				60											
				80											
				100											
				120											
				140											
Isopropyl alcohol (SpRB)	$(CH_3)_2CH-OH$	82	technically pure	20				+	+		+				
				40											
				60											
				80											
				100											
				120											
				140											
Isopropyl ether	$(CH_3)_2CH-O-CH(CH_3)_2$	68	technically pure	20	-	-	-	O	O	+	O	-	-	-	-
				40											
				60											
				80											
				100											
				120											
				140											
Isopropylbenzene				20	-	-	-								
				40											
				60											
				80											
				100											
				120											
				140											
Jam, Marmalade				20	O	O	+	+	+	+	+	+	+	+	+
				40	O	O	+	+	+	+	+	+	+	+	+
				60	O	O	+	+	+	+	+	+	+	+	+
				80	O	O	+	+	+	+	+	+	+	+	+
				100	O	O	+	+	+	+	+	+	+	+	+
				120	O	O	+	+	+	+	+	+	+	+	+
				140	O	O	+	+	+	+	+	+	+	+	+
Lactic acid (SpRB)	$CH_3CHOHCOOH$		10%, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	-	O	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGFEI)	EPDM	FPM	NBR	CR	CSM
					lanolin (SprB)			technically pure	20	+	o	+	+	+	+
				40	o		+	+	+	+					
				60			+	+	+	+					
				80			+	+	+	+					
				100			+	+	+	+					
				120			+	+	+	+					
				140			+	+	+	+					
Lead acetate	$Pb(CH_3COO)_2$		aqueous, saturated	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Lead salts	$PbCl_2, Pb(NO_3)_2, PbSO_4$		saturated	20		+									
				40		+									
				60		+									
				80		+									
				100											
				120											
				140											
Lead carbonate				20	+	+		+	+	+	+				
				40											
				60											
				80											
				100											
				120											
				140											
Lead nitrate	$Pb(NO_3)_2$			20		+	+								
				40		+	+								
				60		+	+								
				80		+	+								
				100		+	+								
				120											
				140											
Lead nitrate				20	+										
				40	+	+	+								
				60	+	+	+								
				80											
				100											
				120											
				140											
Lead tetrafluoroborate				20						+					
				40						+					
				60						+					
				80						+					
				100						+					
				120						+					
				140						+					
linoleic acid				20						+					
				40						+					
				60						+					
				80						+					
				100						+					
				120						+					
				140						+					

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (S/GEFI)	EPDM	PPM	NBR	CR	CSM
					Unseed oil (SpRBI)			technically pure	20	+	+	-	+	+	+
				40	O	+		+	+	+					
				60				+	+	+					
				80				+	+	+					
				100				+	+	+					
				120				+	+	+					
				140				+	+	+					
Liqueurs				20	+			+	+	+	+	+	+	+	+
				40	+			+							
				60											
				80											
				100											
				120											
				140											
Liquid fertilizers				20				+	+	+		+	+		
				40				+	+	+		+	+		
				60				+	+	+		+	+		
				80				+	+	+		+	+		
				100				+	+	+		+	+		
				120				+	+	+		+	+		
				140				+	+	+		+	+		
Lithiumbromide	LiBr			20	+	+		+	+	+	+	+	+		
				40											
				60											
				80											
				100											
				120											
				140											
Lithiumsulfate				20	+	+		+	+	+	+	+	+		
				40											
				60											
				80											
				100											
				120											
				140											
Lubricating oils				20	+	+	-	+	O	+			+	+	+
				40	+	+			O	+			+	+	+
				60	+	+				+			O	+	+
				80						+				O	+
				100						+					O
				120						+					
				140						+					
Magnesium salts	MgCl ₂ , MgCO ₃ , Mg(NO ₃) ₂ , Mg(OH) ₂ , MgSO ₄		all, aqueous, saturated	20	+	+	+	+	+	+		+	+	+	+
				40	O	+	+	+	+	+		+	+	+	+
				60			+	+	+	+		+	+	+	+
				80				+	+	+		+	+	+	+
				100				+	+	+		+	+	+	+
				120				+	+	+		+	+	+	+
				140				+	+	+		+	+	+	+
Magnesiumhydrogen-carbonate				20	+			+	+		+				
				40	+			+	+		+				
				60	+			+	+		+				
				80				+	+						
				100				+	+						
				120											
				140											

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Aggressive Media				Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (S/G/EEI)	EPDM	FFM	NBR	CR	CSM	
Maleic acid (SprB)	$(CH-COOH)_2$	Fp. •131	cold saturated, aqueous	20	+	+	+	+	+	+						
				40	+	+	+	+	+	+						
				60	O	+										
				80												
				100												
				120												
Media water or similar media				20	+	+	+	+	+	+						
				40	+	+	+	+	+	+						
				60	+	+	+	+	+	+						
				80	+	+	+	+	+	+						
				100												
				120												
Mercury	Hg	357	pure	20	+	+	+	+	+	+						
				40	+	+	+	+	+	+						
				60	+			+	+	+						
				80				+	+	+						
				100				+	+	+						
				120												
Mercury (III) -chloride	$HgCl_2$			20	+	+	+	+	+	+						
				40	+	+	+	+	+	+						
				60	+	+	+	+	+	+						
				80	+	+	+	+	+	+						
				100				+	+	+						
				120												
Mercury (III) -cyanide	$Hg(CN)_2$			20	+	+	+	+	+	+						
				40	+	+	+	+	+	+						
				60	+	+	+	+	+	+						
				80	+			+	+	+						
				100				+	+	+						
				120												
Mercury (III) -cyanide	$Hg(NO_3)_2$			20	+	+	+	+	+	+						
				40	+	+	+	+	+	+						
				60	+	+	+	+	+	+						
				80	+			+	+	+						
				100				+	+	+						
				120												
Mercury (III) -sulfate				20	+	+	+	+	+	+						
				40	+	+	+	+	+	+						
				60	+	+	+	+	+	+						
				80	+			+	+	+						
				100				+	+	+						
				120												
Mercury salts	$HgNO_3, Hg Cl_2, Hg(CN)_2$		cold saturated, aqueous	20	+	+	+	+	+	+						
				40	+	+	+	+	+	+						
				60	O	+										
				80												
				100												
				120												
Methane	see natural gas	-161	technically pure	20	+	+	+	+	+	+						
				40	+	+	+	+	+	+						
				60	O	+										
				80												
				100												
				120												

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGFEF)	EPDM	FPM	NBR	CR	CSM
Methanol (SprB)	CH ₃ OH	65	all	20	+	+	-	+	+	-	+	+	+	+	+
				40	+	+	-	+	+	-	+	+	+	+	+
				60	0	+	-	+	+	-	+	+	+	+	+
				80	0	+	-	+	+	-	+	+	+	+	+
				100	0	+	-	+	+	-	+	+	+	+	+
				140	0	+	-	+	+	-	+	+	+	+	+
Methyl acetate	CH ₃ COCCH ₃	56	technically pure	20	-	-	-	+	+	+	-	-	-	-	-
				40	-	-	-	+	+	+	-	-	-	-	-
				60	-	-	-	+	+	+	-	-	-	-	-
				80	-	-	-	0	+	+	-	-	-	-	-
				100	-	-	-	0	+	+	-	-	-	-	-
				140	-	-	-	0	+	+	-	-	-	-	-
Methyl amine	CH ₃ NH ₂	-6	32%, aqueous	20	0	-	-	+	+	0	-	+	-	+	+
				40	0	-	-	+	+	0	-	+	-	+	
				60	0	-	-	+	+	0	-	+	-	+	
				80	0	-	-	+	+	0	-	+	-	+	
				100	0	-	-	+	+	0	-	+	-	+	
				140	0	-	-	+	+	0	-	+	-	+	
Methyl bromide	CH ₃ Br	4	technically pure	20	-	-	-	0	-	+	+	0	-	-	0
				40	-	-	-	0	-	+	+	0	-	-	0
				60	-	-	-	0	-	+	+	0	-	-	0
				80	-	-	-	0	-	+	+	0	-	-	0
				100	-	-	-	0	-	+	+	0	-	-	0
				140	-	-	-	0	-	+	+	0	-	-	0
Methyl chloride	CH ₃ Cl	-24	technically pure	20	-	-	-	0	+	+	-	-	-	-	-
				40	-	-	-	0	+	+	-	-	-	-	-
				60	-	-	-	0	+	+	-	-	-	-	-
				80	-	-	-	0	+	+	-	-	-	-	-
				100	-	-	-	0	+	+	-	-	-	-	-
				140	-	-	-	0	+	+	-	-	-	-	-
Methyl ethyl ketone	CH ₃ COC ₂ H ₅	80	technically pure	20	-	-	-	0	+	-	-	-	-	-	-
				40	-	-	-	0	+	-	-	-	-	-	-
				60	-	-	-	0	+	-	-	-	-	-	-
				80	-	-	-	0	+	-	-	-	-	-	-
				100	-	-	-	0	+	-	-	-	-	-	-
				140	-	-	-	0	+	-	-	-	-	-	-
Methylene chloride	CH ₂ Cl ₂	40	technically pure	20	-	-	-	0	0	+	0	0	-	-	-
				40	-	-	-	0	0	+	0	0	-	-	-
				60	-	-	-	0	0	+	0	0	-	-	-
				80	-	-	-	0	0	+	0	0	-	-	-
				100	-	-	-	0	0	+	0	0	-	-	-
				140	-	-	-	0	0	+	0	0	-	-	-
Methylisobutylketone	C ₉ H ₁₂ O			20	-	-	-	-	-	-	-	-	-	-	-
				40	-	-	-	-	-	-	-	-	-	-	-
				60	-	-	-	-	-	-	-	-	-	-	-
				80	-	-	-	-	-	-	-	-	-	-	-
				100	-	-	-	-	-	-	-	-	-	-	-
				140	-	-	-	-	-	-	-	-	-	-	-

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Aggressive Media				Chemical Resistance															
Medium	Formula	Boiling point °C	Concentration	Temperature °C															
				PVC	CPVC	ABS	PE	PP-H	PVDF (ST/GEFI)	EPDM	FKM	NBR	CR	CSM					
Methylmethacrylate	C ₅ H ₈ O ₂			20	-	-	-	-	-	-	-	-	-	-	-	-	-		
				40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
				60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Methylphenylketone (Acetophenon)	C ₈ H ₈ O			20	-	-	-	-	-	-	-	-	-	-	-	-	-		
				40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
				60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Milk (SpRB)				20	+	+	+	+	+	+	+	+	+	+	+	+	+		
				40	++	++	++	++	++	++	++	++	++	++	++	++	++	++	
				60	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
				80	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Mineral oils, free of aromatics				20	+	+	+	-	+	+	+	+	+	+	+	+	+		
				40	+	+	+	-	+	+	+	+	+	+	+	+	+	+	
				60	+	+	+	O	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	O	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	O	+	+	+	+	+	+	+	+	+	+	+
Mineral water				20	+	+	+	+	+	+	+	+	+	+	+	+	+		
				40	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
				60	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Mixed acids - nitric - hydrofluoric - sulphuric	15% HNO ₃ 15% HF 18% H ₂ SO ₄		3 parts 1 part 2 parts	20	O	O	-	O	-	+	+	+	+	+	+	+	+		
				40	O	O	-	O	-	+	+	+	+	+	+	+	+	+	
				60	O	O	-	O	-	+	+	+	+	+	+	+	+	+	+
				80	O	O	-	O	-	+	+	+	+	+	+	+	+	+	+
				100	O	O	-	O	-	+	+	+	+	+	+	+	+	+	+
Mixed acids - sulphuric - nitric - water	H ₂ SO ₄ HNO ₃ H ₂ O		48% 49% 43%	20	+	+	-	-	-	+	+	+	+	+	+	+	+		
				40	O	O	-	-	-	+	+	+	+	+	+	+	+	+	
				60	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+
				80	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+
				100	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+
Mixed acids - sulphuric - nitric - water	H ₂ SO ₄ HNO ₃ H ₂ O		50% 50% 40%	20	O	O	-	-	-	+	+	+	+	+	+	+	+		
				40	O	O	-	-	-	+	+	+	+	+	+	+	+	+	
				60	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+
				80	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+
				100	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+

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Aggressive Media				Chemical Resistance															
Medium	Formula	Boiling point °C	Concentration	Temperature °C															
				PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEEF)	EPDM	FPM	NBR	CR	CSM					
Mixed acids - sulphuric - nitric - water	H ₂ SO ₄ HNO ₃ H ₂ O	10%	87% 43%	20	O	O	-	-	-	-	O								
				40															
				60															
				80															
				100															
				120															
Mixed acids - sulphuric - nitric - water	H ₂ SO ₄ HNO ₃ H ₂ O	50%	33% 17%	20	O	+	-	-	-	+			+	-	-	-	O		
				40															
				60															
				80															
				100															
				120															
Mixed acids - sulphuric - nitric - water	H ₂ SO ₄ HNO ₃ H ₂ O	10%	20% 70%	20	+	+	-	O	-	+	+					O	+		
				40															
				60															
				80															
				100															
				120															
Mixed acids - sulphuric - nitric - water	H ₂ SO ₄ HNO ₃ H ₂ O	50%	31% 19%	20	+		-	-	-	+			+	-	O	O			
				40															
				60															
				80															
				100															
				120															
Mixed acids - sulphuric - phosphoric - phosphoric	H ₂ SO ₄ H ₃ PO ₄ H ₂ O	30%	60% 10%	20	+	+	+	O	O	+	+			+	O	+			
				40															
				60															
				80															
				100															
				120															
Malasses				20	+	+	+	+	+	+	+	+	+	+	+	+			
				40															
				60	O	+	+	+	+	+	+	+	+	+	+	+			
				80		+													
				100															
				120															
Malasses wort				20	+	+	+	+	+	+	+	+	+	+	+	+			
				40															
				60	+	+	+	+	+	+	+	+	+	+	+	+			
				80		+													
				100															
				120															
Monochloroacetic acid ethyl ester	ClCH ₂ COOC ₂ H ₅	144	technically pure	20	-	-	-	+	+	O			O	-	-	-			
				40															
				60															
				80															
				100															
				120															

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDI (SYGEEI)	EPDM	FPM	NBR	CR	CSM
					Morpholin	C ₄ H ₉ NO	129	technically pure	20 40 60 80 100 120 140	-	-	-	+++	++	++
Mowlith D			usual commercial	20 40 60 80 100 120 140	+	+		+	+	+		+	+	+	+
Naphthalene		218	technically pure	20 40 60 80 100 120 140	-	-	-	0	+	+		+	+	-	0
Natriumhydrogensulfite	NaHSO ₃			20 40 60 80 100 120 140	+	+		+	+	+	+	+			
Natriumsulfate				20 40 60 80 100 120 140	+	+	+	+	+	+	+	+	+		
Natriumtetraborate (Borax)				20 40 60 80 100 120 140	+	+	+	+	+	+	+	+	+		
Nickel salts	(CH ₃ COO) ₂ Ni, NiCl ₂ , Ni(NO ₃) ₂ , Ni SO ₄		cold saturated, aqueous	20 40 60 80 100 120 140	+	+	+	+	+	+	+	+	+	+	+
Nitrating acid	H ₂ SO ₄ HNO ₃ H ₂ O		65% 20% 15%	20 40 60 80 100 120 140	+	+	+	+	+	+	+	+	+	+	+

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (STGEH)	EPDM	FPM	NBR	CR	CSM
					Nitric acid (SpRB)	HNO ₃			20	+	+	-	+	O	+
				40	+	+									
				60	+	+									
				80	+	+									
				100						+					
				120						+					
				140						+					
Nitric acid (SpRB)	HNO ₃			20	+	+	+	+	O	+	+	+			
				40	+	+	+	+							
				60	+	+	+	+							
				80	+	+	+	+							
				100						+					
				120						+					
				140						+					
Nitric acid up to 55% (SpRB)				20	+	+	+	+		+		+			
				40	+	+	+	+							
				60											
				80											
				100											
				120											
				140											
Nitric acid (see note 2.3.1 on jointing) (SpRB)	see Salpetre		6.3%, aqueous												
Nitric acid (see note 2.3.1 on jointing) (SpRB)	see Salpetre		up to 40%, aqueous												
Nitric acid (see note 2.3.1 on jointing) (SpRB)	see Salpetre		6.5%, aqueous												
Nitric acid (see note 2.3.1 on jointing) (SpRB)	see Salpetre		100%												
Nitric acid (see note 2.3.1 on jointing) (SpRB)	see Salpetre		85%												
Nitric oxide	see Nitrous gases														
Nitrotriacetic acid	NICH ₂ -COOH ₃			20				+	+		+				
				40											
				60											
				80											
				100											
				120											
				140											
Nitrobenzene	C ₆ H ₅ -NO ₂	209	technically pure	20	-	-	-	O	+	+	-	O	-	-	-
				40				O	+						
				60				O	+						
				80					+						
				100											
				120											
				140											

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (ST/GEF)	EPDM	FFM	NBR	CR	CSM
Nitrotoluene (o-, m-, p-)		222-238	technically pure	20	-	-	-	-	-	-	-	-	-	-	-
				40	-	-	-	-	-	-	-	-	-	-	-
				60	-	-	-	-	-	-	-	-	-	-	-
				80	-	-	-	-	-	-	-	-	-	-	-
				100	-	-	-	-	-	-	-	-	-	-	-
				140	-	-	-	-	-	-	-	-	-	-	-
Nitrous acid	HNO ₂			20	++	++	-	+	-	+++	+	+	-	-	
				40	++	++	-	+	-	+++	+	+	-	-	
				60	++	++	-	+	-	+++	+	+	-	-	
				80	++	++	-	+	-	+++	+	+	-	-	
				100	++	++	-	+	-	+++	+	+	-	-	
				140	++	++	-	+	-	+++	+	+	-	-	
Nitrous gases	see Nitric oxide		diluted, moist, anhydrous	20	-	-	-	-	-	-	-	-	-	-	
				40	-	-	-	-	-	-	-	-	-	-	
				60	-	-	-	-	-	-	-	-	-	-	
				80	-	-	-	-	-	-	-	-	-	-	
				100	-	-	-	-	-	-	-	-	-	-	
				140	-	-	-	-	-	-	-	-	-	-	
N-Methylpyrrolidon				20	-	-	-	-	-	-	-	-	-	-	
				40	-	-	-	-	-	-	-	-	-	-	
				60	-	-	-	-	-	-	-	-	-	-	
				80	-	-	-	-	-	-	-	-	-	-	
				100	-	-	-	-	-	-	-	-	-	-	
				140	-	-	-	-	-	-	-	-	-	-	
N,N-Dimethylaniline	C ₆ H ₅ N(CH ₃) ₂		technically pure	20	-	-	-	+	+	-	+	-	-	-	
				40	-	-	-	+	+	-	+	-	-	-	
				60	-	-	-	+	+	-	+	-	-	-	
				80	-	-	-	+	+	-	+	-	-	-	
				100	-	-	-	+	+	-	+	-	-	-	
				140	-	-	-	+	+	-	+	-	-	-	
n-Pentylacetote				20	-	-	-	-	-	-	-	-	-		
				40	-	-	-	-	-	-	-	-	-		
				60	-	-	-	-	-	-	-	-	-		
				80	-	-	-	-	-	-	-	-	-		
				100	-	-	-	-	-	-	-	-	-		
				140	-	-	-	-	-	-	-	-	-		
Oleic acid (SpRB)	C ₁₇ H ₃₃ COOH		technically pure	20	+	0	-	+	+	+	-	0	0	-	
				40	+	0	-	+	+	+	-	0	0	-	
				60	+	0	-	0	+	+	-	0	0	-	
				80	+	0	-	+	+	+	-	0	0	-	
				100	+	0	-	+	+	+	-	0	0	-	
				140	+	0	-	+	+	+	-	0	0	-	
Oleum (SpRB)	H ₂ SO ₄ +SO ₃		10% SO ₃	20	-	-	-	-	-	-	-	-	-	-	
				40	-	-	-	-	-	-	-	-	-	-	
				60	-	-	-	-	-	-	-	-	-	-	
				80	-	-	-	-	-	-	-	-	-	-	
				100	-	-	-	-	-	-	-	-	-	-	
				140	-	-	-	-	-	-	-	-	-	-	
Oleum vapours (SpRB)			traces	20	+	-	-	-	-	-	-	+	-	-	0
				40	+	-	-	-	-	-	-	+	-	-	0
				60	+	-	-	-	-	-	-	+	-	-	0
				80	+	-	-	-	-	-	-	+	-	-	0
				100	+	-	-	-	-	-	-	+	-	-	0
				140	+	-	-	-	-	-	-	+	-	-	0

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (S/G/EF)	EPDM	FRM	NBR	CR	CSM
Olive oil (SpRBI)				20	+	-	-				-				
				40	+										
				60	+										
				80	+			O	+	+					
				100	+				+	+					
				120	+				+	+					
				140	+				+	+					
Oxalic acid (SpRBI)	(COOH) ₂		cold saturated, aqueous	20	+	+	+				+	+			
				40	+	+	+				+	+			
				60	+	O	+					O			
				80	+										
				100	+										
				120	+										
				140	+										
Oxygen	O ₂		technically pure	20	+	+	+				+	+			
				40	+		+				+	+			
				60	+		+				+	+			
				80	+						+	+			
				100	+						+	+			
				120	+						+	+			
				140	+						+	+			
Ozone (SpRBI)	O ₃		up to 2%, in air	20	+	+	-		O	O	O	+	-	O	+
				40	+										
				60	+										
				80	+										
				100	+										
				120	+										
				140	+										
Ozone (SpRBI)	O ₃		cold saturated, aqueous	20	+	+	-		O	O	-	-	-	O	+
				40	+							O			
				60	+										
				80	+										
				100	+										
				120	+										
				140	+										
Palm oil, palm nut oil (SpRBI)				20	+	O	+				-				
				40	-										
				60			+				+	+			
				80			O				+	+			
				100							+	+			
				120							+	+			
				140							+	+			
Palmitic acid (SpRBI)	C ₁₅ H ₃₁ COOH	390	technically pure	20	+	-	+	O			O	O			
				40											
				60											
				80											
				100											
				120											
				140											
Paraffin emulsions			usual commercial, aqueous	20	+	+	O	+			-		+	+	+
				40	+	+		+				+	+	+	+
				60			O	+				+	+	+	+
				80				+				+	+	+	+
				100				+				+	+	+	+
				120				+				+	+	+	+
				140				+				+	+	+	+

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF/ST/GEFI	EPDM	FM	NBR	CR	CSM
					Paraffin oil				20	+	+	O			
				40											
				60	O			+	+						
				80				+	+						
				100						+					
				120						+					
				140						+					
p-Dibromo benzene	C ₆ H ₄ Br ₂		technically pure	20	-	-	-	O	O						
				40								+			
				60								+			
				80								+			
				100								+			
				120						+		+			
				140						+		+			
Perchloroethylene (tetrachloroethylene)	Cl ₂ C=CCl ₂	121	technically pure	20	-	-		O	O			+			
				40								+			
				60								+			
				80								+			
				100								+			
				120								+			
				140								+			
Perchloric acid (SpR)	HClO ₄		10%, aqueous	20	+	+	O		+	+	+				
				40	+	+		+	+	+	O	+			
				60	O			+	+	+		+			
				80				+	+	+		+			
				100				+	+	+		+			
				120				+	+	+		+			
				140				+	+	+		+			
Perchloric acid (SpR)			70%, aqueous	20	O	O	-	O	O	+		+			
				40						+		+			
				60						+		+			
				80						+		+			
				100						+		+			
				120						+		+			
				140						+		+			
Petroleum			technically pure	20	+	-		+	O	+		+			
				40								+			
				60				O	O			+			
				80								+			
				100								+			
				120								+			
				140								+			
Petroleum ether (SpR)		40-70	technically pure	20	+	-		O	O	+		+			
				40	+							+			
				60	+			O	O			+			
				80								+			
				100								+			
				120								+			
				140								+			
Phenol (SpR)	C ₆ H ₅ -OH	182	up to 10%, aqueous	20	+	+	-	+	+	+		+			
				40	O			+	+	+	O	+			
				60				+	+	+		+			
				80				+	+	+		+			
				100				+	+	+		+			
				120				+	+	+		+			
				140				+	+	+		+			

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PPH	PVDF (S/G/EF)	EPDM	FFM	NBR	CR	CSM
Phenol (SpRbl)			up to 5%	20 40 60 80 100 120 140	+	+	-	+++	+++	+	+	+	-	-	-
Phenol (SpRbl)	C ₆ H ₅ -OH		up to 90%, aqueous	20 40 60 80 100 120 140	0	-	-	+++	+++	+	-	+	-	0	-
Phenylhydrazine	C ₆ H ₅ -NH-NH ₂	243	technically pure	20 40 60 80 100 120 140	-	-	-	0	0	0	-	+	-	-	-
Phenylhydrazine hydrochloride	C ₆ H ₅ -NH-NH ₂ -HCl		aqueous	20 40 60 80 100 120 140	0	0	-	0	+	+	0	+	0	0	+
Phosgene (SpRbl)	COCl ₂	8	liquid, technically pure	20 40 60 80 100 120 140	-	-	-	-	-	-	-	+	0	+	+
Phosgene (SpRbl)			gaseous, technically pure	20 40 60 80 100 120 140	+	0	-	0	0	+	+	+	+	+	0
Phosphate disodique	see d'isodiumphosphate		saturated												
Phosphoric acid	H ₃ PO ₄		up to 30%, aqueous	20 40 60 80 100 120 140	+	+	+	+	+	+	+	+	0	+	+
Phosphoric acid			50%, aqueous	20 40 60 80 100 120 140	+	+	+	+	+	+	+	+	0	+	+

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Aggressive Media				Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CVC	ABS	PE	PPH	PVDF(ISTGFI)	EPDM	FRM	NBR	CR	CSM	
					Phosphoric acid		85%, aqueous	20 40 60 80 100 120 140	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	O++ O++ O++ O++ O++ O++ O++	O++ O++ O++ O++ O++ O++ O++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	O++ O++ O++ O++ O++ O++ O++	O++ O++ O++ O++ O++ O++ O++
Phosphoric acid	H ₃ PO ₄			20 40 60 80 100 120 140	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	- - - - - - -	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	O O O O O O O	O++ O++ O++ O++ O++ O++ O++	O++ O++ O++ O++ O++ O++ O++	O++ O++ O++ O++ O++ O++ O++	O++ O++ O++ O++ O++ O++ O++	O++ O++ O++ O++ O++ O++ O++
Phosphoric acid	H ₃ PO ₄			20 40 60 80 100 120 140	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	- - - - - - -	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	O++ O++ O++ O++ O++ O++ O++	O++ O++ O++ O++ O++ O++ O++	O++ O++ O++ O++ O++ O++ O++	O++ O++ O++ O++ O++ O++ O++	O++ O++ O++ O++ O++ O++ O++
Phosphoric acid tributyl ester	(H ₃ C ₄ O) ₃ P=O			20 40 60 80 100 120 140	- - - - - - -	- - - - - - -	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++
Phosphorous chlorides: - Phosphorous trichloride - Phosphorous pentachloride - Phosphorous oxichloride (SpRB)	PCl ₃ PCl ₅ POCl ₃	175 162 105	technically pure	20 40 60 80 100 120 140	- - - - - - -	- - - - - - -	++ ++ ++ ++ ++ ++ ++	O O O O O O O	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++
Photographic developer (SpRB)			usual commercial	20 40 60 80 100 120 140	++ O++ O++ O++ O++ O++ O++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	O++ O++ O++ O++ O++ O++ O++	O++ O++ O++ O++ O++ O++ O++	O++ O++ O++ O++ O++ O++ O++	O++ O++ O++ O++ O++ O++ O++	O++ O++ O++ O++ O++ O++ O++
Photographic emulsions (SpRB)				20 40 60 80 100 120 140	++ ++ O++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	O++ O++ O++ O++ O++ O++ O++	O++ O++ O++ O++ O++ O++ O++	O++ O++ O++ O++ O++ O++ O++	O++ O++ O++ O++ O++ O++ O++
Photographic fixer (SpRB)			usual commercial	20 40 60 80 100 120 140	O++ O++ O++ O++ O++ O++ O++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++

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Aggressive Media				Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (ST/GEFI)	EPDM	FFM	NBR	CR	CSM	
Phthalic acid (SpRB)	$C_6H_4(COOH)_2$	Fp.+, 208	saturated, aqueous	20	+	-	-	+	+	+						
				40		O										
				60		.										
				80												
				100												
				140												
Phthalic acid dioctyl ester	$C_{24}H_{38}O_4$			20	-	-	-	+	+	.						
				40												
				60												
				80												
				100												
				140												
Picric acid (SpRB)	$C_6H_3N_3O_7$	Fp. 122	1% aqueous	20	+	-	-	+	+	+						
				40												
				60												
				80												
				100												
				140												
Potash	see potassium carbonate		cold saturated, aqueous	20												
				40												
				60												
				80												
				100												
				140												
Potash lye	KOH		50%	20	+	+		+	+	.						
				40	+	+		+	+							
				60	+	+		+	+							
				80	+	+		+	+							
				100	+	+		+	+							
				140	+	+		+	+							
Potassium (SpRB)	$KMnO_4$		cold saturated, aqueous	20	+	+		+	+	+						
				40	+	+		+	+	+						
				60	O	+		+	+	+						
				80				O	+	+						
				100					+	+						
				140												
Potassium acetate (SpRB)	CH_3COOK		saturated	20	+	+	+	+	+	+						
				40	+	+	+	+	+	+						
				60	+	+	+	+	+	+						
				80	+	+	+	+	+	+						
				100					+	+						
				140												
Potassium bichromate (SpRB)	$K_2Cr_2O_7$	107	saturated, aqueous	20	+	+	+	+	+	+						
				40	+	+	+	+	+	+						
				60	O	+	+	+	+	+						
				80		+	+	+	+	+						
				100		+	+	+	+	+						
				140												
Potassium borate	K_3BO_3		10%, aqueous	20	+	+	+	+	+	+						
				40	+	+	+	+	+	+						
				60	O	+	+	+	+	+						
				80		+										
				100												
				140												

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDI(S)/GEFI	EPDM	IFM	NBR	CR	CSM
					Potassium bromate	$KBrO_3$		cold saturated, aqueous	20	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	O	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Potassium bromide	KBr		all, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	O	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Potassium carbonate (potash)				20	+	+	+	+	+	O	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Potassium chlorate (SpR)	$KClO_3$		cold saturated, aqueous	20	+	+	+	+	+	O	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Potassium chloride	KCl		all, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Potassium chromate (SpRB)	K_2CrO_4		cold saturated, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Potassium cyanide	KCN		cold saturated, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Potassium dichromate	$K_2Cr_2O_7$		saturated	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+

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Aggressive Media				Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (ST/GEFI)	EPDM	FRM	NBR	CR	CSM	
Potassium fluoride	KF		saturated	20	+	+		+	+	+						
				40	+	+		+	+	+						
				60	+	+		+	+	+	+					
				80	+	+		+	+	+	+					
				100	+	+		+	+	+	+					
Potassium Hexacyanoferrate -III	K ₄ [Fe(CN) ₆].3H ₂ O		saturated	20	+	+		+	+	+						
				40	+	+		+	+	+						
				60	+	+		+	+	+	+					
				80	+	+		+	+	+	+					
				100	+	+		+	+	+	+					
Potassium hydrogen carbonate	KHCO ₃		saturated	20	+	+		+	+	+						
				40	+	+		+	+	+						
				60	+	+		+	+	+	+					
				80	+	+		+	+	+	+					
				100	+	+		+	+	+	+					
Potassium hydrogen sulphate	KHSO ₄		saturated	20	+	+		+	+	+						
				40	+	+		+	+	+						
				60	+	+		+	+	+	+					
				80	+	+		+	+	+	+					
				100	+	+		+	+	+	+					
Potassium iodide	KI		cold saturated, aqueous	20	+	+		+	+	+						
				40	+	+		+	+	+						
				60	+	+		+	+	+	+					
				80	+	+		+	+	+	+					
				100	+	+		+	+	+	+					
Potassium nitrate	KNO ₃		50%, aqueous	20	+	+		+	+	+						
				40	+	+		+	+	+						
				60	+	+		+	+	+	+					
				80	+	+		+	+	+	+					
				100	+	+		+	+	+	+					
Potassium perchlorate (SpR)	KClO ₄		cold saturated, aqueous	20	+	+		+	+	+						
				40	+	+		+	+	+						
				60	O	+		+	+	+	+					
				80	+	+		+	+	+	+					
				100	+	+		+	+	+	+					
Potassium persulphate (SpR)	K ₂ S ₂ O ₈		all, aqueous	20	+	+		+	+	+						
				40	+	+		+	+	+						
				60	O	+		+	+	+	+					
				80	+	+		+	+	+	+					
				100	+	+		+	+	+	+					

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PPH	PVDF (SYGFEI)	EPDM	FRM	NBR	CR	CSM
Potassium sulphate	K_2SO_4		all, aqueous	20	+	+	+	+	+	+					
				40	+	+	+	+	+	+					
				60	O	+	+	+	+	+					
				80		+	+	+	+	+					
				100											
				120											
				140											
Potassium sulphide	K_2S		saturated	20	+	+	+								
				40	+	+	+	+							
				60	+	+	+	+							
				80				+	+	+					
				100						O O O					
				120											
				140											
Potassium sulphite	K_2SO_3		saturated	20	+	+	+								
				40	+	+	+	+							
				60	+	+	+	+							
				80				+	+	+					
				100											
				120											
				140											
Potassium-aluminiumsulphate (alum)			50%	20	+	+	+								
				40	+	+	+	+							
				60	+	+	+	+							
				80				+	+	+					
				100											
				120											
				140											
Potassium hexacyanoferrate -IIII	$K_3[Fe(CN)_6]$			20	+	+	+								
				40	+	+	+	+							
				60	+	+	+	+							
				80				+	+	+					
				100											
				120											
				140											
Potassium tartrate				20	+										
				40	+			+							
				60				+	+	+					
				80				+	+	+					
				100											
				120											
				140											
Potassiumhydrogensulphite				20	+										
				40	+										
				60											
				80											
				100											
				120											
				140											
Potassiumhypochlorite	KOCl			20	+	O		+							
				40											
				60											
				80											
				100											
				120											
				140											

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF/ST/GEFF	EPDM	FPM	NR	CR	CSM
					Pottasiumperoxodisulfate	$K_2S_2O_8$		saturated	20 40 60 80 100 120 140	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++				
Pottasiumphosphate	KH_2PO_4 und K_2HPO_4		all, aqueous	20 40 60 80 100 120 140	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	O	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++		++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++	++ ++ ++ ++ ++ ++ ++
Pottasiumphosphate				20 40 60 80 100 120 140	++ ++ ++ ++ ++ ++ ++			++ ++ ++ ++ ++ ++ ++							
Propane	C_3H_8	-42	technically pure, liquid	20 40 60 80 100 120 140	+	-	-	+	+	++ ++ ++ ++ ++ ++ ++		+	+	+	-
Propane			technically pure, gaseous	20 40 60 80 100 120 140	+	+	-	+	+	++ ++ ++ ++ ++ ++ ++		+	+	+	+
Propanol, n- and iso- (SpRB)	C_3H_7OH	97 bzw. 82	technically pure	20 40 60 80 100 120 140	+	O	O	+	+	++ ++ ++ ++ ++ ++ ++	+	+	+	+	+
Propargyl alcohol (SpRB)	$CH_2C\equiv CH-CH_2-OH$	114	7%, aqueous	20 40 60 80 100 120 140	++ ++ ++ ++ ++ ++ ++			+	++ ++ ++ ++ ++ ++ ++	+	+	+	+	+	
Propionic acid (SpRB)	CH_3CH_2COOH	141	50%, aqueous	20 40 60 80 100 120 140	++ ++ ++ ++ ++ ++ ++	O	-	+	++ ++ ++ ++ ++ ++ ++	+	+	+	+	+	

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Aggressive Media				Chemical Resistance													
Medium	Formula	Boiling point °C	Concentration	Temperature °C													
				PVC	CPVC	ABS	PE	PP-H	PVDF (S/G/EF)	EPDM	FPM	NBR	CR	CSM			
Propionic acid (SpRB)		141	technically pure	20	+	O	-	-	-	-	-	-	-	-	-	-	-
				40	O												
				60													
				80					O	O							
				100					O	O							
				120													
				140													
Propylene glycol (SpRB)	C ₃ H ₈ O ₂	188	technically pure	20	+	-	O	-	+	+	+	+	+	+	+	+	+
				40	+				+	+	+	+	+	+	+	+	+
				60	+				+	+	+	+	+	+	+	+	+
				80					+	+	+	+	+	+	+	+	+
				100					+	+	+	+	+	+	+	+	+
				120													
				140													
Propylene oxide	C ₃ H ₆ O	35	technically pure	20	O	-	-	-	+	+	+	O	-	-	-	-	-
				40													
				60													
				80													
				100													
				120													
				140													
Pyridine	C ₅ H ₅ N	115	technically pure	20	-	-	-	-	O	O	+	O	-	-	-	-	-
				40													
				60													
				80													
				100													
				120													
				140													
Pyrogallol	C ₆ H ₃ (OH) ₃		100%	20													
				40													
				60													
				80													
				100													
				120													
				140													
Ramsit fabric waterproofing agents			usual commercial	20	+	+			+	+	+	+	+	+	+	+	+
				40	+												
				60	+												
				80													
				100													
				120													
				140													
Salicylic acid	C ₆ H ₄ (OH)COOH		saturated	20	+	+	O	+	+	+	+	+	+	+	+	+	+
				40	+				+	+	+	+	+	+	+	+	+
				60					+	+	+	+	+	+	+	+	+
				80					+	+	+	+	+	+	+	+	+
				100					+	+	+	+	+	+	+	+	+
				120													
				140													
Sea water	see Brine			20	+	+	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+	+	+
Silicic acid	Si(OH) ₄			20	+	+	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+	+	+

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PPH	PVDF (SYGEFI)	EPDM	FPM	NBR	CR	CSM
Silicone oil				20	+	+	+								
				40	+	+									
				60	+	+									
				80	+	+									
				100	+	+									
				120	+	+									
				140	+	+									
Silver	AgCN		saturated	20	+	+	+								
				40	+	+	+								
				60	+	+	+								
				80	+	+	+								
				100	+	+	+								
				120	+	+	+								
				140	+	+	+								
Silver salts	AgNO ₃ , AgCN, AgCl		cold saturated, aqueous	20	+	+	+								
				40	+	+	+								
				60	O	+	+								
				80	+	+	+								
				100	+	+	+								
				120	+	+	+								
				140	+	+	+								
Silvercyanide				20	+	+	+								
				40	+	+	+								
				60	+	+	+								
				80	+	+	+								
				100	+	+	+								
				120	+	+	+								
				140	+	+	+								
Soap solution (SpRBI)			all, aqueous	20	+	+	+								
				40	+	+	+								
				60	O	+	+								
				80	+	+	+								
				100	+	+	+								
				120	+	+	+								
				140	+	+	+								
Soda	see Sodium carbonate														
Sodium acetate	CH ₃ COONa		all, aqueous	20	+	+	+								
				40	+	+	+								
				60	+	+	+								
				80	+	+	+								
				100	+	+	+								
				120	+	+	+								
				140	+	+	+								
Sodium aluminium sulfate				20	+	+	+								
				40	+	+	+								
				60	+	+	+								
				80	+	+	+								
				100	+	+	+								
				120	+	+	+								
				140	+	+	+								
Sodium arsenite	Na ₃ AsO ₃		saturated	20	+	+	+								
				40	+	+	+								
				60	+	+	+								
				80	+	+	+								
				100	+	+	+								
				120	+	+	+								
				140	+	+	+								

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (ISYGEFI)	EPDM	FPM	NBR	CR	CSM
Sodium benzoate	C ₆ H ₅ -COONa		cold saturated, aqueous	20	+	+	-	+	+	+					
				40		+		+	+	+		O			
				60	O	+		+	+	+					
				80		+		+	+	+					
				100											
				140									O		
Sodium bicarbonate	NaHCO ₃		cold saturated, aqueous	20	+	+	+	+	+	+					
				40	+	+	+	+	+	+					
				60	+	+	+	+	+	+					
				80				+	+	+					
				100											
				140											
Sodium bisulphate	NaHSO ₄		10%, aqueous	20	+	+	+	+	+	+					
				40	+	+	+	+	+	+					
				60	O			+	+	+					
				80				+	+	+					
				100				+	+	+					
				140											
Sodium bisulphite	NaHSO ₃		all, aqueous	20	+	+		+	+	+					
				40		O		+	+	+					
				60				+	+	+					
				80				+	+	+					
				100				+	+	+					
				140											
Sodium borate	Na ₂ BO ₃		saturated	20	+	+		+	+	+					
				40	+	+		+	+	+					
				60	+	+		+	+	+					
				80		+			+						
				100											
				140											
Sodium bromate	NaBrO ₃		all, aqueous	20	+	+		O	O	+					
				40	O	+				+					
				60						+					
				80						+					
				100						+					
				140											
Sodium bromide	NaBr		all, aqueous	20	+	+	+	+	+	+					
				40	O	+	+	+	+	+					
				60		+	+	+	+	+					
				80		+		+	+	+					
				100				+	+	+					
				140											
Sodium carbonate	see soda		cold saturated, aqueous												
Sodium chlorate (SpRBI)	NaClO ₃		all, aqueous	20	+	+	+	+	+	+					
				40	+	+	+	+	+	+					
				60	O	+	+	+	+	+					
				80		+		+	+	+					
				100				+	+	+					
				140											

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CVC	ABS	PE	PP-H	PVDF(S/GFF)	EPDM	FPM	NBR	CR	CSM
					Sodium chlorite (SpRB)	NaClO ₂		diluted, aqueous	20	O	+	+			
				40		+	+								
				60		+	+								
				80		+	+								
				100											
				120											
				140											
Sodium chromate (SpRB)	Na ₂ CrO ₄		diluted, aqueous	20	O	+	+	+							
				40		O	+	+							
				60				+							
				80				+							
				100				+							
				120				+							
				140				+							
Sodium disulphite	Na ₂ S ₂ O ₅		all, aqueous	20	O	+	+		+						
				40		O	+	+							
				60											
				80											
				100											
				120											
				140											
Sodium dithionite	see hyposulphite		up to 10%, aqueous												
Sodium fluoride	NaF		cold saturated, aqueous	20	+	+	+	+	+						
				40		+	+	+	+						
				60		+	+	+	+						
				80		+	+	+	+						
				100											
				120											
				140											
Sodium hypochlorite (SpRB)	NaOCl		12.5% active chlorine, aqueous	20	+				O	O		+			+
				40		+						+			
				60		O									
Sodium iodide	NaI		all, aqueous	20	+	+	+	+	+			+	+	+	+
				40		+	+	+	+			+	+	+	+
				60		O						+	+	+	+
				80			+					O	+	+	O
				100									+	+	
				120											
				140											
Sodium nitrate	NaNO ₃		cold saturated, aqueous	20	+	+	+	+	+			+	+	+	+
				40		+	+	+	+			+	+	+	+
				60		O	+	+	+			+	+	+	+
				80								+	+	+	+
				100								+	+	+	+
				120								+	+	+	+
				140								+	+	+	+
Sodium nitrite	NaNO ₂		cold saturated, aqueous	20	+	+	+	+	+			+	+	+	+
				40		+	+	+	+			+	+	+	+
				60		+	+	+	+			+	+	+	+
				80		+	+	+	+			+	+	+	+
				100		+	+	+	+			+	+	+	+
				120								+	+	+	+
				140								+	+	+	+

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Aggressive Media				Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEEF)	EPDM	FPM	NBR	CR	CSM	
					Sodium oxalate	$\text{Na}_2\text{C}_2\text{O}_4$		cold saturated, aqueous	20 40 60 80 100 120 140	+ + O + + +	+ + + +	+ +	+ +	+ +		
Sodium perbarate	$\text{NaBO}_3 \cdot 4\text{H}_2\text{O}$		saturated	20 40 60 80 100 120 140	+ + + +	+ + +	+ +	+ +	+ +	+ +	+ +					
Sodium perchlorate	NaClO_4		saturated	20 40 60 80 100 120 140	+ + + +	+ +	+ +	+ +			+ +	+ +				
Sodium persulphate (SpRB)	$\text{Na}_2\text{S}_2\text{O}_8$		cold saturated, aqueous	20 40 60 80 100 120 140	+ + O +	+ +	+ +	+ +	+ +	+ +	+ +	+ +	- +	+ +	+ +	+ +
Sodium phosphate	Na_3PO_4		cold saturated, aqueous	20 40 60 80 100 120 140	+ + O +	+ +	+ +	+ +	+ +	+ +	+ +	+ +	+ +	+ +	+ +	+ +
Sodium silicate	Na_2SiO_3		all, aqueous	20 40 60 80 100 120 140	+ + O +	+ +	+ +	+ +	+ +	+ +	+ +	+ +	+ +	+ +	+ +	+ +
Sodium Sulfide	Natriumsulfid															
Sodium sulphate	$\text{Na}_2\text{SO}_4, \text{NaHSO}_4$		cold saturated, aqueous	20 40 60 80 100 120 140	+ + O +	+ +	+ +	+ +	+ +	+ +	O O	+ +	+ +	+ +	+ +	+ +
Sodium sulphide	Na_2S		cold saturated, aqueous	20 40 60 80 100 120 140	+ + O +	+ +	+ +	+ +	+ +	O O	+ +	+ +	+ +	- +	+ +	+ +

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Aggressive Media		Chemical Resistance														
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (S/GEFF)	EPDM	FKM	NBR	CR	CSM	
					Sodium sulphite	Na ₂ SO ₃		cold saturated, aqueous	20 40 60 80 100 120 140	+ O + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +
Sodium thiosulphate	Na ₂ S ₂ O ₃		cold saturated, aqueous	20 40 60 80 100 120 140	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +
Sodiumchloride	NaCl		each, aqueous	20 40 60 80 100 120 140	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +
Sodiumcyanide	NaCN			20 40 60 80 100 120 140	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +
Sodiumdichromate	Na ₂ Cr ₂ O ₇			20 40 60 80 100 120 140	O + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +
Sodiumhydrogen-carbonate	NaHCO ₃			20 40 60 80 100 120 140	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +
Sodiumhydrogensulfate	NaHSO ₄			20 40 60 80 100 120 140	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +	+ + + +
Spindle oil				20 40 60 80 100 120 140	O O -	O O -	O O -	O O -	O O -	O O -	O O -	O O -	O O -	O O -	O O -	O O -

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Aggressive Media				Chemical Resistance														
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (S/GEF)	EPDM	FPM	NBR	CR	CSM			
Spinning bath acids containing carbon disulphide (SpRBI)			100 mg CS ₂ /l	20	+				+	+								
				40	+													
				60	+													
				80	+													
				100	+													
Spinning bath acids containing carbon disulphide (SpRBI)			200 mg CS ₂ /l	20	O			+	+	+								
				40	O													
				60	O													
				80	O													
				100	O													
Spinning bath acids containing carbon disulphide (SpRBI)			700 mg CS ₂ /l	20	-			+	+	+								
				40	-													
				60	-													
				80	-													
				100	-													
Stannous chloride	see Tin II chloride		cold saturated, aqueous															
Stannous chloride - Tin IV chloride	SnCl ₄		cold saturated, aqueous	20				+	+	+								
				40				+	+	+								
				60				+	+	+								
				80				+	+	+								
				100				+	+	+								
				120														
				140														
Starch solution	C ₆ H ₁₀ O ₅ n		oil, aqueous	20	+	+	+	+	+	+		+	+	+	+			
				40	+	+	+	+	+	+		+	+	+	+			
				60	+	+	+	+	+	+		+	+	+	+			
				80	+	+	+	+	+	+		+	+	+	+			
				100	+	+	+	+	+	+		+	+	+	+			
Starch syrup			usual commercial	20	+	+	+	+	+	+		+	+	+	+			
				40	+	+	+	+	+	+		+	+	+	+			
				60	+	+	+	+	+	+		+	+	+	+			
				80	+	+	+	+	+	+		+	+	+	+			
				100	+	+	+	+	+	+		+	+	+	+			
Stearic acid (SpRBI)	C ₁₇ H ₃₅ COOH	Fp. 69	technically pure	20	+	O	+	O	+	+		+	+	+	+			
				40	+	+	+	+	+	+		+	+	+	+			
				60	+	+	+	+	+	+		+	+	+	+			
				80	+	+	+	+	+	+		+	+	+	+			
				100	+	+	+	+	+	+		+	+	+	+			
Styral				20	-	-	-		+			+						
				40	-	-	-											
				60	-	-	-											
				80	-	-	-											
				100	-	-	-											

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEEI)	EPDM	FPM	NBR	CR	CSM
					Succinic acid	HOOC-CH ₂ -CH ₂ -COOH	Fp*, 185	aqueous, all	20	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Sugar syrup			usual commercial	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	O	+	O	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+
				120	+	+	+	+	+	+	+	+	+	+	+
				140	+	+	+	+	+	+	+	+	+	+	+
Sulfur	S	Fp*, 119	technically pure	20	O	O	-	+	+	+	+	+	-	+	+
				40	-	-	-	+	+	+	+	+	-	+	+
				60	-	-	-	+	+	+	+	+	-	+	+
				80	-	-	-	+	+	+	+	+	-	+	+
				100	-	-	-	+	+	+	+	+	-	+	+
				120	-	-	-	+	+	+	+	+	-	+	+
				140	-	-	-	+	+	+	+	+	-	+	+
Sulfur dioxide	SO ₂	-10	technically pure, anhydrous	20	+	+	-	+	+	O	O	+	-	-	O
				40	+	+	-	+	+	-	O	+	-	-	O
				60	+	+	-	+	+	-	-	O	-	-	O
				80	+	+	-	+	+	-	-	-	-	-	O
				100	+	+	-	+	+	-	-	-	-	-	O
				120	+	+	-	+	+	-	-	-	-	-	O
				140	+	+	-	+	+	-	-	-	-	-	O
Sulfur dioxide	SO ₂		technically pure, moist	20	-	-	-	-	-	-	-	O	-	-	O
				40	-	-	-	-	-	-	-	-	-	-	O
				60	-	-	-	-	-	-	-	-	-	-	O
				80	-	-	-	-	-	-	-	-	-	-	O
				100	-	-	-	-	-	-	-	-	-	-	O
				120	-	-	-	-	-	-	-	-	-	-	O
				140	-	-	-	-	-	-	-	-	-	-	O
Sulfur dioxide	SO ₂		all, moist	20	+	+	-	+	+	+	+	+	-	-	O
				40	+	+	-	+	+	+	+	+	-	-	O
				60	O	+	-	+	+	+	+	+	-	-	O
				80	+	+	-	+	+	+	+	+	-	-	O
				100	+	+	-	+	+	+	+	+	-	-	O
				120	+	+	-	+	+	+	+	+	-	-	O
				140	+	+	-	+	+	+	+	+	-	-	O
Sulfur trioxide	SO ₃			20	-	-	-	-	-	-	-	-	-	-	-
				40	-	-	-	-	-	-	-	-	-	-	-
				60	-	-	-	-	-	-	-	-	-	-	-
				80	-	-	-	-	-	-	-	-	-	-	-
				100	-	-	-	-	-	-	-	-	-	-	-
				120	-	-	-	-	-	-	-	-	-	-	-
				140	-	-	-	-	-	-	-	-	-	-	-
Sulfuric acid saturated by Chlorine	H ₂ SO ₄ +Cl ₂		60%	20						+					
				40						+					
				60						+					
				80						+					
				100						+					
				120						+					
				140						+					

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Aggressive Media				Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (S/G/EEI)	EPDM	FFM	NBR	CR	CSM	
Sulfuric acid (see note 2.3.1 on jointing)	H ₂ SO ₄	120	up to 40%, aqueous	20	+	+	+	+	+	+	+	+	+	+	+	
				40	+	+	+	+	+	+	+	+	+	+	+	
				60	O	+	+	+	+	+	+	+	+	+	+	+
				80	+	+	+	+	+	+	+	+	+	+	+	+
				100	+	+	+	+	+	+	+	+	+	+	+	+
Sulfuric acid (see note 2.3.1 on jointing) (SpRB)	H ₂ SO ₄	140	up to 60%, aqueous	20	+	+	-	+	+	+	+	+	+	+	+	
				40	+	+	+	+	+	+	+	+	+	+	+	
				60	+	+	+	+	+	+	+	+	+	+	+	
				80	+	+	+	+	+	+	+	+	+	+	+	
				100	+	+	+	+	+	+	+	+	+	+	+	
Sulfuric acid (see note 2.3.1 on jointing) (SpRB)	H ₂ SO ₄	195	up to 80%, aqueous	20	+	+	-	+	+	+	+	+	+	+	+	
				40	+	+	+	+	+	+	+	+	+	+		
				60	+	+	+	+	+	+	+	+	+	+		
				80	+	+	+	+	+	+	+	+	+	+		
				100	+	+	+	+	+	+	+	+	+	+		
Sulfuric acid (see note 2.3.1 on jointing) (SpRB)	H ₂ SO ₄	250	90%, aqueous	20	+	+	-	+	+	+	+	+	+	+	+	
				40	+	+	+	+	+	+	+	+	+	+		
				60	+	+	+	+	+	+	+	+	+	+		
				80	+	+	+	+	+	+	+	+	+	+		
				100	+	+	+	+	+	+	+	+	+	+		
Sulfuric acid (see note 2.3.1 on jointing) (SpRB)	H ₂ SO ₄	250	96%, aqueous	20	+	+	-	-	-	+	+	+	+	+	+	
				40	+	+	+	+	+	+	+	+	+	+		
				60	O	+	+	+	+	+	+	+	+	+		
				80	+	+	+	+	+	+	+	+	+	+		
				100	+	+	+	+	+	+	+	+	+	+		
Sulfuric acid (see note 2.3.1 on jointing) (SpRB)	H ₂ SO ₄	340	98%	20	+	+	-	-	-	+	+	+	+	+	+	
				40	O	+	+	+	+	+	+	+	+	+		
				60	+	+	+	+	+	+	+	+	+	+		
				80	+	+	+	+	+	+	+	+	+	+		
				100	+	+	+	+	+	+	+	+	+	+		
Sulfurous acid	H ₂ SO ₃		saturated, aqueous	20	+	+	+	+	+	+	+	+	+	+	+	
				40	+	+	+	+	+	+	+	+	+	+		
				60	O	+	+	+	+	+	+	+	+	+		
				80	+	+	+	+	+	+	+	+	+	+		
				100	+	+	+	+	+	+	+	+	+	+		

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SIGGFI)	EPDM	FRM	NBR	CR	CSM
Sulfuryl chloride	SO ₂ Cl ₂	69	technically pure	20	-	-	-	-	-	○					
				40											
				60											
				80											
				100											
Surfactants (SpRB)			up to 5%, aqueous	20	○	○	-	+	-	○		+	+	+	+
				40	○	○									
				60	○	○					○	○			
				80	○	○					○	○			
				100	○	○					○	○			
Surfactants (ESC)				20	○	○	○	○	○	○	○	○	○	○	○
				40											
				60											
				80											
				100											
Tallow (SpRB)			technically pure	20	+	-	-	+	+	+	+	+	+	+	+
				40	+										
				60	+										
				80	+										
				100	+										
Tannic acid (SpRB)			all, aqueous	20	+	+	+	+	+	+		+	+	+	+
				40	+	+	+	+	+	+					
				60	+	+	+	+	+	+					
				80	+	+	+	+	+	+					
				100	+	+	+	+	+	+					
Tanning extracts from plants (SpRB)			usual commercial	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+					
				60	+	+	+	+	+	+					
				80	+	+	+	+	+	+					
				100	+	+	+	+	+	+					
Tartaric acid				20											
				40											
				60											
				80											
				100											
Tartaric acid	HO ₂ C-CHOHI-CHOHI-CO ₂ H		all, aqueous	20	+	+	+	+	+	+	+	+	+	+	
				40	+	+	+	+	+	+	+	+	+	+	
				60	+	+	+	+	+	+	+	+	+	+	
				80	○										
				100											

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEEF)	EPDM	FPVM	NBR	CR	CSM
					Tartaric acid up to 10%				20 40 60 80 100 120 140						+++
Tetrachlorethylene				20 40 60 80 100 120 140	-	-	-	-	-	+	-	+			
Tetrachloroethane	<chem>Cl2CH-CHCl2</chem>	146	technically pure	20 40 60 80 100 120 140	-	-	-	O	O	+	-	O	-	-	-
Tetrachloroethylene	see Perchloroethylene	121													
Tetraethylene lead (SpRB)	<chem>(C2H5)4Pb</chem>		technically pure	20 40 60 80 100 120 140	+	+	-	+	+	+	+	+	+	+	+
Tetrahydrofuran	<chem>C4H8O</chem>	66	technically pure	20 40 60 80 100 120 140	-	-	-	O	O	-	O	-	-	-	-
Tetrahydronaphthalene	Teralin	207	technically pure												
Thionyl chloride	<chem>SOCl2</chem>	79	technically pure	20 40 60 80 100 120 140	-	-	-	-	-	-	O	+	-	-	-
Tin (IV) -chloride				20 40 60 80 100 120 140	+	+					+	+	+	+	+

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (S/G/EF)	EPDM	FRM	NBR	CR	CSM
					Tin(III)-chloride	SnCl ₂			20 40 60 80 100 120 140			+	+	+	
Toluene	C ₆ H ₅ -CH ₃	111	technically pure	20 40 60 80 100 120 140	-	-	O	O	+		-	+	-	-	
Triacetin (Glycerintriacetate)	C ₉ H ₁₄ O ₆			20 40 60 80 100 120 140	-	-	+	+	+		+				
Tributylphosphate	(C ₄ H ₉) ₃ PO ₄	289	technically pure	20 40 60 80 100 120 140	-	-	+	+	+		+	-	-	-	
Trichloroacetic acid	Cl ₃ C-COOH	196	technically pure	20 40 60 80 100 120 140	O	-	+	+	O		O	-	-	-	
Trichloroacetic acid	Cl ₃ C-COOH		50%, aqueous	20 40 60 80 100 120 140	+	-	+	+	+		O	-	-	-	
Trichloroethane	Methylchloroform	74	technically pure												
Trichloroethylene	Cl ₂ C=CHCl	87	technically pure	20 40 60 80 100 120 140	-	-	-	O	+		-	+	-	-	
Trichloromethane	Chloroform	61													

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Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEEI)	EPDM	FFM	NBR	CR	CSM
					Tricresyl phosphate (SpRB)	$H_3C-C_6H_5-O_3PO_4$		technically pure	20	-	-	-	+	+	
				40				+	+						
				60				+	+						
				80				+	+						
				100				+	+						
				120				+	+						
				140				+	+						
Triethanolamine (SpRB)	$NI CH_2-CH_2-OH_3$	Fp. *21	technically pure	20	O	-	-	+	+		O		O		
				40				+	+						
				60				+	+						
				80				+	+						
				100				+	+						
				120				+	+						
				140				+	+						
Triethylamine (SpRB)	$NI CH_2-CH_3_3$	89	technically pure	20	-	-	-	+	+	O					
				40				+	+						
				60				+	+						
				80				+	+						
				100				+	+						
				120				+	+						
				140				+	+						
Trifluoro acetic acid (SpRB)	$F_3C-COOH$		up to 50%	20	-	-	-	+	+	+	O				
				40				+	+	+					
				60				+	+	+					
				80				+	+	+					
				100				+	+	+					
				120				+	+	+					
				140				+	+	+					
Triethyl phosphate (SpRB)	$(C_2H_5)_3 PO_4$		technically pure	20	-	-	-	+	+	O	+		O		
				40				+	+						
				60				+	+						
				80				+	+						
				100				+	+						
				120				+	+						
				140				+	+						
Turpentine oil (SpRB)			technically pure	20	+	-	-	O	O	+			O		
				40	O								+		
				60									+		
				80									+		
				100									+		
				120									+		
				140									+		
Urea (SpRB)	$H_2N-CO-NH_2$	Fp. *133	up to 30%, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	O	+	+	+	+	+	+	+	+	+	+
				80				+	+	+	+	+	+	+	+
				100				+	+	+	+	+	+	+	+
				120				+	+	+	+	+	+	+	+
				140				+	+	+	+	+	+	+	+
Urine				20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	O	+	+	+	+	+	+	+	+	+	+
				80				+	+	+	+	+	+	+	+
				100				+	+	+	+	+	+	+	+
				120				+	+	+	+	+	+	+	+
				140				+	+	+	+	+	+	+	+

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Aggressive Media				Chemical Resistance													
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGFEI)	EPDM	FPM	NBR	CR	CSM		
Vaseline			technically pure	20	○	○	-	+	○	+	-	+	+	+	-		
				40	-	-	-	-	-	-	-	-	-	-	-		
				60	-	-	-	-	-	-	-	-	-	-	-		
				80	-	-	-	-	-	-	-	-	-	-	-		
				100	-	-	-	-	-	-	-	-	-	-	-		
Vegetable oils			technically pure	20	○	-	-	+	+	+	-	+	+	+	○		
				40	-	-	-	-	-	-	-	-	-	-			
				60	-	-	-	-	-	-	-	-	-	-			
				80	-	-	-	-	-	-	-	-	-	-			
				100	-	-	-	-	-	-	-	-	-	-			
Vegetable oils and fats (SprB)			technically pure	20	○	○	-	○	+	+	-	+	+	+	○		
				40	-	-	-	-	-	-	-	-	-	-			
				60	-	-	-	-	-	-	-	-	-	-			
				80	-	-	-	-	-	-	-	-	-	-			
				100	-	-	-	-	-	-	-	-	-	-			
Vinegar	see wine vinegar																
Vinyl acetate	$CH_2=CHOCOCH_3$	73	technically pure	20	-	-	-	+	+	-	+	-	-	-			
				40	-	-	-	+	+	-	-	-	-				
				60	-	-	-	+	○	-	-	-	-				
				80	-	-	-	+	○	-	-	-	-				
				100	-	-	-	+	○	-	-	-	-				
Vinyl chloride	$CH_2=CHCl$	-14	technically pure	20	-	-	-	-	-	+	-	+	-	-			
				40	-	-	-	-	-	+	-	-	-				
				60	-	-	-	-	-	+	-	-	-				
				80	-	-	-	-	-	+	-	-	-				
				100	-	-	-	-	-	+	-	-	-				
Viscose spinning solution			technically pure	20	+	-	-	+	+	+	+	+	-	○	+		
				40	+	-	-	+	+	+	+	+	+	-	○	+	
				60	+	-	-	+	+	+	+	+	+	+	-	○	+
				80	+	-	-	+	+	+	+	+	+	+	-	○	+
				100	+	-	-	+	+	+	+	+	+	+	-	○	+
Waste gases containing - Alkaline			technically pure	20	+	+	+	+	+	○	+	+	+	+	+		
				40	+	+	+	+	+	○	+	+	+	+	+		
				60	+	+	+	+	+	○	+	+	+	+	+		
				80	+	+	+	+	+	○	+	+	+	+	+		
				100	+	+	+	+	+	○	+	+	+	+	+		
Waste gases containing - Carbon oxides			all	20	+	+	+	+	+	+	+	+	+	+	+		
				40	+	+	+	+	+	+	+	+	+	+	+		
				60	+	+	+	+	+	+	+	+	+	+	+		
				80	+	+	+	+	+	+	+	+	+	+	+		
				100	+	+	+	+	+	+	+	+	+	+	+		

(Courtesy George Fischer Engineering Handbook)

Aggressive Media				Chemical Resistance													
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (S/G/EF)	EPDM	FFM	NBR	CR	CSM		
Waste gases containing - Hydrochloric acid			all	20	+	+		+	+	+							
				40	+	+		+	+	+							
				60	+	+		+	+	+	+						
				80		+								+			
				100										+			
				120											+		
				140												+	
Waste gases containing - Hydrogen fluoride (SprB)			traces	20	+	+		+	+	+							
				40	+	+		+	+	+							
				60	+	+		+	+	+							
				80		+								+			
				100											+		
				120												+	
				140													+
Waste gases containing - Nitrous gases			traces	20	+	+		+	+	+							
				40	+	+		+	+	+							
				60	+	+		+	+	+							
				80		+								+			
				100											+		
				120												+	
				140													+
Waste gases containing - Sulphur dioxide			traces	20	+	+		+	+	+							
				40	+	+		+	+	+							
				60	+	+		+	+	+							
				80		+								+			
				100											+		
				120												+	
				140													+
Waste gases containing - Sulphur trioxide (SprB)			traces	20	+	+		+	+	+							
				40	+	+		+	+	+							
				60	+	+		+	+	+							
				80		+								+			
				100											+		
				120												+	
				140													+
Waste gases containing - Sulphuric acid			all	20	+	+		+	+	+							
				40	+	+		+	+	+							
				60	+	+		+	+	+							
				80		+								+			
				100											+		
				120												+	
				140													+
Water - distilled - deionised	H ₂ O	100		20	+	+	+	+	+	+							
				40	+	+	+	+	+	+							
				60	+	+	+	+	+	+							
				80		+								+			
				100											+		
				120												+	
				140													+
Water, condensed				20	+	+	+	+	+	+							
				40	+	+	+	+	+	+							
				60	○	+	+	+	+	+							
				80		+								+			
				100											+		
				120												+	
				140													+

(Courtesy George Fischer Engineering Handbook)

Aggressive Media				Chemical Resistance																
Medium	Formula	Boiling point °C	Concentration	Temperature °C																
				PVC	CPVC	ABS	PE	PP-H	PVDF (SYGFEI)	EPDM	FPM	NBR	CR	CSM						
Water, drinking, chlorinated				20	+	+														
				40	+	+	+													
				60	+	+	+													
				80	+	+	+													
				100	+	+	+													
				120	+	+	+													
				140	+	+	+													
Water, waste water without organic solvent and surfactants				20	+	+														
				40	+	+	+													
				60	+	+	+													
				80	+	+	+													
				100	+	+	+													
				120	+	+	+													
				140	+	+	+													
Wax alcohol (SpRB)	C ₃₁ H ₆₃ OH		technically pure	20	+	+	0	-												
				40	+	+	0	-												
				60	+	+	0	-												
				80	+	+	0	-												
				100	+	+	0	-												
				120	+	+	0	-												
				140	+	+	0	-												
Wine vinegar (SpRB)			usual commercial	20	+	+	0	0												
				40	+	+	0	0												
				60	+	+	0	0												
				80	+	+	0	0												
				100	+	+	0	0												
				120	+	+	0	0												
				140	+	+	0	0												
Wines, red and white			usual commercial	20	+	0	+	+	+	+	+	+	+	+	+	+	+			
				40	+	0	+	+	+	+	+	+	+	+	+	+	+			
				60	+	0	+	+	+	+	+	+	+	+	+	+	+			
				80	+	0	+	+	+	+	+	+	+	+	+	+	+			
				100	+	0	+	+	+	+	+	+	+	+	+	+	+			
				120	+	0	+	+	+	+	+	+	+	+	+	+	+			
				140	+	0	+	+	+	+	+	+	+	+	+	+	+			
Xylene	C ₈ H ₁₀ (CH ₃) ₂	138? 144	technically pure	20	-	-	-	-	-	+	+	-	-	-	-	-	-			
				40	-	-	-	-	-	+	+	-	-	-	-	-	-			
				60	-	-	-	-	-	+	+	-	-	-	-	-	-			
				80	-	-	-	-	-	+	+	-	-	-	-	-	-			
				100	-	-	-	-	-	+	+	-	-	-	-	-	-			
				120	-	-	-	-	-	+	+	-	-	-	-	-	-			
				140	-	-	-	-	-	+	+	-	-	-	-	-	-			
yeasts			all, aqueous	20	+	+	+	+	+	+	+	+	+	+	+	+				
				40	+	+	+	+	+	+	+	+	+	+	+	+				
				60	+	+	+	+	+	+	+	+	+	+	+	+				
				80	+	+	+	+	+	+	+	+	+	+	+	+				
				100	+	+	+	+	+	+	+	+	+	+	+	+				
				120	+	+	+	+	+	+	+	+	+	+	+	+				
				140	+	+	+	+	+	+	+	+	+	+	+	+				
Zinc salts	ZnCl ₂ , ZnCO ₃ , Zn(NO ₃) ₂ , ZnSO ₄		all, aqueous	20	+	+	+	+	+	+	+	+	+	+	+	+				
				40	+	+	+	+	+	+	+	+	+	+	+	+				
				60	+	+	+	+	+	+	+	+	+	+	+	+				
				80	+	+	+	+	+	+	+	+	+	+	+	+				
				100	+	+	+	+	+	+	+	+	+	+	+	+				
				120	+	+	+	+	+	+	+	+	+	+	+	+				
				140	+	+	+	+	+	+	+	+	+	+	+	+				

(Courtesy George Fischer Engineering Handbook)

Aggressive Media				Chemical Resistance														
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (S/G/EF)	EPDM	FM	NBR	CR	CSM			
Zinccarbonate				20	+	+	+	+	+	+	+	+	+					
				40	+	+	+	+	+	+	+	+	+					
				60	+	+	+	+	+	+	+	+	+	+				
				80	+	+	+	+	+	+	+	+	+	+	+			
				100	+	+	+	+	+	+	+	+	+	+	+			
Zincchloride			saturated	120	+	+	+	+	+	+	+	+	+					
				140	+	+	+	+	+	+	+	+	+					
				20	+	+	+	+	+	+	+	+	+	+				
				40	+	+	+	+	+	+	+	+	+	+	+			
				60	+	+	+	+	+	+	+	+	+	+	+			
Zincnitrate	Zn(NO ₃) ₂		saturated	80	+	+	+	+	+	+	+	+	+					
				100	+	+	+	+	+	+	+	+	+					
				120	+	+	+	+	+	+	+	+	+	+				
				140	+	+	+	+	+	+	+	+	+	+	+			
				20	+	+	+	+	+	+	+	+	+	+	+			
Zincoxide			Suspension	40														
				60														
				80														
				100														
				120														
Zincphosphate			saturated	20	+	+	+	+	+	+	+	+	+					
				40	+	+	+	+	+	+	+	+	+					
				60	+	+	+	+	+	+	+	+	+	+				
				80	+	+	+	+	+	+	+	+	+	+	+			
				100	+	+	+	+	+	+	+	+	+	+	+			
Zincstearate			Suspension	20	-	-	-	+	+	+	+	+	+	+	+			
				40				+	+	+	+	+	+	+	+	+		
				60				+	+	+	+	+	+	+	+	+		
				80				+	+	+	+	+	+	+	+	+		
				100				+	+	+	+	+	+	+	+	+		
Zincsulfate	ZnSO ₄			20	+	+	+	+	+	+	+	+	+					
				40	+	+	+	+	+	+	+	+	+	+				
				60	+	+	+	+	+	+	+	+	+	+	+			
				80	+	+	+	+	+	+	+	+	+	+	+	+		
				100	+	+	+	+	+	+	+	+	+	+	+	+		
1-Chloropentan	C ₅ H ₁₁ Cl			20	-	-	-											
				40														
				60														
				80														
				100														

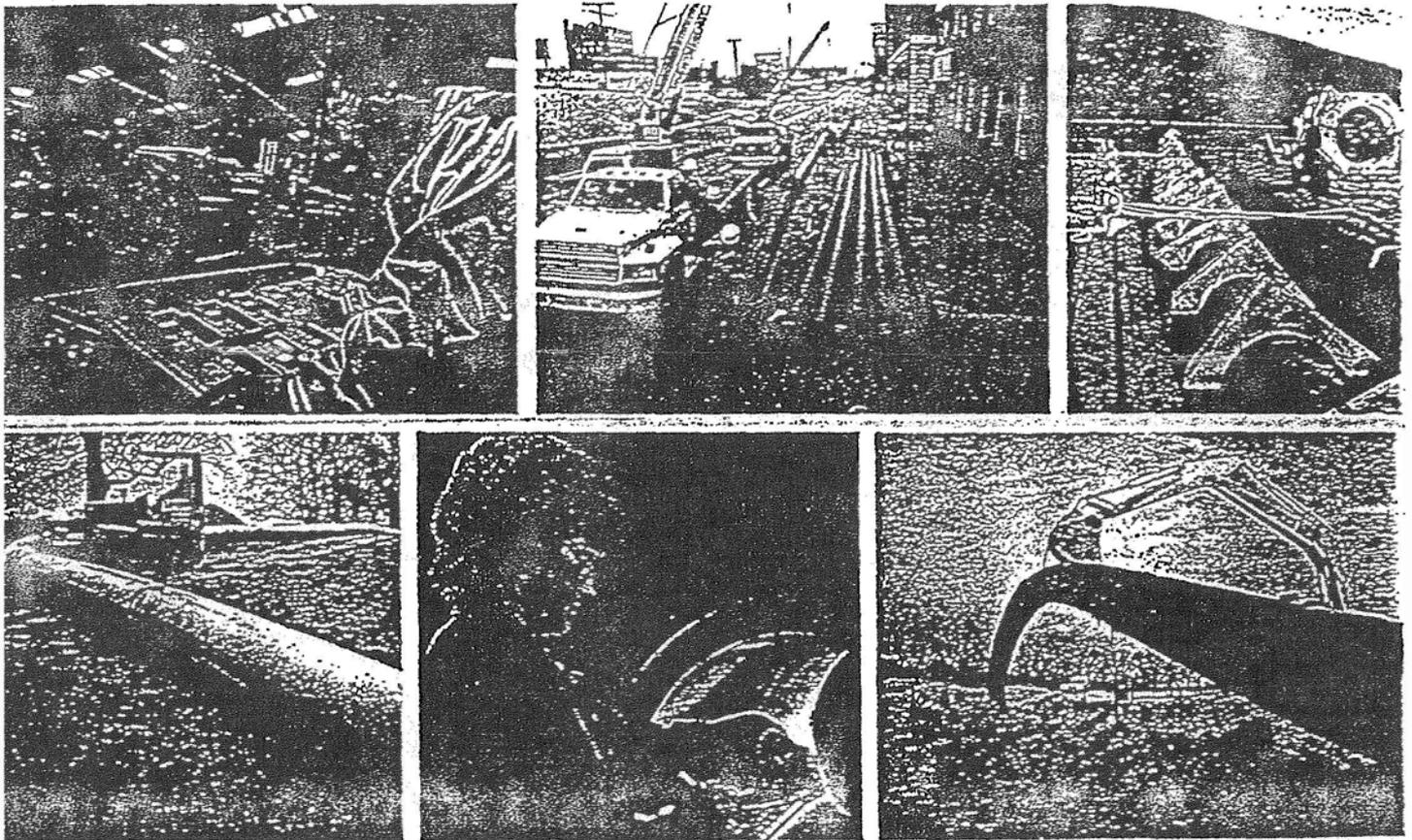
(Courtesy George Fischer Engineering Handbook)

Aggressive Media				Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (S/G/EF)	EPDM	FPM	NBR	CR	CSM
1,1,2-Trifluoro, 1,2,2-Trichloroethane (Freon 113) (SpRB)	$\text{FC}_1\text{C}-\text{CCl}_2$	47	technically pure	20 40 60 80 100 120 140	+	+	-			+		+	+	+	+

(Courtesy George Fischer Engineering Handbook)

DRISCOPIPE

Engineering Characteristics



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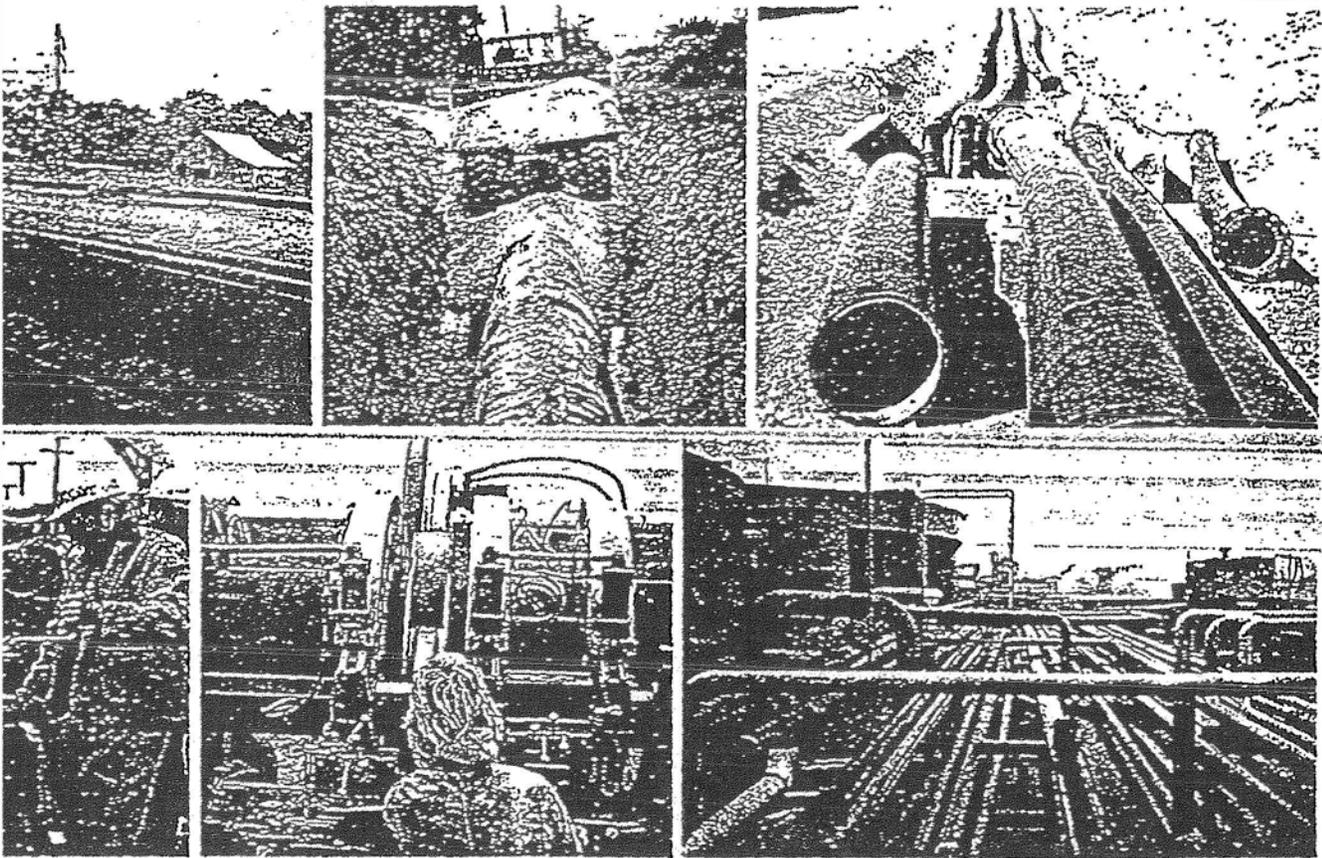
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Photographs shown are typical Dnscope installations.



Driscopipe[®] Engineering Characteristics

Introduction

Driscopipe high density polyethylene piping systems offer the modern engineer the opportunity to take advantage of the unusual characteristics of these materials and use them to solve many old problems and to design systems for applications where traditional materials are either unsuitable or too expensive. When compared to the older traditional piping materials, Driscopipe polyethylene piping systems offer a new freedom in environmental design, extended service life, significant savings for installation labor and equipment costs, and reduced maintenance for pipeline systems where operating conditions are within the pressure and temperature capabilities of the material.

This brochure outlines the Engineering Characteristics of Driscopipe high density polyethylene pipe and fittings and points out many of the advantages and benefits to be realized through the use of these systems. The discussion is directed primarily toward the large diameter (3" through 54") Driscopipe 8600 and Driscopipe 1000 Industrial and Municipal product lines. However, these engineering characteristics are also typical of other Driscopipe polyethylene product lines.

Physical Properties

Driscopipe 8600 is manufactured from Marlex M-8000 very high molecular weight high density PE 3408 resin. Pipe and fittings made from Marlex M-8000 are extremely tough and durable, and possess exceptional long term strength. Marlex M-8000 is a proprietary product and is extruded only by Phillips Driscopipe, Inc.

Driscopipe 1000 is manufactured from Marlex TR-480, a PE 3408 polyethylene pipe resin in a molecular weight range which permits the pipe to be extruded by conventional methods. In this respect, Driscopipe 1000 is comparable to other extra high molecular weight, high density, PE 3408 polyethylene pipes commercially available in North America.

Sheets detailing typical physical properties for Driscopipe 1000 and Driscopipe 8600 are available upon request.

Long Term Hydrostatic Strength

One of the outstanding engineering characteristics of Driscopipe high density polyethylene pipe is its long term hydrostatic strength under various thermal and environmental conditions. Life expectancy is conservatively estimated to be in excess of 50 years using the standard design basis. This strength is determined by standardized methods and procedures which the plastic pipe industry has used for many years to evaluate the long term strength of all types of plastic pipe.

Pipe hoop stress versus time to failure plots of long term hydrostatic pressure data for thermoplastic pipe have been studied and analyzed for many years. The mathematical equations used to evaluate the test data and extrapolate values to longer periods of time were chosen after careful evaluation of more than 1,000 sets of long term test data representing more than 400 plastic pipe compounds. Continued testing on new compounds and extended testing of older compounds have proven the validity of these test methods. Actual data from more than 11½ years (100,000 hours) of continuous testing shows the industry methods to be slightly conservative in that actual values are slightly higher than those calculated by the industry-accepted ASTM method.

The reduction in strength which occurs with time, as indicated by the stress-life curves, does not represent a strength degradation of the material but is more in the nature of a relaxation effect. Plastic pipe samples which have been on test for periods up to 70,000 hours have been de-pressurized and checked for permanent reduction of strength by using the quick-burst test. No loss has been found when compared to samples previously quick-burst from the same test lot.

All evidence confirms that the methods used to predict the long term strength of plastic pipe are sound methods. Through the years, these policies and procedures, used to develop recommended hydrostatic design strengths, have influenced manufacturers to research and develop improved piping products such as Driscopipe 8600 and Driscopipe 1000.

Typical calculated long term strengths are shown below:

Long Term Strength @ 73.4°F(23°C)

Time	Hoop Stress, psi
100,000 hrs. (11.43 yrs.)	1635
438,000 hrs. (50 yrs.)	1604
500,000 hrs. (57 yrs.)	1601
1,000,000 hrs. (114 yrs.)	1586

The 114-year long term strength has been included to show more about the nature of the method used by the industry to evaluate the long term strength of plastic pipe and to illustrate the very slow reduction in strength as time progresses.

Long term hoop stresses for design purposes are normally selected at a level which is much lower than the long term strength of the materials. This ensures that the pipe is operating in a hoop stress range where creep (relaxation) of the materials is nil and assures service life in excess of 50 years. Design stress levels are discussed further in the next section.

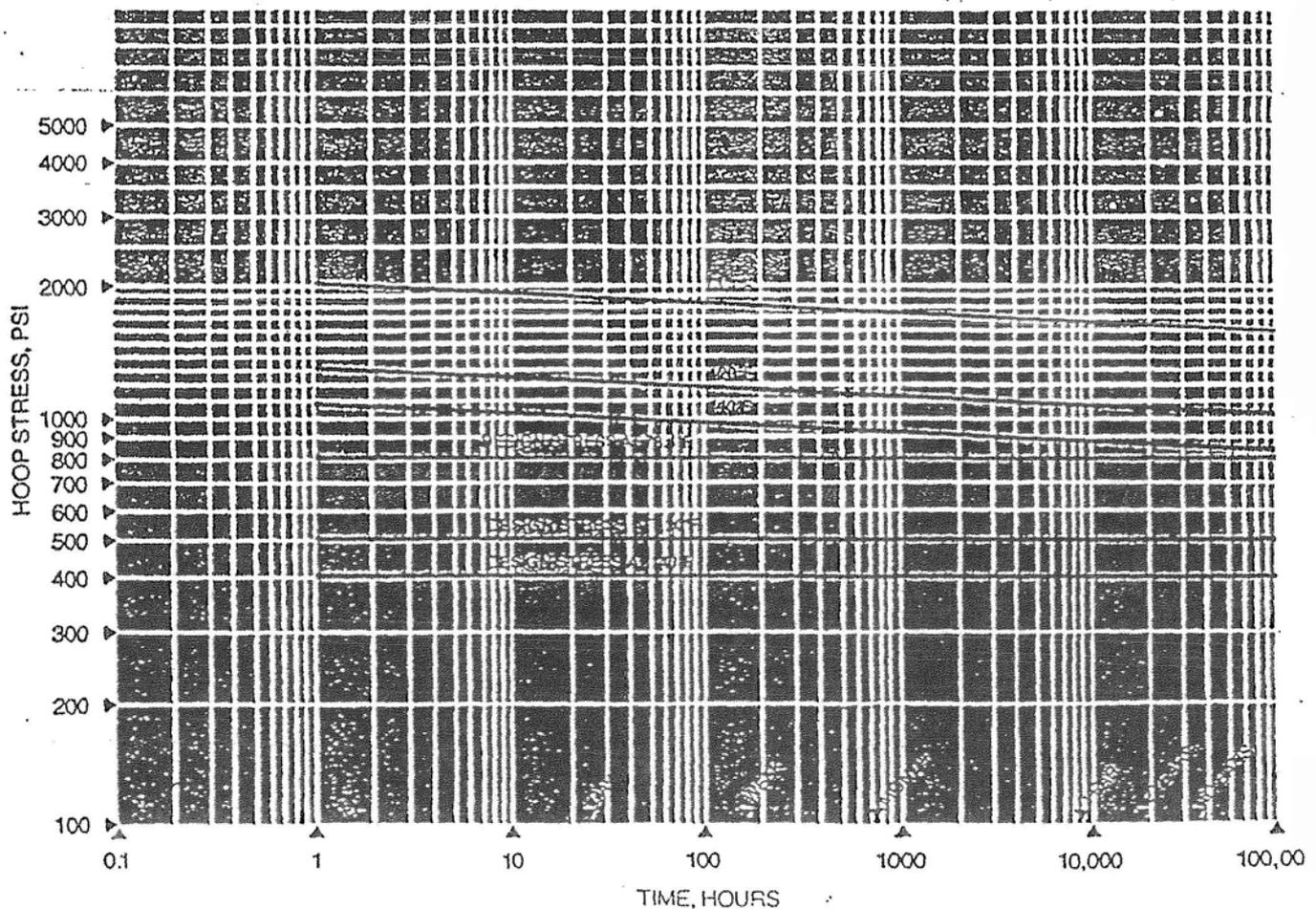
The long term hydrostatic tests are conducted by using ASTM standard test procedures which may be applied to all types of plastic pipe (ASTM D 1598 Test for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure). Stress-life tests are conducted by using numerous pipe samples which are filled with water (or other environmental fluids) and subjected to a controlled pressure at a controlled temperature.

Samples are held on test until they fail. The pressure, temperature and time-to-failure data from all samples are used to calculate and plot stress-life curves for the particular type pipe being tested (ASTM D 2837 Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials). This data is then used to predict the probable safe life of the pipe at various stress levels (working pressures) and various temperatures. Because it is not practical to test at all temperature levels, these tests are generally conducted at temperatures of 73.4°F and one or more higher temperatures such as 100°F, 120°F and 140°F.

These stress-life curves give a relationship of the expected life span of the pipe when subjected to various internal stress levels (working pressures) at various temperatures. By comparing stress-life curves, one can compare relative long term performance ability of different plastic pipes. Stress-life curves for Driscopipe 8600 and Driscopipe 1000 are shown in Figure 1.

Figure 1

Stress-Life of Driscopipe® 8600 and Driscopipe® 1000



These stress-life curves were obtained using water as test medium. However, years of laboratory testing and field experience have shown that these same curves may be used to design Driscopipe systems for natural gas, salt water, sewage and hundreds of other industrial and municipal fluids, mixtures and effluents. The long term strength of Driscopipe indicated by these curves must be de-rated in some environmental circumstances, such as in the presence of liquid hydrocarbons or abrasive fluids, although the pipe is very suitable for use in these environments. An outstanding engineering advantage of Driscopipe is its exceptionally long term service life in the presence of internal and external corrosive service conditions.

Design Pressure Ratings

Since plastic pipe was introduced in the late 50s, the safety factor for design of water systems at standard temperature has been 2 to 1. The 2:1 design factor which was officially adopted by the plastic pipe industry in 1963, was based on allowances for many sources of variation. The guiding principle has always been to make the selection on a conservative basis but not to be unreasonably conservative.

The sources of variation for which allowances are made include ... variation in test methods and procedures among laboratories ... variation among lots of the same compound ... variation of lots of pipe from the compound in different plants and from different extruders ... variation in compounds of the same general class ... variations in handling and installation techniques ... variation in operating pressures (water hammer and surge) ... a strength-time allowance to give service life well beyond 50 years ... and, finally, the great unknown. Each of the

factors was judged to reduce the 100,000 hour design strength by 5%-10% or 20% ... for a total of 100% ... or a design factor of 2:1. This is why polyethylene pipe, with a designated 100,000 hour strength of 1600 psi at 73.4°F, has a hydrostatic design strength of 800 psi hoop stress.

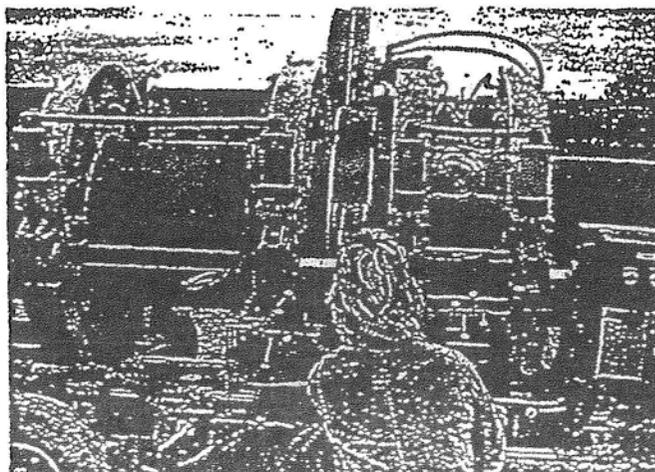
The design pressures for Driscopipe are determined by the following equation, adopted internationally by the industry for this purpose:

$$P = \frac{2S}{SDR-1} \times F \quad \text{or} \quad P = 2S \frac{t}{D-t} \times F$$

- Where: D = Specified Outside Diameter, Inches
P = Design Pressure, psi
S = Long Term Hydrostatic Strength, psi, at the design temperature
t = Minimum Wall Thickness, Inches
F = Service Design Factor
SDR = Standard Dimension Ratio of D/t

The traditional Service Design Factor for water at standard temperature (73.4°F) is one-half (.5). The Service Design Factor for oil or liquid hydrocarbons is 0.25 @ 73°F. The service design factor may be adjusted by the design engineer to reflect the particular conditions anticipated for the application. The temperature selected for design should consider both internal and external conditions. The design temperature should be based on the temperature of the pipe itself. For practical purposes, it is safer to design to the highest temperature.

The design service factor for water may also be used for solutions of inorganic salts, alkaline fluids, non-oxidizing acids, low concentrations of oxidizing acids and many other solutions. See the discussion on chemical resistance for more information.



All standard design pressure ratings shown in Driscopipe literature are based on water at 73.4°F temperature; ie, a safety factor of 2:1 based on the long term hydrostatic strength of the material. Driscopipe is applicable at pressures from 0 to 265 psi and temperatures from below 32°F up to 180°F. Standard Dimension Ratios (SDR) are available from SDR 32.5 to SDR 7.0

Flow Characteristics

Driscopipe polyethylene has excellent flow characteristics as compared to traditional materials. An extremely smooth interior surface offers low resistance to flow. It maintains these excellent flow properties throughout its service life in most applications due to the inherent chemical and abrasion resistance of the material. Because of smooth walls and the non-wetting characteristic of polyethylene, higher flow capacity and less friction loss is possible with Driscopipe. In many cases this higher flow capacity may permit the use of smaller pipe at a lower cost.

A "C" factor of 155 is commonly used in the Hazen-Williams formula for calculating flow in pressure applications. For gravity flow, an "n" factor of .009 is used in Manning's formula.

Experimental test data regarding pumping and pressure drop through Driscopipe is available upon request. This study compares the flow through 8" Driscopipe with and without internal fusion beads using clear water. It also includes flow data for some clay-water slurries and clay-water-sand slurries. Velocities up to 20 fps are studied. Data includes determination of Hazen-Williams "C" factor, Reynolds number, boundary drag, relative roughness, sand grain roughness and friction loss at various velocities.

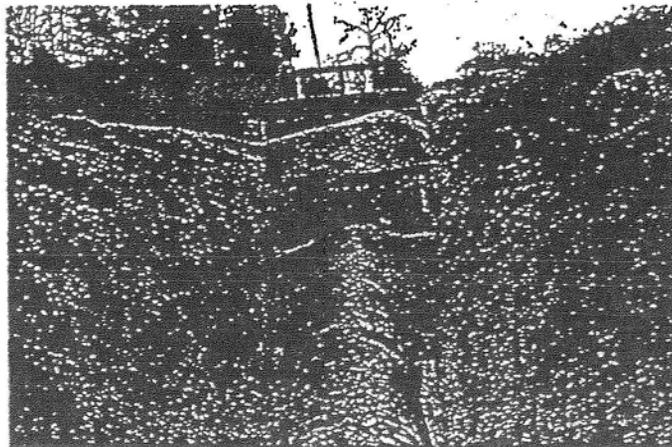
Lightweight – Flexible

The inherent light weight and flexibility of Driscopipe provides many cost saving benefits related to handling, storage, hauling, unloading, stringing, joining and installation. Because of its light weight, Driscopipe can be moved, handled and placed in the ditch with smaller and less expensive construction equipment. Usually, manpower requirements are also reduced.

Driscopipe weighs less than water; it has a specific gravity of .955-.957. Because it will float, it can be joined in long strings and easily towed into position on job sites where water is encountered. The combination of light weight and flexibility provides opportunity to fusion join the pipe in a convenient work area and pull it into position in difficult work areas where terrain or other obstacles present installation problems. The pipe can be joined above ground and rolled or lowered into the trench thus allowing the use of smaller trench widths and eliminating the necessity of placing men and equipment inside the trench. Such installation methods can dramatically reduce the time required for installation in many instances.

The flexibility of Driscopipe allows it to be curved over, under and around obstacles and to make elevation and directional changes, thus eliminating fittings and reducing installation costs. The pipe can be cold bent as it is installed to a radius of 20-40 times the pipe diameter. This flexibility and the butt fusion joining method make Driscopipe ideally suited for inserting it inside older piping systems to renew and renovate such systems at a much lower cost than would be possible otherwise.

Pipe flexibility and toughness also allow small diameter Driscopipe to be plowed-in or pulled-in with suitable equipment.



Toughness – “Ductile PE Pipe”

Overall “toughness” of Driscopipe is an important characteristic of the pipe which is derived from many of the chemical and physical properties of the material as well as the extrusion method. The pipe is ductile. It flexes, bends and absorbs impact loads over a wide temperature range of -180°F up to $+180^{\circ}\text{F}$. This inherent resiliency and flexibility allow the pipe to absorb surge pressures, vibration and stresses caused by soil movement. Driscopipe can be deformed without permanent damage and with no adverse effect on long term service life. It is flexible for contouring to installation conditions. The toughness of Driscopipe is one of its outstanding engineering characteristics leading to innovative piping design.

Even though “toughness” has become generally recognized by the industry as a highly desirable characteristic ... there is no standard test which can be used to directly compare the “toughness” among polyethylenes ... as well as among the different plastic materials which are considered suitable for piping.

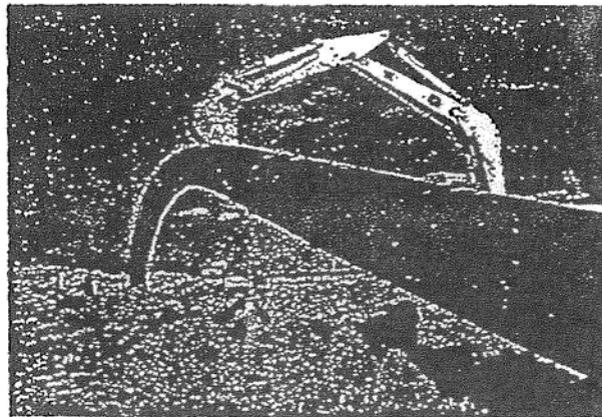
A “toughness” test has not been devised is simply because it is influenced by so many of the physical and chemical properties of the material. The extreme toughness of Driscopipe has been noted as one of its outstanding features since its introduction to the industry ... yet to explain “toughness”, many properties are discussed and demonstrated. To obtain a complete evaluation of the toughness of a plastic material, it is necessary to see demonstrations

of tests and to conduct some tests in person in order to compare it with materials which are more familiar, such as cast iron, steel, cement, copper, etc.

Toughness is related to ... Environmental Stress Crack Resistance (ESCR) ... Notch sensitivity ... Resistance to secondary stresses from external loading ... Impact strength ... Tear strength ... Flexibility ... Kink resistance ... Abrasion and scratch resistance ... Flexural strength ... Elongation ... Chemical resistance ... Tensile strength ... Ductility ... Creep resistance ... Temperature resistance ... Density ... Molecular weight ... and the thermoplastic nature of the material. Part of the toughness of any polyethylene material can be attributed to its flexibility, flexural strength and impact resistance as compared to the more rigid thermoplastic materials such as PVC. Polyethylene is ductile and will elongate many times more than PVC. Consequently, it will absorb more impact without damage or failure. PE will flex or elongate and stress relieve itself rather than rupture. Generally, impact strength is greater for the higher molecular weight PE resins. Impact resistance is also important from the standpoint of a piping system being able to absorb energy imposed on it by external forces.

The expansive force of water freezing inside Driscopipe will not damage it.

ESCR is one of the properties closely related to “toughness” and has been studied as a possible means to define and measure toughness. The exceptional resistance of Driscopipe 8600 to environmental stress cracking as compared to other PE materials is discussed further in the next section.



Driscopipe 8600 is unique and differs from Driscopipe 1000 and from all other polyethylene pipes. Driscopipe 8600 exhibits a superior toughness which gives the pipe the highest impact strength, highest tear strength and lowest notch sensitivity of any polyethylene pipe currently available. Driscopipe 8600 offers the highest resistance to cuts, scratches and abrasions which occur when handling and installing the pipe.

These properties are maintained throughout its temperature range without a loss of ductility or reduced resistance to notch sensitivity. Driscopipe has been successfully installed in numerous arctic applications. Some of these applications have included direct burial in the unstable arctic permafrost.

To learn more of the relative toughness of Driscopipe 8600, we encourage you to take a piece of pipe with a butt fusion joint and try to tear it up without using sharp tools. Pound it flat with a sledge hammer ... slam it against a corner of angle iron ... run over it with a truck ... then do the same with steel, copper, PVC, cast iron and the less rugged PEs. It's not very scientific ... but we believe you'll be convinced that Driscopipe 8600 has extremely high toughness. We have evaluated Driscopipe many times in laboratory and field test experiments to demonstrate and prove this toughness.

- One excellent indicator of the relative toughness of Driscopipe 8600, as compared to other polyethylene pipe materials, can be observed in the ASTM Standard Test for determination of flow rate of the thermoplastic materials.

When Driscopipe 8600 is heated to 190°C (374°F) to measure the flow rate, it requires 432.5 pounds/sq. in. force, applied for 10 minutes, to flow 1½ grams of 8600 material through the orifice of the test unit! Other commercially available polyethylene pipe materials will flow 10 to 20 times this amount under the same conditions.

- When Driscopipe 8600 is heated to 475-500°F to melt it for fusion joining, it requires 150 pounds pressure per square inch of material to make the melted surfaces flow together. This is another indicator of toughness. Other commercially available polyethylene pipe materials require about one-half that amount of pressure and some competitive pipes require less than 25 psi!
- Driscopipe 8600 has been pressure tested for long periods at temperatures up to 140°F and performance requirements at these high temperatures can be used in purchase specifications to assure that the user is getting the highest performing polyethylene pipe.



Environmental Stress Crack Resistance

The most recent ASTM specification written to identify polyethylene plastic pipe and fittings materials is ASTM D 3350, "Polyethylene Plastics Pipe and Fittings Materials", adopted in 1974. This specification uses six (6) properties to classify PE material ... one of these is ESCR.

ASTM D 3350 lists three cell limits for ESCR classification which use the ESCR test outlined in ASTM D 1693, Test Method for Environmental Stress Cracking of Ethylene Plastics. The cell limits are:

Cell Classification Limit	Test Condition		Percent of Failures Allowed	Test Temp. °C
	ASTM D 1693	Test Duration Hours		
1	A	48	50	50°
2	B	24	50	50°
3	C	192	20	100°

Minimum Notch for A is .020"; for B and C is .012".
 Minimum Thickness for A is .120"; for B and C is .070".
 A and B use a diluted aqueous solution reagent, C uses full strength reagent.

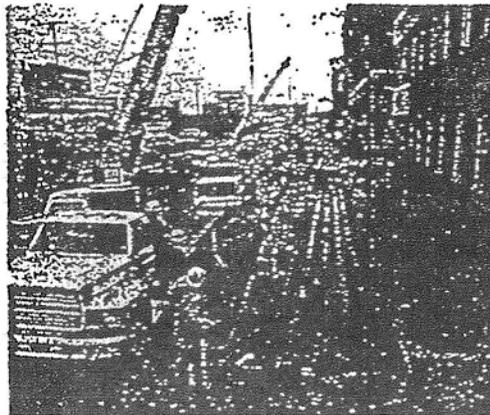
This method of testing for ESCR was first written in 1959 and was developed primarily to evaluate polyethylene as a jacketing material for power and communications cable. Although the method requires the use of laboratory compression molded specimens rather than pipe, it became the generally accepted method for evaluating ESCR of PE materials used for piping. Its wide use was responsible for its inclusion in ASTM D 3550 to describe one of the six primary properties of a PE pipe material.

The test method, ASTM D-1693, is an accelerated test method to determine the resistance of a polyethylene material to environmental stress cracking. It is a measure of the ability of the polyethylene to withstand secondary stress loadings. These loadings are typically thought of as low-level, long-term, external stresses which may act upon the polyethylene pipe in field installations.

Under conditions of the test, high local multiaxial stresses are developed through the introduction of a controlled imperfection (notch). The notched sample is subjected to an elevated temperature bath of a surface active agent. Environmental stress cracking has been found to occur most readily under such conditions.

A note in the test specifications states that, generally, low density (Type I) polyethylenes are tested under Condition A, medium and high density (Type II and Type III) polyethylenes are generally tested under Condition B and high density resins with high melt viscosity, such as pipe grade P34, are tested under Condition C.

As pipe grade polyethylenes have improved, the testing requirements of ASTM D-1693 have become less stringent for P34 pipe grade polyethylenes such as Driscopipe 8600 and Driscopipe 1000. As a result, a more severe stress crack resistance test has been developed to evaluate high density polyethylene pipe. The ASTM F-1248 stress crack resistance test method was developed by a gas distribution company for quality control purposes and is often referred to as Ring ESCR since it tests actual produced pipe ring samples rather than molded specimens.



ASTM F-1248 utilizes rings cut from a pipe sample. The rings are notched on one side and compressed between parallel plates until the distance between the plates is three times the specified pipe minimum wall thickness. The compressed ring samples are subjected to an elevated temperature bath of a surface active agent and visibly inspected for crack formation or propagation.

The Ring ESCR test provides useful information regarding the different polyethylene pipe grade materials. Driscopipe 8600 shows no tendency for sample failures when tested in excess of 10,000 hours. This further reinforces the unique ability of Driscopipe 8600 to provide the highest degree of resistance to the external stresses inherent to a pipeline installation.

Driscopipe 1000, an extra high molecular weight HDPE pipe, will exhibit a ring ESCR of $F_{50} > 1000$ hours. Other lower molecular weight pipes may exhibit lower F_{50} values.

Chemical Corrosion Resistance

The outstanding resistance of Driscopipe to attack by most chemicals makes it suitable to transport these chemicals or to be installed in an environment where these chemicals are present. Factors which determine the suitability and service life of each particular application include the specific chemical and its concentration, pressure, temperature, period of contact and service conditions which may introduce stress concentrations in the pipe or fittings.

Driscopipe is, for all practical purposes, chemically inert within its temperature use range. This advantageous engineering characteristic is one of the primary reasons for the wide use of Driscopipe in industrial applications. It does not rot, rust, pit, corrode or lose wall thickness through chemical or electrical reaction with the surrounding soil, whether acid, alkaline, wet or dry. It neither supports the growth of, nor is affected by, algae, bacteria or fungi and is resistant to marine biological attack. It contains no ingredients which make it attractive to rodents, gophers, etc.

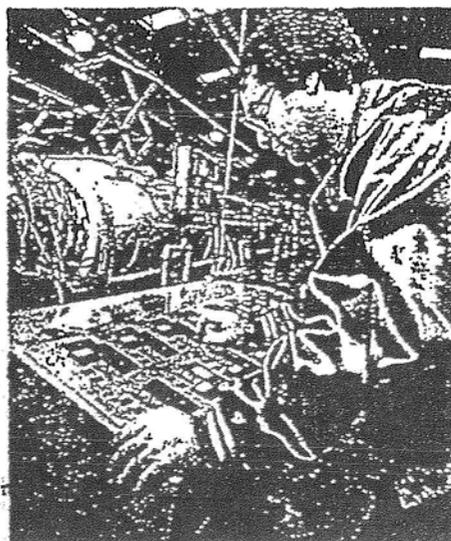
Information relative to the resistance of Driscopipe to a wide range of chemicals is shown in the following tables. This information is based on results of immersion tests (usually 3 months) at various temperatures. Changes in tensile strength and elongation are evaluated at a rapid strain rate to emphasize any strength decay in the material.

Most acids, bases and other chemicals can be transported by Driscopipe using the same design parameters as would apply to water, natural or manufactured gas and water solutions of inorganic salts. Strong oxidizing agents such as fuming sulfuric acid may adversely affect the pipe, depending upon concentration, temperature and period of contact. In many cases, such as gravity flow waste lines, these chemicals can be handled because of dilution and intermittent flow.

Some chemicals, such as all types of liquid hydrocarbons, will mechanically absorb into the wall of the pipe and cause a reduction in hoop stress but this does not degrade the material. This effect is temporary if exposure is intermittent. Where exposure is continuous, it is necessary to derate the pressure capability of the pipe for long term service. This includes such products as gasoline, ethyl alcohol, benzene, carbon tetrachloride, crude and refined oils, etc. Where 5-100% hydrocarbon liquids are continuously present in a pressure system, a service design factor of .25 should be used to calculate design pressures instead of the service design factor of .5 used with water.

$$P = \frac{2S}{SDR-1} \times F \quad \text{or} \quad P = 2S \frac{t}{D-t} \times F$$

Where: D = Outside Diameter, Inches
P = Design Pressure, psi
S = Long Term Hydrostatic Strength, psi, at the design temperature
t = Minimum Wall Thickness, Inches
F = Service Design Factor
SDR = Standard Dimension Ratio of D/t



CHEMICAL RESISTANCE OF DRISCOPE

S – Satisfactory
 U – Unsatisfactory
 M – Marginal
 N – Not known

All concentrations are 100% unless noted otherwise.

On reagents marked marginal, chemical attack will be recognized by a loss of physical properties of the pipe which may require a change in design factors.

Reagent	70°F	140°F	Reagent	70°F	140°F
	(21°C)	(60°C)		(21°C)	(60°C)
Acetic Acid 1-10%	S	S	Boric Acid Conc.	S	S
Acetic Acid 10-60%	S	M	Bromic Acid 10%	S	S
Acetic Acid 80-100%	S	M	Bromine Liquid 100%	M	U
Acetone	M	U	Butanediol 10%	S	S
Acrylic Emulsions	S	S	Butanediol 60%	S	S
Aluminum Chloride-Dilute	S	S	Butanediol 100%	S	S
Aluminum Chloride Conc.	S	S	Butyl Alcohol 100%	S	S
Aluminum Fluoride Conc.	S	S	Calcium Bisulfide	S	S
Aluminum Sulfate Conc.	S	S	Calcium Carbonate Sattd	S	S
Alums (All Types) Conc.	S	S	Calcium Chlorate Sattd	S	S
Ammonia 100% Dry Gas	S	S	Calcium Chloride Sattd	S	S
Ammonium Carbonate	S	S	Calcium Hydroxide	S	S
Ammonium Chloride Sattd	S	S	Calcium Hypochlorite BLGH Sol.	S	S
Ammonium Fluoride 20%	S	S	Calcium Nitrate 50%	S	S
Ammonium Hydroxide 0.88 S.G.	S	S	Calcium Sulfate	S	S
Ammonium Metaphosphate Sattd	S	S	Camphor Oil	N	U
Ammonium Nitrate Sattd	S	S	Carbon Dioxide 100% Dry	S	S
Ammonium Persulfate Sattd	S	S	Carbon Dioxide 100% Wet	S	S
Ammonium Sulfate Sattd	S	S	Carbon Dioxide Cold Sattd	S	S
Ammonium Sulfide Sattd	S	S	Carbon Disulfide	N	U
Ammonium Thiocyanate Sattd	S	S	Carbon Monoxide	S	S
Amyl Acetate	M	U	Carbon Tetrachloride	M	U
Amyl Alcohol 100%	S	S	Carbonic Acid	S	S
Amyl Chloride 100%	N	U	Castor Oil Conc.	S	S
Aniline 100%	S	N	Chlorine Dry Gas 100%	S	M
Antimony Chloride	S	S	Chlorine Moist Gas	M	U
Aqua Regia	U	U	Chlorine Liquid	M	U
Barium Carbonate Sattd	S	S	Chlorobenzene	M	U
Barium Chloride	S	S	Chloroform	M	U
Barium Hydroxide	S	S	Chlorosulfonic Acid 100%	M	U
Barium Sulfate Sattd	S	S	Chrome Alum Sattd	S	S
Barium Sulfide Sattd	S	S	Chromic Acid 20%	S	S
Beer	S	S	Chromic Acid Up to 50%	S	S
Benzene	M	U	Chromic Acid and Sulfuric Acid	S	M
Benzene Sulfonic Acid	S	S	Cider	S	S
Bismuth Carbonate Sattd	S	S	Citric Acid Sattd	S	S
bleach Lye 10%	S	S	Coconut Oil Alcohols	S	S
Black Liquor	S	S	Cola Concentrates	S	S
Borax Cold Sattd	S	S	Copper Chloride Sattd	S	S
Boric Acid Dilute	S	S	Copper Cyanide Sattd	S	S
			Copper Fluoride 2%	S	S
			Copper Nitrate Sattd	S	S
			Copper Sulfate Dilute	S	S
			Copper Sulfate Sattd	S	S
			Cottonseed Oil	S	S
			Crude Oil*	S	M
			Cuprous Chloride Sattd	S	S
			Cychohexanol	S	S
			Cyclohexanone	M	U
			Detergents Synthetic	S	S
			Developers, Photographic	S	S
			Dextrin Sattd	S	S
			Dextrose Sattd	S	S
			Dibutylphthalate	S	M
			Disodium Phosphate	S	S
			Diazo Salts	S	S
			Diethylene Glycol	S	S
			Diglycolic Acid	S	S
			Dimethylamine	M	U
			Emulsions, Photographic	S	S
			Ethyl Acetate 100%	M	U
			Ethyl Alcohol 100%	S	S
			Ethyl Alcohol 35%	S	S
			Ethyl Butyrate	M	U
			Ethyl Chloride	M	U
			Ethyl Ether	U	U
			Ethylene Chloride	U	U
			Ethylene Chlorohydrin	U	U
			Ethylene Dichloride	M	U
			Ethylene Glycol	S	S
			Ferric Chloride Sattd	S	S
			Ferric Nitrate Sattd	S	S
			Ferrous Chloride Sattd	S	S
			Ferrous Sulfate	S	S
			Fish Solubles	S	S
			Fluoboric Acid	S	S
			Fluorine	S	U
			Fluosilicic Acid 32%	S	S
			Fluosilicic Acid Conc.	S	S
			Formaldehyde 40%	S	N
			Formic Acid 0-20%	S	S
			Formic Acid 20-50%	S	S
			Formic Acid 100%	S	S
			Fructose Sattd	S	S
			Fruit Pulp	S	S
			Fuel Oil	S	U
			Furfural 100%	M	U
			Furfuryl Alcohol	M	U
			Gallic Acid Sattd	S	S
			Gas Liquids*	S	M
			Gasoline*	M	U
			Gin	S	U
			Glucose	S	S
			Glycerine	S	S
			Glycol	S	S
			Glycolic Acid 30%	S	S
			Grape Sugar Sattd Aq.	S	S
			Hexanol, Tert.	S	S
			Hydrobromic Acid 50%	S	S
			Hydrocyanic Acid Sattd	S	S
			Hydrochloric Acid 10%	S	S
			Hydrochloric Acid 30%	S	S
			Hydrochloric Acid 35%	S	S
			Hydrochloric Acid Conc.	S	S
			Hydrofluoric Acid 40%	S	S
			Hydrofluoric Acid 60%	S	S
			Hydrofluoric Acid 75%	S	S
			Hydrogen 100%	S	S
			Hydrogen Bromide 10%	S	S
			Hydrogen Chloride Gas Dry	S	S

*HDPE Resin Service Design Factor for hydrocarbons per the formula on page 3 and 8 is F = 0.25 to compensate for hydrocarbon saturation effects on long term hydrostatic strength.

continued from page 9

CHEMICAL RESISTANCE OF DRISCOPIPE

Reagent	70°F (21°C)	140°F (60°C)	Reagent	70°F (21°C)	140°F (60°C)	Reagent	70°F (21°C)	140°F (60°C)
Hydrogen Peroxide 30%	S	S	Phosphorous (Yellow) 100%	S	N	Sodium Bicarbonate Sattd	S	S
Hydrogen Peroxide 90%	S	M	Phosphorus Pentoxide 100%	S	N	Sodium Bisulfate Sattd	S	S
Hydrogen Phosphide 100%	S	S	Photographic Solutions	S	S	Sodium Bisulfite Sattd	S	S
Hydroquinone	S	S	Pickling Baths			Sodium Borate	S	S
Hydrogen Sulfide	S	S	Sulfuric Acid	S	S	Sodium Bromide Dilute Sol.	S	S
Hypochlorous Acid Conc.	S	S	Hydrochloric Acid	S	S	Sodium Carbonate Con.	S	S
Inks	S	S	Sulfuric-Nitric	S	U	Sodium Carbonate	S	S
Iodine (Alic. Sol.) Conc.	S	U	Plating Solutions			Sodium Chlorate Sattd.	S	S
Lactic Acid 10%	S	S	Brass	S	S	Sodium Chloride Sattd	S	S
Lactic Acid 90%	S	S	Cadmium	S	S	Sodium Cyanide	S	S
Latex	S	S	Chromium	N	N	Sodium Dichromate Sattd	S	S
Lead Acetate Sattd	S	S	Copper	S	S	Sodium Ferriocyanide	S	S
Lube Oil	S	M	Gold	S	S	Sodium Ferrocyanide Sattd	S	S
Magnesium Carbonate Sattd	S	S	Indium	S	S	Sodium Fluoride Sattd	S	S
Magnesium Chloride Sattd	S	S	Lead	S	S	Sodium Hydroxide Conc.	S	S
Magnesium Hydroxide Sattd	S	S	Nickel	S	S	Sodium Hypochlorite	S	S
Magnesium Nitrate Sattd	S	S	Rhodium	S	S	Sodium Nitrate	S	S
Magnesium Sulfate Sattd	S	S	Silver	S	S	Sodium Sulfate	S	S
Mercuric Chloride Sattd	S	S	Tin	S	S	Sodium Sulfide 25%	S	S
Mercuric Cyanide Sattd	S	S	Zinc	S	S	Sodium Sulfide Sattd Sol.	S	S
Mercurous Nitrate Sattd	S	S	Potassium Bicarbonate Sattd	S	S	Sodium Sulfite Sattd	S	S
Mercury	S	S	Potassium Borate 1%	S	S	Stannous Chloride Sattd	S	S
Methyl Alcohol 100%	S	S	Potassium Bromate 10%	S	S	Stannic Chloride Sattd	S	S
Methyl Bromide	M	U	Potassium Bromide Sattd	S	S	Starch Solution Sattd	S	S
Methyl Chloride	M	U	Potassium Carbonate	S	S	Stearic Acid 100%	S	S
Methyl Ethyl Ketone 100%	M	U	Potassium Chlorate Sattd	S	S	Sulfuric Acid 0-50%	S	S
Methylsulfuric Acid	S	S	Potassium Chloride Sattd	S	S	Sulfuric Acid 70%	S	M
Methylene Chloride 100%	M	U	Potassium Chromate 40%	S	S	Sulfuric Acid 80%	S	U
Milk	S	S	Potassium Cyanide Sattd	S	S	Sulfuric Acid 96%	M	U
Mineral Oils	S	U	Potassium Dichromate 40%	S	S	Sulfuric Acid 98%	M	U
Molasses Comm.	S	S	Potassium Ferri/			Sulfuric Acid, Fuming	U	U
Nickel Chloride Sattd	S	S	Ferro Cyanide Sattd	S	S	Sulfurous Acid	S	S
Nickel Nitrate Conc.	S	S	Potassium Fluoride	S	S	Tallow	S	M
Nickel Sulfate Sattd	S	S	Potassium Hydroxide 20%	S	S	Tannic Acid 10%	S	S
Nicotine Dilute	S	S	Potassium Hydroxide Conc.	S	S	Tanning Extracts Comm.	S	S
Nicotinic Acid	S	S	Potassium Nitrate Sattd	S	S	Tartaric Acid Sattd	N	N
Nitric Acid 0-30%	S	S	Potassium Perborate Sattd	S	S	Tetrahydrofurane	N	U
Nitric Acid 30-50%	S	M	Potassium Perchlorate 10%	S	S	Titanium Tetrachloride Sattd	N	U
Nitric Acid 70%	S	M	Potassium Sulfate Conc.	S	S	Toluene	M	U
Nitric Acid 95-98%	U	U	Potassium Sulfide Conc.	S	S	Transformer Oil	S	M
Nitrobenzene 100%	U	U	Potassium Sulfite Conc.	S	S	Trisodium Phosphate Sattd	S	S
Octyl Cresol	S	U	Potassium Persulfate Sattd	S	S	Trichloroethylene	U	U
Oils and Fats*	S	M	Propargyl Alcohol	S	S	Urea Up to 30%	S	S
Oleic Acid Conc.	S	U	Propyl Alcohol	S	S	Urine	S	S
Oleum Conc.	U	U	Propylene Dichloride 100%	U	U	Vinegar Comm.	S	S
Orange Extract	S	S	Propylene Glycol	S	S	Vanilla Extract	S	S
Oxalic Acid Dilute	S	S	Rayon Coagulating Bath	S	S	Wetting Agents	S	S
Oxalic Acid Sattd	S	S	Sea Water	S	S	Whiskey	S	N
Ozone 100%	S	U	Selenic Acid	S	S	Wines	S	S
Perchloric Acid 10%	S	S	Shortening	S	S	Xylene	M	U
Petroleum Ether	U	U	Silicic Acid	S	S	Yeast	S	S
Phenol 90%	U	U	Silver Nitrate Sol.	S	S	Zinc Chloride Sattd	S	S
Phosphoric Acid Up to 30%	S	S	Soap Solution Any Conc'n	S	S	Zinc Sulfate Sattd	S	S
Phosphoric Acid Over 30%	S	S	Sodium Acetate Sattd	S	S			
Phosphoric Acid 90%	S	S	Sodium Benzoate 35%	S	S			

For additional chemical resistance listings, consult the P.P.I. technical report #TR 19/10-84, Table I and the ISO technical report #ISO/Data 8-1979, Tables I, II, III.

Temperature Characteristics

Since polyethylene is a thermoplastic material, many of its physical and chemical properties are dependent on temperature and will change as the temperature of the material is increased or decreased. However, the exposure of Driscopipe to temperature variations within the recommended operating range does not result in degradation of the material. As these temperature changes are reversed, the material properties also reverse to their original values.

You will note from the information on physical properties that Driscopipe has a brittleness temperature below -180°F and a softening temperature of $+257^{\circ}\text{F}$. The recommended operating temperature is limited only on the higher temperature side to a range of $140\text{--}180^{\circ}\text{F}$, dependent upon the pressure of the application and other operating and installation considerations. On the lower temperature side, Driscopipe gains strength without becoming brittle and is ideal for use at sub-zero temperatures.

Driscopipe becomes molten at $400\text{--}500^{\circ}\text{F}$ and temperatures in this range are used to fusion join the piping system. Pipe is extruded at about the same temperature. To protect the material against degradation at the higher temperature, it is chemically stabilized. This stabilizer protects the material against thermal degradation which might otherwise occur during manufacture, outside storage and installation.

Driscopipe has been tested for thousands of hours at elevated temperatures of 140°F and 180°F without thermal degradation. These long term pressure tests at the higher temperatures are used to obtain recommended design strengths for the pipe at these temperatures.

Since all thermoplastic piping materials are affected by temperature, it is a general practice to characterize these materials at ambient temperature of 23°C (73.4°F). Nearly all ASTM tests relating to physical, mechanical and chemical properties of thermoplastic materials are conducted at this temperature. If a test is conducted, or a property defined, at other than 73.4°F , it is always noted.

One example of the effect of temperature on Driscopipe is the change in long term strength of the material as shown on the stress-life curves. This type behavior is true for all thermoplastics but there are large differences between the performance of specific materials at the higher temperatures.

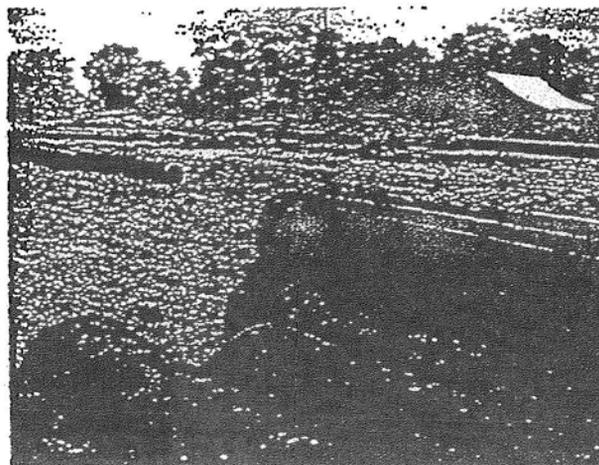
Knowledge of the long term strength of Driscopipe at the various temperatures allows selective design of a system. Accurate interpolations can be made for other temperatures between those which are known when data at three or more temperature levels is available.

Other properties of thermoplastic pipe which change with temperature and can affect system design and installation procedures include the following.

Burst strength – Short term (1 minute) burst tests on Driscopipe at various temperatures show these typical hoop stress values:

Temperature, $^{\circ}\text{F}$	Hoop Stress, psi
73.4°	3250
32°	4300
0°	5290
-20°	5670
-40°	6385

Driscopipe will quick-burst at a pressure approximately four times greater than the rated operating pressure.



Chemical Resistance – The ability of most thermoplastics to resist degradation in the presence of corrosive chemicals is reduced as temperature increases. This is also true for Driscopipe but to a lesser extent because of its high density and high molecular weight. The effect of temperature on Driscopipe in the presence of various chemicals is shown in the chemical resistance tables.

Flexibility – As temperature is decreased, the flexibility of Driscopipe is also decreased. This has very little effect on installation except that at the lower winter temperatures, coiled pipe becomes more difficult, mechanically, to uncoil and stretch out in the ditch. Although Driscopipe becomes stiffer at low temperature, it can be bent, uncoiled or plowed in with sufficient mechanical power and no damage will occur to the pipe because of bending it at cold temperatures.

Other Physical Properties – There is a slight change with temperature of impact strength, notch sensitivity, flexural modulus, hardness and elongation ... but none are of such extent as to affect design parameters or installation procedures over the normal range of temperatures.

Modulus of Elasticity – Typical values for the variance in modulus of elasticity with temperature change is shown below.

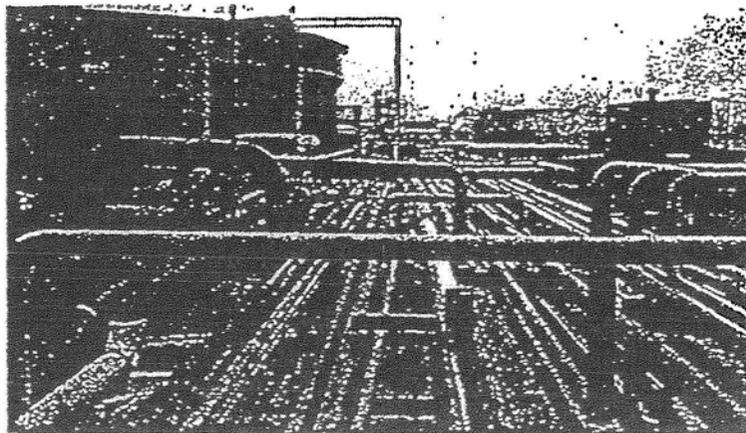
Temperature °F	Modulus of Elasticity, psi
-20°	300,000
0°	260,000
32°	200,000
75°	130,000
100°	105,000
140°	60,000

Thermal Expansion and Contraction – Polyethylene, like other thermoplastics, has a coefficient of expansion higher than metals. This coefficient is usually determined by a standard test method which employs the use of molded specimens. Measurements are made with a quartz dilatometer while the test specimen is held at elevated temperature. Typical coefficient values by this method range from $.75 \times 10^{-4}$ for Driscopipe 8600 to $.83 \times 10^{-4}$ for Driscopipe 1000.

The coefficient of linear expansion may also be determined by measuring the change in length of unrestrained pipe samples at different temperatures. The calculated coefficient is somewhat higher on extruded pipe than on molded test specimens. This appears to be true for all polyethylene pipe. The average coefficient calculated from measurements made on Driscopipe in the temperature range 0°F to 140°F, is 1.2×10^{-4} in/in/°F.

The circumferential coefficient of expansion and contraction for Driscopipe is approximately $.6 \times 10^{-4}$ in/in/°F in the range of 0° to 140°F ... or about ½ the linear coefficient. This circumferential change with temperature rarely presents any problems in system design. There may be need to consider this factor if compression fittings are used.

The expansion or contraction for Driscopipe can be stated in an easy rule of thumb ... the pipe will expand or contract approximately 1.4" per 100 feet for each 10°F change in temperature. Thus a 1000 foot unrestrained line which undergoes a 20°F increase in temperature change will increase in length 28 inches. The relatively large amount of expansion and contraction of plastic pipe generally presents no real problems in installation. The pipe has a relatively low elastic modulus and consequently there is less stress build-up. These stresses, caused by temperature change, are easily dissipated due to the thermoplastic nature of the material which relaxes and adjusts with time.



Tests have been conducted wherein the temperature of a section of unrestrained pipe was changed 130°F in a period of a few minutes. The total force created by contraction was measured and proved to be about (½) one-half the theoretical calculated value. Thermoplastic materials are unique in their ability to stress-relieve themselves. Actual changes in temperature in most applications take place slowly over an extended period of time. The total stresses imposed will vary but are generally much lower than the calculated values.

Direct buried pipe will generally have ample soil friction and interference to restrain movement of the pipe under normal application temperature changes. It is a good idea to make the final tie-ins on a system at a temperature which is as close to operating temperature as possible. This is particularly true for insert liner systems where there is no soil restraint.

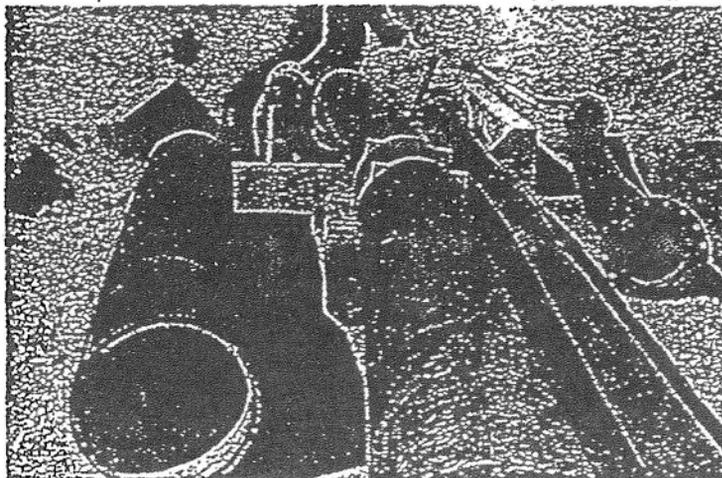
Normal good direct burial installation practices which include snaking the pipe in the ditch, proper backfill and compaction, making the tie-in at the proper temperature, etc. should be used at all times and will substantially reduce the possibility of pull out at tie-in connections on such installations. However, planning the transition tie-in becomes more important when Driscopipe is used for insert renewal inside another pipe because there is no restraint from earth loading.

Contraction of the pipe due to reduction in temperature is freely transmitted to the transition connection and may result in pull-out if proper design

precautions are not taken. In those cases, it may be necessary to provide additional anchoring at the terminations of the insert liner. Concrete anchors poured into undisturbed soil and cast around anchor projections in the Driscopipe line will restrict movement at the end of the line. Anchor projections on the Driscopipe liner can be made by fusing a blind tee into the line or by the use of two reducers, to the next larger size of pipe, fused together in the line.

Thermal Conductivity – This property of Driscopipe is lower than that for metals and can sometimes be exploited in the design of the system. It may eliminate or reduce the need for insulating pipe which carries water or other fluids through freezing temperatures. Thermal Conductivity of Driscopipe is 2.7 BTU per hour per sq. ft. per °F per inch of thickness. The slow heat transfer inhibits freezing and, if normal burial precautions are used, accidental freezing is usually eliminated. If the pipe does freeze, it does not fracture but fluid flow will be stopped. It will resume its function upon thawing. Direct application of intense heat should not be used to thaw a line. Antifreeze compounds such as methanol, isopropanol and ethylene glycol can be used without detrimental effect on the pipe.

Ignition Temperatures – The flash point for high density polyethylene using the Cleveland open cup method (ASTM D92) is 430°F. The flash ignition and self ignition temperatures using ASTM D1929 are 645°F and 660°F.



Weatherability

Two principal factors influence the weathering of plastic pipe in outside above ground applications ... temperature changes caused by seasonal variations and solar heating and solar radiation of ultraviolet rays. Effects of temperature variations on Driscopipe were discussed in the preceding section. Expansion and contraction of a line above ground, due to differential heating, will cause the line to move laterally, particularly if it is empty. This movement can easily be controlled within desired limits through the use of restraints.

Driscopipe is also protected against degradation caused by ultraviolet rays when exposed to direct sunlight. The material contains 2½% of finely divided carbon black which also accounts for the black color of Driscopipe. Carbon black is the most effective single additive capable of enhancing the weathering characteristic of plastic materials. The protection even relatively low levels of carbon black impart to the plastic is so great that it is not necessary to use other light stabilizers or UV absorbers.

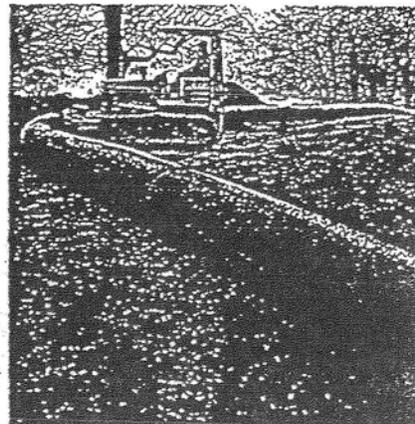
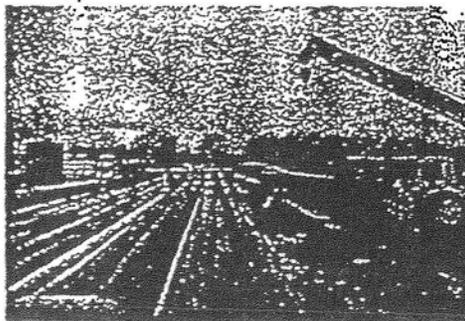
Weatherability tests indicate that Driscopipe can be safely used outside in most climates for periods of many years without danger of loss of physical properties due to UV exposure. Phillips has done extensive testing of polyethylene compounds containing 2 to 3% carbon black and compared these to other UV stabilizers to determine their effectiveness for protection against UV degradation in outdoor exposure. Samples were aged in outdoor exposure in three geographical locations: Phoenix,

Arizona, Bartlesville, Oklahoma (Phillips 66 headquarters) and Akron, Ohio. From these actual tests, it was determined that one year exposure in Arizona was equivalent to at least two years in Bartlesville and greater than three and one-half years in Akron.

Weather-Ometer tests were run under standard conditions as set out in ASTM D 1499-64 and compared with the actual test samples in the three locations described above. From this test work, it was determined, conservatively, that 5000 hours (approximately 7 months) in the Weather-Ometer compares to greater than 42 months exposure in Arizona. Samples containing 2 to 3% carbon black and thermal stabilizers as used in Driscopipe have been tested for greater than 25,000 hours (2.85 years) in the Weather-Ometer without any brittleness or loss of physical properties. This is equivalent to over 17 years in Arizona and over 60 years in Akron, Ohio.

Permeability

The permeability of gases, vapors or liquids through a plastic membrane is generally considered to be an activated diffusion process. That is, the gas, vapor or liquid dissolves in the membrane and then diffuses to a position of lower concentration. The permeation rate is determined by the functional groups of the permeating molecules and by the density of the plastic ... the higher the density, the lower the permeability. Listed below are typical permeability rates for HDPE.



	Permeability Rate*
Carbon Dioxide	345
Hydrogen	321
Oxygen	111
Helium	247
Ethane	236
Natural Gas	113
Freon 12	95
Nitrogen	53

*Cubic centimeters per day per 100 sq. inches per mil thickness at atmospheric pressure differential.

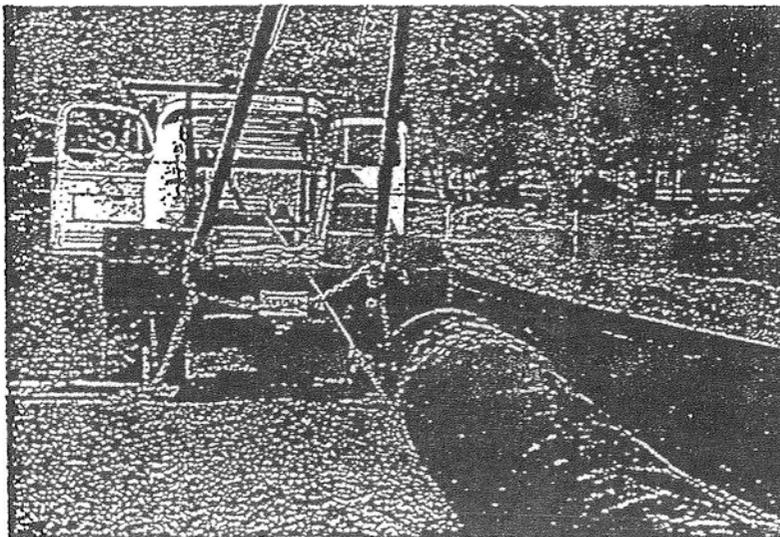
These permeation rates are considered very low. They result in negligible loss of product and create no hazard. For example, polyethylene piping systems are the predominant material used to construct new gas distribution systems and to renew old deteriorated systems. The permeation rate will vary in direct proportion to the differential pressure applied.

If the internal operating pressure is 60 psi, for example, the permeability rate would be approximately 4 times that shown above but volume losses would still be extremely low. Calculated volume loss in one mile of SDR 11 pipe (any size) in one day, for natural gas, would be $\frac{1}{4}$ of one cubic foot. At 120 psi, it would be $\frac{1}{2}$ cubic foot per day.

Abrasion Resistance

One of the many outstanding characteristics of Driscopipe polyethylene is its resistance to abrasion. The inherent resilience and toughness of Driscopipe allows the mining industry to use this pipe in numerous surface applications where more conventional materials would be unsatisfactory, either because of the terrain encountered or the abrasiveness of the slurry to be moved. Quite often, a Driscopipe system offers substantial economic advantage as a means of transport over more conventional transportation methods used in the mining industry. Some of the more common applications include tailings lines and the transport of gypsum, limestone, sand, slimes and coal.

Due to its unique toughness, as indicated by low melt flow values, Driscopipe 8600 provides improved abrasion resistance over all other polyethylene piping materials. Controlled pipe loop pumping tests have demonstrated that Driscopipe can outlast steel pipe by as much as 4 to 1. One such test, performed by Williams Brothers Engineering, Tulsa, Oklahoma, compared Driscopipe to steel in pumping a coarse particle size magnetite iron ore slurry. At 13½ ft/sec velocity, Driscopipe was better by a factor of 4:1 and at 17 ft/sec by a factor of 3:1.



Heat Fusion Joining

The heat fusion joining technique has a long history of use for joining polyethylene pipe materials. The heat fusion method of joining PE pipe began shortly after the first commercial production of high density polyethylene in the early 1950s ... both developed by Phillips 66.

The integrity and superiority of heat fusion are now recognized universally. The modern day heat fusion joint is the same joint made in 1956 ... only the fusion equipment has evolved to gain efficiency, reliability and convenience. The principles learned on early equipment for making a successful joint are still in use today. Phillips designed, developed and built many models of heat fusion equipment from 1956 until the early 1970s. Since that time, Phillips has guided this development by others. The extensive line of high quality, efficient fusion equipment offered by McElroy Manufacturing, Inc., Tulsa, Oklahoma is one of the results of this long history of development. Phillips pioneered the idea and development of heat fusion and has used it exclusively in every high density polyethylene piping system sold by Phillips since 1956. There are millions of these joints in service today. In fact, 92% of all natural gas distribution pipe to homes, farms and factories is installed with polyethylene pipe and fittings. Heat fusion joints are industry accepted and field proven.

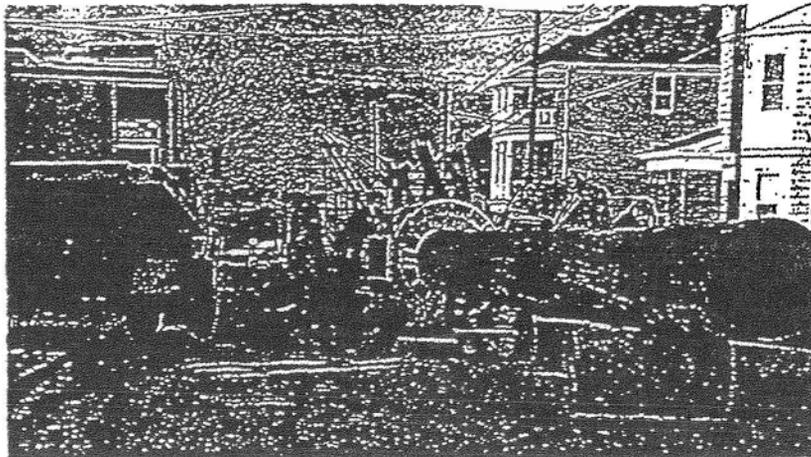
The heat fusion joining system has been so successful that it is the "standard" joining system for polyethylene. There are many reasons ... here are some.

Heat fusion joining ideally meets the requirements for a fast joining method to facilitate all phases of construction work in a safe and reliable manner.

The heat fusion joint is structurally superior to the socket fusion joint by configuration and, therefore, better meets the requirements of service. The heat joint configuration allows it to better disperse stresses initiated by pipe deflection and external loading. Stress concentration is minimized when the joint is placed in a strain and the joint is more "forgiving" when ground settlement occurs. In a socket joint, there is an extremely high ratio of "joint wall" to "pipe wall", resulting in stress intensification from external loading.

The Driscopipe heat fusion joining system is a simple, visual procedure with straight forward instructions. No "timing cycles" are necessary. The visual procedure allows the operator to concentrate on his work rather than a clock. Visually, he knows when the pipe ends have melted to the degree required to fuse them together. Visually, he observes and controls fusion pressure by observing the amount and configuration of the fusion bead as it is formed.

In the course of this work, the fusion operator is faced with a wide variety of job conditions. Changes in air temperature, material temperature, wind velocity, sun exposure, humidity, as well as condition of the terrain and the equipment all influence the joining requirements. Quality work under field conditions is more consistent with a simple, straight-forward, visual procedure.

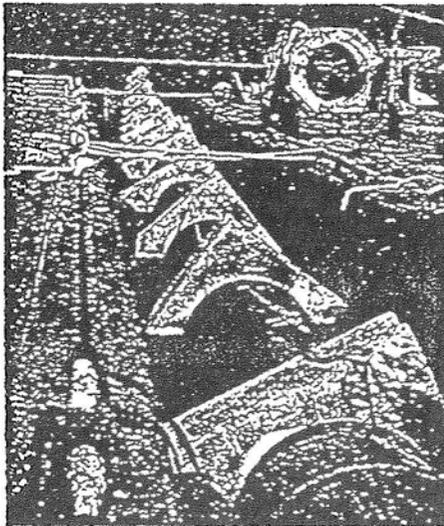


One heat fusion operator, with equipment, typically handles the whole operation himself, sometimes using a second person as a helper. Pipe tolerances, ovality and curvature are no problem and "melt" is easily controlled by the visual procedure.

Heat fusion joints offer a large advantage over socket coupled joints for plow-in installation and for insert renewal applications. Socket coupled pipe requires larger size plow chutes and bore holes. Heat fused pipe one size larger can usually be handled and installed through bore holes and plow chutes selected for socket coupled pipe. Larger sizes of heat fused pipe can be used inside old mains for insert renewal because it does not require the extra space for the coupling.

Heat fusion joints may easily be cut out and re-done. This fact has a bearing on the quantity and quality of training necessary and favorably affects operator attitude toward quality in the field. These joints can be easily cut out and destructively tested in the field to check joining proficiency and equipment condition and it's inexpensive. There is no coupling to destroy and throw away.

The heat fusion joining system is especially effective with Driscopipe 8600. The melt of this material is very viscous and tough. The operator can apply ample pressure to form the heat fusion joint with little danger of forcing the molten material from between the two ends of the joint, as can be done with the softer, less viscous, high density materials.



Driscopipe 8600 can be fusion joined to other polyethylene piping materials when necessary. Special joining techniques are required to achieve good joints. Phillips Driscopipe technical personnel are available to instruct and demonstrate the fusion joining procedure for joining Driscopipe to other polyethylene materials.

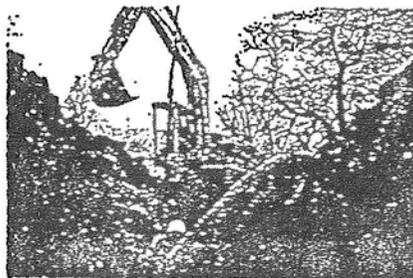
Fatigue Resistance

Driscopipe 8600 very high molecular weight, high density polyethylene has superior resistance to fatigue failure caused by cyclic loading. Independent laboratory tests were conducted to determine the suitability of Driscopipe 8600 for use as the cold water supply pipe and the barge mooring leg of the Mini-OTEC Project (Hawaii, 1979). In that application, 2150' of 24" 60 psi Driscopipe 8600 was deployed vertically in a deep ocean trench just offshore Keahole Point and was subject to cyclic distortion caused by wave action, current, and barge motion.

Cyclic tests showed that Driscopipe 8600 very high molecular weight PE could endure more than 100,000 cycles at a stress of 1800 psi without failure. Copies of this test report are available upon request.

Driscopipe 1000 offers good fatigue service life also, but not equal to 8600. Neither requires de-rating like PVC AWWA C-900 pipe. In fact, per AWWA C-906 for 4" to 63" HDPE pipe, no water hammer or fatigue de-rating factor need be applied to Driscopipe 8600 or Driscopipe 1000 ductile PE pipe.

The Driscopipe performance team offers you innovative solutions to your piping requirements. Contact your nearest Driscopipe Sales Representative. He'll give you personalized technical service, installation assistance and all the cost-saving advantages of a Driscopipe Piping System. Engineered for Performance!





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butane may condense and liquefy in the pipe. Such liquefied fuel gasses are known to permeate polyethylene pipe, and result in unreliable heat fusion or electrofusion joints.

In potable water applications, permeating chemicals could affect the pipe or water in the pipe. ANSI/AWWA standards provide the following guidance for potable water applications:

“The selection of materials is critical for water service and distribution piping where there is likelihood the pipe will be exposed to significant concentrations of pollutants comprised of low molecular weight petroleum products or organic solvents or their vapors. Research has documented that pipe materials such as polyethylene, polybutylene, polyvinyl chloride, and asbestos cement, and elastomers, such as used in jointing gaskets and packing glands, may be subject to permeation by lower molecular weight organic solvents or petroleum products. If water pipe must pass through such a contaminated area or an area subject to contamination, consult with the manufacturer regarding permeation of pipe walls, jointing materials, and so forth, *before* selecting materials for use in that area.”¹

Chemical Attack

A direct chemical attack on the polymer will result in permanent, irreversible polymer damage or chemical change by chain scission, cross-linking, oxidation, or substitution reactions. Such damage

or change cannot be reversed by removing the chemical.

Chemical Resistance Information

The following chemical resistance guide, Table 5-1 (next page), presents immersion test chemical resistance data for a wide variety of chemicals.

- This data may be applicable to gravity flow and low stress applications.
- It may not be applicable when there is applied stress such as internal pressure, or applied stress at elevated temperature.

Unless stated otherwise, polyethylene was tested in the relatively pure, or concentrated chemical.

It is generally expected that dilute chemical solutions, lower temperatures, and the absence of stress have less potential to affect the material. At higher temperature, or where there is applied stress, resistance may be reduced, or polyethylene may be unsuitable for the application. Further, combinations of chemicals may have effects where individual chemicals may not.

Testing is recommended where information about suitability for use with chemicals or chemical combinations in a particular environment is not available. PLEXCO cannot provide chemical testing services.

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¹ ANSI/AWWA C906-90, Section 1.2; ANSI/AWWA C901-96, Section 4.1.

Table 5-1 Chemical Resistance

Because the particular conditions of each application may vary, Table 5-1 information should be used only as a preliminary guide for PLEXCO and SPIROLITE polyethylene pipe materials. This information is offered in good faith, and is believed to be accurate at the time of publication, but it is offered without any warranty, expressed or implied. Additional information may be required, particularly in regard to unusual or special applications. Determinations of suitability for use in particular chemical or environmental conditions may require specialized laboratory testing.

Additional information on chemical compatibility may be found in PPI TR-19, *Thermoplastic Piping for the Transport of Chemicals*.

Chemical Resistance Key

Key†	Meaning
X	resistant (swelling <3% or weight loss <0.5%; elongation at break not substantially changed)
/	limited resistance (swelling 3 - 8% or weight loss 0.5 - 5%; elongation at break reduced by <50%)
—	not resistant (swelling > 8% or weight loss >5%; elongation at break reduced by >50%)
D	discoloration
*	aqueous solutions in all concentrations
**	only under low mechanical stress

† Where a key is not printed in the table, data is not available.

Medium	73°F	140°F	Medium	73°F	140°F
Acetaldehyde, gaseous	X	/	Ammonia, liquid (100%)	X	X
Acetic acid (10%)	X	X	Ammonium chloride	*X	X
Acetic acid (100%) (Glacial acetic acid)	X	/D	Ammonium fluoride, aqueous (up to 20%)	X	X
Acetic anhydride	X	/D	Ammonium nitrate	*X	X
Acetone	X	X	Ammonium sulphate	*X	X
Acetylene tetrabromide	**/ to —	—	Ammonium sulfide	*X	X
Acids, aromatic	X	X	Amyl acetate	X	X
Acrylonitrile	X	X	Aniline, pure	X	X
Adipic acid	X	X	Anisole	/	—
Allyl alcohol	X	X	Antimony trichloride	X	X
Aluminum chloride, anhydrous	X	X	Aqua regia	—	—
Aluminum sulphate	*X	X	Barium chloride	*X	X
Alums	X	X	Barium hydroxide	*X	X

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<i>Medium</i>	73°F	140°F	<i>Medium</i>	73°F	140°F
Beeswax	X	**/ to —	Cyclohexanone	X	X
Benzene	/	/	Decahydronaphthalene	X	/
Benezenesulphonic acid	X	X	Desiccator grease	X	/
Benzoic acid	*X	X	Detergents, synthetic	X	X
Benzyl alcohol	X	X to /	Dextrin, aqueous (18% saturated)	X	X
Borax, all concentrations	X	X	Dibutyl ether	X to /	—
Boric acid	*X	X	Dibutyl phthalate	X	/
Brine, saturated	X	X	Dichloroacetic acid (100%)	X	/D
Bromine	—	—	Dichloroacetic acid (50%)	X	X
Bromine vapor	—	—	Dicloroacetic acid methyl ester	X	X
Butanetriol	X	X	Dichlorobenzene	/	—
Butanol	X	X	Dicloroethane	/	/
Butoxyl	*X	/	Dicloroethylene	—	—
Butyl acetate	X	/	Diesel oil	X	/
Butyl glycol	X	X	Diethyl ether	X to /	/
Butyric acid	X	/	Diisobutyl ketone	X	/ to —
Calcium chloride	*X	X	Dimethyl formamide (100%)	X	X to /
Calcium hypochlorite	*X	X	Dioxane	X	X
Camphor	X	/	Emulsifiers	X	X
Carbon dioxide	X	X	Esters, aliphatic	X	X to /
Carbon disulphide	/	—	Ether	X to /	/
Carbon tetrachloride	**/ to —	—	Ethyl acetate	/	—
Caustic potash	X	X	Ethyl alcohol	X	X
Caustic soda	X	X	Ethyl glycol	X	X
Chlorine, liquid	—	—	Ethyl hexanol	X	X
Chlorine bleaching solution (12% active chlorine)	/	—	Ethylene chloride (dichloroethene)	/	/
Chlorine gas, dry	/	—	Ethylene diamine	X	X
Chlorine gas, moist	/	—	Fatty acids (>C ⁶)	X	/
Chlorine water (disinfection of mains)	X	—	Feric chloride*	X	X
Chloroacetic acid (mono)	X	X	Fluorine	—	—
Chlorobenzene	/	—	Fluorocarbons	/	—
Chloroethanol	X	XD	Fluorosilic acid, aqueous (up to 32%)	X	X
Chloroform	**/ to —	—	Formaldehyde (40%)	X	X
Chlorosulphonic acid	—	—	Formamide	X	X
Chromic acid (80%)	X	—D	Formic acid	X	—
Citric acid	X	X	Fruit juices	X	X
Coconut oil	X	/	Fruit pulp	X	X
Copper salts	*X	X	Furfuryl alcohol	X	XD
Corn oil	X	/	Gelatine	X	X
Creosote	X	XD	Glucose	*X	X
Creosol	X	XD	Glycerol	X	X
Cyclohexane	X	X	Glycerol chlorohydrin	X	X
Cyclohexanol	X	X	Glycol (conc.)	X	X

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<i>Medium</i>	73°F	140°F	<i>Medium</i>	73°F	140°F
Glycolic acid (50%)	X	X	Nitric acid (25%)	X	X
Glycolic acid (70%)	X	X	Nitric acid (50%)	/	—
Halothane	/	/	Nitrobenzene	X	/
Hydrazine hydrate	X	X	o-Nitrotoluene	X	/
Hydrobromic acid (50%)	X	X	Octyl cresol	/	—
Hydrochloric acid (all concentrations)	X	X	Oils, ethereal	/	/
Hydrocyanic acid	X	X	Oils, vegetable & animal	X	X to /
Hydrofluoric acid (40%)	X	/	Oleic acid (conc.)	X	/
Hydrofluoric acid (70%)	X	/	Oxalic acid (50%)	X	X
Hydrogen	X	X	Ozone	/	—
Hydrogen chloride gas, moist and dry	X	X	Ozone, aqueous solution (Drinking water purification)	X	
Hydrogen peroxide (30%)	X	X	Paraffin oil	X	X
Hydrogen peroxide (100%)	X		Perchloric acid (20%)	X	X
Hydrogen sulfide	X	X	Perchloric acid (50%)	X	/
Iodine, tincture of, DAB 7 (German Pharmacopoeia)	X	/D	Perchloric acid (70%)	X	—D
Isooctane	X	/	Petrol	X	X to /
Isopropanol	X	X	Petroleum	X	/
Isopropyl ether	X to /	—	Petroleum ether	X	/
Jam	X	X	Petroleum jelly	**X to /	/
Keotones	X	X to /	Phenol	X	XD
Lactic acid	X	X	Phosphates	*X	X
Lead acetate	*X	X	Phosphoric acid (25%)	X	X
Linseed oil	X	X	Phosphoric acid (50%)	X	X
Magnesium chloride	*X	X	Phosphoric acid (95%)	X	/D
Magnesium sulphate	*X	X	Phosphorus oxychloride	X	/D
Maleic acid	X	X	Phosphorus pentoxide	X	X
Malic acid	X	X			
Menthol	X	/	Phosphorus trichloride	X	/
Mercuric chloride (sublimite)	X	X	Photographic developers, commecial	X	X
Mercury	X	X	Phthalic acid (50%)	X	X
Methanol	X	X	Polyglycols	X	X
Methyl butanol	X	X	Potassium bichromate (40%)	X	X
Methyl ethyl ketone	X	/ to —	Potassium borate, aqueous (1%)	X	X
Methyl glycol	X	X	Potassium bromate, aqueous (up to 10%)	X	X
Methylene chloride	/	/	Potassium bromide	*X	X
Mineral oils	X	X to /	Potassium chloride	*X	X
Molasses	X	X	Potassium chromate, aqueous (40%)	X	
Monochloroacetic acid	X	X	Potassium cyanide	*X	X
Monochloroacetic ethyl ester	X	X	Potassium hydroxide (30% solution)	X	X
Monochloroacetic methyl ester	X	X	Potassium nitrate	*X	X
Morpholine	X	X	Potassium permanganate	X	XD
Naptha	X	/	Propanol	X	X
Naphthalene	X	/	Propionic acid (50%)	X	X
Nickel salts	*X	X	Propionic acid (100%)	X	/

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<i>Medium</i>	73°F	140°F	<i>Medium</i>	73°F	140°F
Propylene glycol	X	X	Thiophene	/	/
Pseudocumene	/	/	Toluene	/	—
Pyridine	X	/	Transformer oil	X	/
Seawater	X	X	Tributyl phosphate	X	X
Silicic acid	X	X	Trichloroacetic acid (50%)	X	X
Silicone oil	X	X	Trichloroacetic acid (100%)	X	/ to —
Silver nitrate	X	X	Trichloroethylene	**X to /	—
Sodium benzoate	X	X	Triethanolamine	X	X
Sodium bisulphite, weak aqueous solutions	X	X	Turpentine, oil of	x to /	/
Sodium carbonate	*X	X	Tween 20 and 90 (Atlas Chemicals)	X	X
Sodium chloride	*X	X	Urea	*X	X
Sodium chlorite (50%)	X	/	Vinegar (commercial conc.)	X	X
Sodium hydroxide (30% solution)	X	X	Viscose spinning solutions	X	X
Sodium hypochlorite (12% active chlorine)	/	—	Waste gases containing		
Sodium nitrate	*X	X	carbon dioxide	X	X
Sodium silicate	*X	X	carbon monoxide	X	X
Sodium sulfide	*X	X	hydrochloric acid (all conc.)	X	X
Sodium thiosulphate	X	X	hydrogen fluoride (traces)	X	X
Spermaceti	X	/	nitrous vitriol (traces)	X	X
Spindle oil	X to /	/	sulfur dioxide (low conc.)	X	X
Starch	X	X	sulphuric acid, moist (all conc.)	X	X
Steric acid	X	/	Water gas	X	X
Succinic acid (50%)	X	X	Xylene	—	—
Sugar syrup	X	X	Yeast, aqueous preparations	X	X
Sulfates	*X	X	Zinc chloride	*X	X
Sulfur	X	X			
Sulfur dioxide, dry	X	X			
Sulfur dioxide, moist	X	X			
Sulfur trioxide	—	—			
Sulfuric acid (10%)	X	X			
Sulfuric acid (50%)	X	X			
Sulfuric acid (98%)	/	—			
Sulfuric acid, fuming	—	—			
Sulfurous acid	X	X			
Sulfuryl chloride	—				
Tallow	X	X			
Tannic acid (10%)	X	X			
Tartaric acid	X	X			
Tetrachloroethane	**X to /	—			
Tetrahydrofurane	**X to /				
Tetrahydronaphthalene	X	/			
Thionyl chloride	—	—			

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SUNDANCE WEST**

**VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 6: GEOSYNTHETICS APPLICATIONS AND
COMPATIBILITY DOCUMENTATION**

**ATTACHMENT III.6.F
PVC PIPE REFERENCE DOCUMENTATION**

PVC Chemical Resistance

KEY — E = Excellent G = Good L = Limited U = Unsuitable O = No test

Chemical	PVC I		PVC II		Chemical	PVC I		PVC II	
	72°F.	140°F.	72°F.	140°F.		72°F.	140°F.	72°F.	140°F.
Acetaldehyde	U	U	U	U	Beet - Sugar Liquor	E	E	E	E
Acetamide	O	O	U	U	Benzaldehyde	U	U	U	U
Acetate Solvents - Crude	U	U	U	U	Benzene	U	U	U	U
Acetate Solvents - Pure	U	U	U	U	Benzenesulfonic Acid - 10%	E	E	E	E
Acetic Acid 0-10%	E	E	G	L	Benzenesulfonic Acid	U	U	U	U
Acetic Acid 10-20%	E	E	G	L	Benzoic Acid	E	E	E	E
Acetic Acid 20-30%	E	G	G	L	Benzol	U	U	U	U
Acetic Acid 30-60%	E	E	G	L	Bismouth Carbonate	E	E	E	E
Acetic Acid 80%	G	L	L	L	Black Liquor (Paper Industry)	E	E	E	E
Acetic Acid - Glacial	G	U	L	U	Bleach - 12.5% Active Cl ₂	E	G	G	L
Acetic Acid - Vapors	E	U	U	U	Borax	E	E	E	E
Acetic Anhydride	U	U	U	U	Borax Liquors	E	E	E	E
Acetone	U	U	U	U	Boric Acid	E	E	E	E
Acetylene	L	L	U	U	Boron, TriFluoride	E	E	E	E
Adipic Acid	E	E	E	E	Breeder Pellets - Fish Deriv.	E	E	E	E
Alcohol - Allyl - 96%	G	L	L	U	Brine	E	E	E	E
Alcohol - Amyl	E	L	L	U	Bromic Acid	E	E	E	E
Alcohol - Butyl	E	G	L	U	Bromine - Liquid	U	U	U	U
Alcohol - Ethyl	E	E	L	G	Bromine (Gas) - 25%	U	U	U	U
Alcohol - Methyl	E	E	E	E	Bromine - Water	E	E	L	U
Alcohol - Propargyl	E	E	E	E	Butadiene	E	E	E	E
Alcohol - Propyl	E	E	E	G	Butane	E	E	E	E
Allyl - Chloride	U	U	U	U	Butane, Butylene	E	E	E	E
Alum	E	E	E	E	Butane, Diol	E	E	E	E
Alum, Ammonium	E	E	E	E	Butanol	E	U	U	U
Alum, Chrome	E	E	E	E	Butanol - Primary	E	E	U	U
Alum, Potassium	E	E	E	E	Butanol - Secondary	E	L	U	U
Aluminum Chloride	E	E	E	E	Butter milk	E	E	E	E
Aluminum Fluoride	E	E	E	E	Butyl Acetate	U	U	U	U
Aluminum Hydroxide	E	E	E	E	Butyl Phenol	E	U	L	U
Aluminum Oxychloride	E	E	E	E	Butylene	E	O	E	O
Aluminum Nitrate	E	E	E	E	Butynediol (Erthritol)	E	U	U	U
Aluminum Sulfate	E	E	E	E	Butyric Acid 20%	G	U	U	U
Ammonia - Dry Gas	E	E	E	E	Butyric Acid	E	U	L	U
Ammonia, Aqua (10%)	E	E	E	E	Calcium Bisulfide	E	E	E	E
Ammonia - Liquid	L	U	O	O	Calcium Bisulfite	E	E	E	E
Ammonium Acetate	E	E	E	E	Calcium Carbonate	E	E	E	E
Ammonium BiFluoride	E	E	E	E	Calcium Chlorate	E	E	E	E
Ammonium Carbonate	E	E	E	E	Calcium Chloride	E	E	E	E
Ammonium Chloride	E	E	E	E	Calcium Hydroxide	E	E	E	E
Ammonium Fluoride - 25%	E	L	U	U	Calcium Hypochlorite	E	E	E	E
Ammonium Hydroxide - 28%	E	E	E	E	Calcium Nitrate	E	E	E	E
Ammonium Metaphosphate	E	E	E	E	Calcium Oxide	E	E	E	U
Ammonium Monophosphate	E	E	E	E	Calcium Sulfate	E	E	E	E
Ammonium Nitrate	E	E	E	E	Cane Sugar Liquors	E	E	E	E
Ammonium Persulfate	E	E	E	E	Carbic Acid	E	E	E	E
Ammonium Phosphatel (Ammoniacal)	E	E	O	O	Carbon Bisulfide	U	U	U	U
Ammonium Phosphate - Neutral	E	E	E	E	Carbon Dioxide (Aqueous S.L.)	E	E	E	E
Ammonium Sulfate	E	E	E	E	Carbon Dioxide Gas (Wet)	E	E	E	E
Ammonium Sulfide	E	E	E	E	Carbon Monoxide	E	E	E	E
Ammonium Thiocyanate	U	U	U	U	Carbon Tetrachloride	L	U	U	U
Amyl Acetate	U	U	U	U	Carbonated Water	E	E	E	E
Amyl Chloride	U	U	U	U	Carbonic Acid	E	E	E	E
Aniline	U	U	U	U	Casein	E	E	E	E
Aniline Chlorohydrate	U	U	U	U	Castor Oil	E	E	E	E
Aniline Dyes	U	U	U	U	Caustic Potash	E	E	E	E
Aniline Hydrochloride	U	U	U	U	Caustic Soda	E	E	E	E
Anthraquinone	E	E	E	L	Cellosolve	G	L	L	U
Anthraquinonesulfonic Acid	E	E	E	E	Chloracetic Acid	E	E	E	E
Anitimony Trichloride	E	E	E	E	Chloral Hydrate	E	E	E	E
Aqua Regia	E	L	U	U	Chloric Acid 20%	E	E	E	E
Arsenic Acid - 80%	E	G	U	G	Chlorinated Solvents	U	U	U	U
Arylsulfonic Acid	E	E	L	E	Chlorine (Dry)	E	L	L	L
Asphalt	E	E	E	E	Chlorine Gas (Moist)	G	L	L	L
Barium Carbonate	E	E	E	E	Chlorine Water	E	E	E	E
Barium Chloride	E	E	E	E	Chloroacetic Acid	E	E	E	E
Barium Hydroxide	E	E	E	E	Chlorobenzene	U	U	U	U
Barium Sulfate	E	E	E	E	Chlorobenzyl Chloride	U	U	U	U
Barium Sulfide	E	E	E	E	Chloro Form	U	U	U	U
Beer	E	E	E	E	Chlorosulfonic Acid (100%)	E	U	O	O
					Chrome Alum	E	E	E	E

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Chemical	PVC I		PVC II		Chemical	PVC I		PVC II	
	72 °F.	140 °F.	72 °F.	140 °F.		72 °F.	140 °F.	72 °F.	140 °F.
Chromic Acid 10%	E	E	E	E	Gas - Natural (Wet)	E	E	E	E
Chromic Acid 25%	E	L	G	L	Gasoline (Leaded)	E	E	E	E
Chromic Acid 30%	E	L	G	L	Gasoline (unleaded)	E	E	E	E
Chromic Acid 40%	E	L	L	L	Gasoline - Refined	E	E	E	E
Chromic Acid 50%	E	L	L	L	Gasoline - Sour	E	E	E	E
Citric Acid	E	E	E	E	Gelatin	E	E	E	E
Coconut Oil	E	E	E	E	Glucose	E	E	E	E
Coke Oven Gas	E	E	E	E	Glycerine (Glycerol)	E	E	E	E
Copper Carbonate	E	E	E	E	Glycol	E	E	E	E
Copper Chloride	E	E	E	E	Glue	E	E	E	E
Copper Cyanide	E	E	E	E	Glycolic Acid 30%	E	E	E	E
Copper Fluoride	E	E	E	E	Green Liquor (Paper Industry)	E	E	E	E
Copper Nitrate	E	E	E	E	Heptane	E	G	L	U
Copper Sulfate	E	E	E	E	Hexane	E	L	L	U
Care Oils	E	E	E	E	Hexanol Tertiary	E	L	L	U
Corn Oil	E	E	E	E	Hydrobromic Acid - 20%	E	E	E	G
Corn Syrup	E	E	E	E	Hydrochloric Acid - 0-25%	E	G	E	E
Cottonseed Oil	E	E	E	E	Hydrochloric Acid - 25-40%	E	E	E	G
Cresol	U	U	U	U	Hydrocyanic Acid or				
Cresylic Acid 50%	U	U	L	U	Hydrogen Cyanide	E	E	E	E
Croton Aldehyde	U	U	U	U	Hydrofluoric Acid 4%	E	L	G	G
Crude Oil - Sour	E	E	E	E	Hydrofluoric Acid 10%	E	L	L	U
Crude Oil - Sweet	E	E	E	E	Hydrofluoric Acid 48%	E	L	G	U
Cuprous Chloride	E	E	E	E	Hydrofluoric Acid 60%	E	L	G	U
Cyclohexane	U	U	U	U	Hydrofluoric Acid 100%	G	L	G	U
Cyclohexanol	U	U	U	U	Hydrogen	E	E	E	L
Cyclohexanon	U	U	U	U	Hydrogen Peroxide - 30%	E	E	E	G
					Hydrogen Peroxide - 50%	E	E	E	L
					Hydrogen Peroxide - 90%	E	E	U	U
Deminerlized Water	E	E	E	E	Hydrogen Sulfide - Aqueous				
Dextrin	E	E	E	E	Solution	E	E	E	E
Dextrose	E	E	E	E	Hydrogen Sulfide - Dry	E	E	E	E
Diazo Salts	E	E	E	E	Hydroquinone	E	E	E	E
Diesel Fuels	E	E	E	E	Hydroxylamine Sulfate	E	E	E	E
Diethye Amine	U	U	U	U	Hypochlorous Acid	E	E	E	E
Diocylphthalate	U	U	U	U	Hypo-(Sodium Thiosulfate)	E	E	E	E
Disodium Phosphate	U	U	U	U	Iodine	U	U	U	U
Diethyl Ether	U	U	U	U	Iodine (in Alcohol)	U	U	U	U
Diglycolic Acid	E	E	E	E	Iodine Solution (10%)	U	U	U	U
Dioxane - 1,4	O	O	O	O	Iodoform	O	O	O	O
Divinyl Benzene	O	O	O	O	Isopropylalcohol	E	E	E	G
Drying Oil	O	O	O	O	Jet Fuels, JP4 & JP5	E	E	E	E
Ethers	U	U	U	U	Kerosene	E	E	E	E
Ethyl Acetate	U	U	U	U	Ketones	U	U	U	U
Ethyl Acrylate	U	U	U	U	Kraft Liquor (Paper Industry)	E	E	E	E
Ethyl Chloride	U	U	U	U	Lacquer Thinners	L	U	L	U
Ethyl Ether	U	U	U	U	Lactic Acid 28%	E	E	E	E
Ethylene Bromide	U	U	U	U	Lard Oil	E	E	E	G
Ethylene Chlorohydrin	U	U	U	U	Lauric Acid	E	E	E	E
Ethylene Dichloride	U	U	U	U	Lauryl Chloride	E	E	E	E
Ethylene Glycol	E	E	E	E	Lauryl Sulfate	E	E	E	E
Ethylene Oxide	U	U	U	U	Lead Acetate	E	E	E	E
Fatty Acide	E	E	E	E	Lime Sulfur	E	E	E	E
Ferric Chloride	E	E	E	E	Linoleic Acid	E	E	E	E
Ferric Nitrate	E	E	E	E	Linseed Oil	E	E	E	E
Ferric Sulfate	E	E	E	E	Liquers	E	E	E	E
Ferrous Nitrate	E	E	E	E	Liquors	E	E	E	E
Fish Solubles	E	E	E	E	Lithium Bromide	E	E	E	E
Flourine Gas - Dry	L	U	U	U	Lubricating Oil	E	E	E	E
Flourine Gas - Wet	L	U	U	U	Machine Oil	E	E	E	E
Fluoroboric Acid - 25%	E	E	E	E	Magnesium Carbonate	E	E	E	E
Fluorosilicic Acid	E	E	E	E	Magnesium Chloride	E	E	E	E
Formaldehyde	E	G	G	L	Magnesium Citrate	E	E	E	E
Food Products such as Milk,					Magnesium Hydroxide	E	E	E	E
Buttermilk, Molasses, Salad					Magnesium Nitrate	E	E	E	E
Oils, Fruit	E	E	E	E	Magnesium Sulfate	E	E	E	E
Formic Acid	E	U	E	U	Maleic Acid	E	E	E	E
Freon - 12	E	G	E	G	Malic Acid	E	E	E	E
Fructose	E	E	E	E	Mercuric Chloride	E	E	G	G
Fruit Pulps and Juices	E	E	E	E	Mercuric Cyanide	E	E	G	G
Fuel Oil (containing H ₂ SO ₄)	E	U	U	U	Mercurous Nitrate	E	E	G	G
Furfural	U	U	U	U	Mercury	E	E	G	G
Gallic Acid	E	E	E	E					
Gas - Coke Oven	E	E	G	G					
Gas - Manufactured	U	U	U	U					
Gas - Natural (Dry)	E	E	E	E					

Chemical	PVC I		PVC II		Chemical	PVC I		PVC II	
	72 °F.	140 °F.	72 °F.	140 °F.		72 °F.	140 °F.	72 °F.	140 °F.
Methane	E	E	E	E	Photographic Solutions	E	E	E	E
Methyl Bromide	U	U	U	U	Phthalic Acid	O	O	O	O
Methyl Cellosolve	U	U	U	U	Picric Acid	U	U	U	U
Methyl Chloride	U	U	U	U	Plating Solutions:				
Methyl Chloroform	U	U	U	U	Brass	E	E	E	E
Methyl Ethyl Ketone	U	U	U	U	Cadium	E	E	E	E
Methyl Iso-Butyl Ketone	U	U	U	U	Chromium	E	E	E	E
Methyl Salicylate	E	E	E	E	Copper	E	E	E	E
Methyl Sulfate	E	E	E	E	Gold	E	E	E	E
Methyl Sulfonic Acid	E	E	E	E	Iron	E	E	E	E
Methyl Sulfuric Acid	E	E	E	E	Judium	E	E	E	E
Methylene Chloride	E	E	E	E	Lead	E	E	E	E
Milk	E	E	E	E	Nickel	E	E	E	E
Mineral Oils	E	E	E	E	Rhodium	E	E	E	E
*Mixed Acids (H ₂ SO ₄ & HNO ₃)	E	E	E	E	Silver	E	E	E	E
Molasses	E	E	E	E	Tin	E	E	E	E
Monoethanolamine	E	E	E	E	Zinc	E	E	E	E
Muriatic Acid	E	E	E	E	Potassium Acid Sulfate	E	E	E	E
Naptha	E	E	E	E	Potassium Aluminum Sulfate	E	E	E	E
Napthalene	U	U	U	U	Potassium Alum	E	E	E	E
Natural Gas, Dry & Wet	E	E	E	E	Potassium Antimonate	E	E	E	E
Nickel Acetate	E	E	E	E	Potassium Bicarbonate	E	E	E	E
Nickel Chloride	E	E	E	E	Potassium Bichromate	E	E	E	E
Nickel Nitrate	E	E	E	E	Potassium Bisulfite	E	E	E	E
Nickel Sulfate	E	E	E	E	Potassium Borate 1%	E	E	E	E
Nickel Sulphate	E	E	E	E	Potassium Borate	E	E	E	E
Nicotine	E	E	E	E	Potassium Bromate 10%	E	E	E	E
Nicotine Acid	E	E	E	E	Potassium Bromate	E	E	E	E
Nitric Acid Anhydrous	U	U	U	U	Potassium Bromide	E	E	E	E
Nitric Acid 10%	E	E	E	E	Potassium Carbonate	E	E	E	E
Nitric Acid 20%	E	E	E	E	Potassium Chlorate (ag)	E	E	E	E
Nitric Acid 35%	E	E	E	E	Potassium Chlorate	E	E	E	E
Nitric Acid 40%	E	E	E	E	Potassium Chloride	E	E	E	E
Nitric Acid 60%	E	E	E	E	Potassium Chromate (Aln)	E	E	E	E
Nitric Acid 68%	E	E	E	E	Potassium Chromate (Neut.)	E	E	E	E
Nitric Acid 70%	E	E	E	E	Potassium Chromate 40%	E	E	E	E
Nitric Acid 100%	E	E	E	E	Potassium Cuprocyanide	E	E	E	E
Nitric Acid, Red Fuming	U	U	U	U	Potassium Cyanide	E	E	E	E
Nitrobenzene	U	U	U	U	Potassium Dichromate 40%	E	E	E	E
Nitropropane	O	O	O	O	Potassium Dichromate	E	E	E	E
Nitrous Acid (10%)	E	E	E	E	Potassium Dichrom (Alkaline)	E	E	E	E
Nitrous Oxide	E	E	E	E	Potassium Dichrom (Neutral)	E	E	E	E
Oenol (Unsaturated Alcohol)	E	E	E	E	Potassium Diphosphate	E	E	E	E
Oil and Fats	E	E	E	E	Potassium Ferricyanide	E	E	E	E
Oleic Acid	E	E	E	E	Potassium Ferrocyanide	E	E	E	E
Oleum	U	U	U	U	Potassium Fluoride	E	E	E	E
Oxalic Acid	E	E	E	E	Potassium Hydroxide	E	E	E	E
Oxygen	E	E	E	E	Potassium Hypochlorite	E	E	E	E
Ozone	G	L	U	U	Potassium Iodide	E	E	E	E
Palmitic Acid 10%	E	E	E	E	Potassium Nitrate	E	E	E	E
Palmitic Acid 70%	E	E	E	E	Potassium Perborate	E	E	E	E
Paraffin	E	E	E	E	Potassium Perchlorate	E	E	E	E
Pentane	O	O	O	O	Potassium Perchlorite	E	E	E	E
Paracetic Acid 40%	E	E	E	E	Potassium Permanganate 10%	E	E	E	E
Perchloric Acid 10%	E	E	E	E	Potassium Permanganate 25%	G	L	U	U
Perchloric Acid 15%	E	E	E	E	Potassium Persulfate	E	E	E	E
Perchloric Acid 70%	E	E	E	E	Potassium Sulfate	E	E	E	E
Perchloroethylene	O	O	O	O	Potassium Sulfide	E	E	E	E
Petrolatum	E	E	E	E	Potassium Thiosulfate	E	E	E	E
Phenol	E	E	E	E	Propane	E	E	E	E
Phenol (90%)	U	U	U	U	Propylene Dichloride	U	U	U	U
Phenylhydrazine	U	U	U	U	Propylene Glycol	E	E	E	E
Phenylhydrazine Hydrochloride	E	U	L	U	Pyrogalllic Acid	O	O	O	O
Phosgene (Gas)	E	U	L	U	Rayon Coagulating Bath	E	E	E	E
Phosgene (Liquid)	E	U	L	U	Rachelle Salts	E	E	E	E
Phosphoric Acid 0-25%	E	E	E	E	Sea Water	E	E	E	E
Phosphoric Acid 25-50%	E	E	E	E	Salen's Acid (Aqueous)	O	O	O	O
Phosphoric Acid 50-75%	E	E	E	E	Salicylaldehyde	O	O	O	O
Phosphoric Acid - 85%	E	E	E	E	Salt Water	E	E	E	E
Phosphorous (Yellow)	E	E	E	E	Selenic Acid	E	E	E	E
Phosphorous (Red)	E	E	E	E	Sewage	E	E	E	E
Phosphorous Pentoxide	E	E	E	E	Sillicic Acid	E	E	E	E
Phosphorous Trichloride	E	E	E	E	Silver Cyanide	E	E	E	E
Photographic Chemicals	E	E	E	E	Silver Nitrate	E	E	E	E
					Silver Sulfate	E	E	E	E
					Soap Solution	E	E	E	E

*Use PVC 1120

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Chemical	PVC I		PVC II		Chemical	PVC I		PVC II	
	72°F.	140°F.	72°F.	140°F.		72°F.	140°F.	72°F.	140°F.
Soaps	E	E	E	E	Sulphuric Acid 50-75%	E	E	E	G
Sodium Acetate	E	E	E	E	Sulphuric Acid 75-90%	E	E	L	L
Sodium Alum	E	E	E	E	Sulphuric Acid 95%	E	G	U	U
Sodium Acid Sulfate	E	E	E	E	Sulphurous Acid	G	U	L	U
Sodium Aluminate	E	E	E	E	Tan Oil	E	E	E	E
Sodium Antimonate	E	E	E	E	Tannic Acid	E	E	E	E
Sodium Arsenite	E	E	E	E	Tanning Liquors	E	E	E	E
Sodium Benzoate	E	E	E	E	Tartaric Acid	E	E	E	E
Sodium Bicarbonate	E	E	E	E	Tetrachloroethane	O	O	O	O
Sodium Bisulfate	E	E	E	E	Tetraethyl Lead	E	G	G	L
Sodium Bisulfite	E	E	E	E	Tetrahydro Furane	U	U	U	U
Sodium Borate	E	E	E	E	Thionyl Chloride	U	U	U	U
Sodium Bromide	E	E	E	E	Tepineol	G	L	G	L
Sodium Carbonate (Soda Ash)	E	E	E	E	Tin Chloride	E	E	E	E
Sodium Chlorate	E	G	G	L	Titanium Tetrachloride	E	U	U	U
Sodium Chloride	E	E	E	E	Toluol or Toluene	U	U	U	U
Sodium Chlorite	E	E	O	O	Toxaphene (90%)	O	O	O	O
Sodium Cyanide	E	E	E	E	Tributyl Phosphate	U	U	U	U
Sodium Dichromate	E	E	E	E	Trichloroacetic Acid	E	E	E	E
Sodium Dichromate (Neutral)	E	E	E	E	Trichloroethylene	U	U	U	U
Sodium Ferricyanide	E	E	E	E	Tricresylphosphate	U	U	U	U
Sodium Ferrocyanide	E	E	E	E	Triethanolamine	E	E	G	G
Sodium Fluoride	E	E	E	E	Triethylamine	E	G	G	L
Sodium Hydroxide 10%	E	E	E	E	Trimethyl Propane	E	E	E	E
Sodium Hydroxide 15%	E	E	E	E	Trisodium Phosphate	E	E	E	E
Sodium Hydroxide 35%	E	E	E	E	Turpentine	E	E	E	U
Sodium Hydroxide 70%	E	E	O	O	Urea	E	E	E	E
Sodium Hydroxide (Satr)	E	E	E	E	Urine	E	E	E	E
Sodium Hypochlorite	E	E	E	E	Vegetable Oil	E	E	E	E
Sodium Iodide	E	E	E	E	Vinegar	E	E	E	U
Sodium Nitrate	E	E	E	E	Vinyl Acetate	U	U	U	U
Sodium Nitrite	E	E	E	E	Water - Acid Mine	E	E	E	E
Sodium Perborate	E	E	O	O	Water - Distilled	E	E	E	E
Sodium Peroxide	E	E	E	E	Water - Fresh	E	E	E	E
Sodium Phosphate	E	E	E	E	Water - Salt	E	E	E	E
Sodium Phosphate - Acid	E	E	E	G	Water - Sewage	E	E	E	E
Sodium Silicate	E	E	E	E	Whiskey	E	E	E	E
Sodium Sulfate	E	E	E	E	White Gasoline	E	E	E	E
Sodium Sulfide	E	E	E	E	White Liquor (Paper Industry)	E	E	E	E
Sodium Sulfite	E	E	E	E	Wines	E	E	E	E
Sodium Thiosulfate (Hypo)	E	E	E	E	Xylene or Xylol	U	U	U	U
Sour Crude Oil	E	E	E	E	Zinc Chloride	E	E	E	E
Stannic Chloride	E	E	E	E	Zinc Chromate	E	E	E	E
Stannous Chloride (50%)	E	E	E	E	Zinc Cyanide	E	E	E	E
Stannous Chloride	E	G	E	E	Zinc Nitrate	E	E	E	E
Starch	E	E	E	E	Zinc Sulfate	E	E	E	E
Stearic Acid	E	E	E	E	Mixtures of Acids:				
Stoddards Solvent	E	E	U	U	Nitric 15%				
Sulfated Detergents	E	E	E	E	Hydrofluoric 4%	E	E	E	G
Sulfur	E	E	E	E	Sodium Dichromate 13%				
Sulfur Dioxide Gas - Dry	E	E	E	E	Nitric Acid 16				
*Sulfur Dioxide Gas - Wet	E	L	U	U	Water 71%	E	E	E	G
Sulfur Trioxide	E	E	E	G					
Sulphur Dioxide - Liquid	G	U	L	U					
Sulphuric Acid 0-10%	E	E	E	G					
Sulphuric Acid 10-30%	E	E	E	G					
Sulphuric Acid 30-50%	E	E	E	G					

*Use PVC 1120

This information has been obtained from reliable sources and can be used as a guide to assist in the proper application of PVC pipe. CertainTeed, however, cannot warrant its accuracy. It is suggested that you run your own tests for critical applications.

Pipe & Plastics Group

CertainTeed Corporation
P.O. Box 860
Valley Forge, PA 19482
(610) 341-6820
(610) 341-6837 Fax

Code No. 40-10-29

Printed in U.S.A.
0398

**APPLICATION FOR PERMIT
SUNDANCE WEST**

**VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 6: GEOSYNTHETICS APPLICATIONS AND
COMPATIBILITY DOCUMENTATION**

**ATTACHMENT III.6.G
SUNDANCE WEST SOLID WASTE AND WASTEWATER
LABORATORY RESULTS**

COVER LETTER

Wednesday, January 27, 2010

Mike Crepeau
Gordon Environmental, Inc.
213 S. Camino del Pueblo
Bernalillo, NM 87004
TEL: (505) 867-6990
FAX (505) 867-6991

RE: SSI

Order No.: 1001152

Dear Mike Crepeau:

Hall Environmental Analysis Laboratory, Inc. received 4 sample(s) on 1/13/2010 for the analyses presented in the following report.

These were analyzed according to EPA procedures or equivalent. Below is a list of our accreditations. To access our accredited tests please go to www.hallenvironmental.com or the state specific web sites.

Reporting limits are determined by EPA methodology. No determination of compounds below these (denoted by the ND or < sign) has been made.

Please don't hesitate to contact HEAL for any additional information or clarifications.

Sincerely,


Andy Freeman, Laboratory Manager

NM Lab # NM9425 NM0901
AZ license # AZ0682
ORELAP Lab # NM100001
Texas Lab# T104704424-08-TX



CLIENT: Gordon Environmental, Inc.
Project: SSI
Lab Order: 1001152

CASE NARRATIVE

Analytical Comments for METHOD 8260_W, SAMPLE 1001152-02a: necessary dilution due to late eluting hydrocarbons

Hall Environmental Analysis Laboratory, Inc.

Date: 27-Jan-10

CLIENT: Gordon Environmental, Inc.
Lab Order: 1001152
Project: SS1
Lab ID: 1001152-01

Client Sample ID: MP-4P
Collection Date: 1/12/2010 8:25:00 AM
Date Received: 1/13/2010
Matrix: AQUEOUS

Analyses	Result	PQL	Qual	Units	DF	Date Analyzed
EPA METHOD 300.0: ANIONS						
						Analyst: TAF
Fluoride	5.7	1.0		mg/L	10	1/27/2010 10:02:52 AM
Chloride	25	5.0		mg/L	10	1/27/2010 10:02:52 AM
Nitrate (As N)+Nitrite (As N)	ND	1.0		mg/L	5	1/27/2010 10:20:16 AM
Phosphorus, Orthophosphate (As P)	ND	0.50	H	mg/L	1	1/27/2010 8:18:26 AM
Sulfate	25	0.50		mg/L	1	1/27/2010 8:18:26 AM
EPA METHOD 7470: MERCURY						
						Analyst: SNV
Mercury	ND	0.00020		mg/L	1	1/21/2010 4:37:07 PM
EPA 6010B: TOTAL RECOVERABLE METALS						
						Analyst: SNV
Arsenic	ND	0.020		mg/L	1	1/24/2010 5:21:34 PM
Barium	1.7	0.10		mg/L	5	1/24/2010 5:44:24 PM
Cadmium	ND	0.0020		mg/L	1	1/24/2010 5:21:34 PM
Calcium	110	5.0		mg/L	5	1/24/2010 5:44:24 PM
Chromium	0.035	0.0060		mg/L	1	1/24/2010 5:21:34 PM
Iron	28	2.5		mg/L	50	1/24/2010 5:46:42 PM
Lead	0.0068	0.0050		mg/L	1	1/24/2010 5:21:34 PM
Magnesium	14	1.0		mg/L	1	1/24/2010 5:21:34 PM
Potassium	12	1.0		mg/L	1	1/24/2010 5:21:34 PM
Selenium	ND	0.050		mg/L	1	1/24/2010 5:21:34 PM
Silver	ND	0.0050		mg/L	1	1/24/2010 5:21:34 PM
Sodium	76	1.0		mg/L	1	1/24/2010 5:21:34 PM
EPA METHOD 8260B: VOLATILES						
						Analyst: DAM
Benzene	ND	1.0		µg/L	1	1/14/2010 11:47:25 PM
Toluene	ND	1.0		µg/L	1	1/14/2010 11:47:25 PM
Ethylbenzene	ND	1.0		µg/L	1	1/14/2010 11:47:25 PM
Acetone	ND	10		µg/L	1	1/14/2010 11:47:25 PM
2-Butanone	ND	10		µg/L	1	1/14/2010 11:47:25 PM
Xylenes, Total	ND	1.5		µg/L	1	1/14/2010 11:47:25 PM
Surr: 1,2-Dichloroethane-d4	99.3	54.6-141		%REC	1	1/14/2010 11:47:25 PM
Surr: 4-Bromofluorobenzene	99.4	60.1-133		%REC	1	1/14/2010 11:47:25 PM
Surr: Dibromofluoromethane	107	78.5-130		%REC	1	1/14/2010 11:47:25 PM
Surr: Toluene-d8	98.9	79.5-126		%REC	1	1/14/2010 11:47:25 PM
SM 2320B: ALKALINITY						
						Analyst: DAM
Alkalinity, Total (As CaCO3)	190	20		mg/L CaCO3	1	1/15/2010 4:52:00 PM
Carbonate	ND	2.0		mg/L CaCO3	1	1/15/2010 4:52:00 PM
Bicarbonate	190	20		mg/L CaCO3	1	1/15/2010 4:52:00 PM
EPA 120.1: SPECIFIC CONDUCTANCE						
						Analyst: DAM
Specific Conductance	560	0.010		µmhos/cm	1	1/15/2010 4:52:00 PM

Qualifiers:

- * Value exceeds Maximum Contaminant Level
- E Estimated value
- J Analyte detected below quantitation limits
- ND Not Detected at the Reporting Limit
- S Spike recovery outside accepted recovery limits

- B Analyte detected in the associated Method Blank
- H Holding times for preparation or analysis exceeded
- MCL Maximum Contaminant Level
- RL Reporting Limit

Hall Environmental Analysis Laboratory, Inc.

Date: 27-Jan-10

CLIENT: Gordon Environmental, Inc.	Client Sample ID: MP-4P
Lab Order: 1001152	Collection Date: 1/12/2010 8:25:00 AM
Project: SSI	Date Received: 1/13/2010
Lab ID: 1001152-01	Matrix: AQUEOUS

Analyses	Result	PQL	Qual	Units	DF	Date Analyzed
EPA 120.1: SPECIFIC CONDUCTANCE						Analyst: DAM
SM4500-H+B: PH						
pH	8.18	0.1		pH units	1	1/15/2010 4:52:00 PM Analyst: DAM
SM2540C MOD: TOTAL DISSOLVED SOLIDS						Analyst: MMS
Total Dissolved Solids	298	40.0		mg/L	1	1/19/2010 8:35:00 AM

Qualifiers:

- * Value exceeds Maximum Contaminant Level
- E Estimated value
- J Analyte detected below quantitation limits
- ND Not Detected at the Reporting Limit
- S Spike recovery outside accepted recovery limits

- B Analyte detected in the associated Method Blank
- H Holding times for preparation or analysis exceeded
- MCL Maximum Contaminant Level
- RL Reporting Limit

Hall Environmental Analysis Laboratory, Inc.

Date: 27-Jan-10

CLIENT: Gordon Environmental, Inc.
Lab Order: 1001152
Project: SSI
Lab ID: 1001152-02

Client Sample ID: Tank
Collection Date: 1/12/2010 3:10:00 PM
Date Received: 1/13/2010
Matrix: AQUEOUS

Analyses	Result	PQL	Qual	Units	DF	Date Analyzed
EPA METHOD 300.0: ANIONS						
						Analyst: TAF
Fluoride	1.2	1.0		mg/L	10	1/27/2010 8:35:50 AM
Chloride	420	25		mg/L	50	1/16/2010 4:57:51 AM
Nitrogen, Nitrate (As N)	2.6	1.0		mg/L	10	1/14/2010 12:43:16 PM
Phosphorus, Orthophosphate (As P)	ND	5.0		mg/L	10	1/14/2010 12:43:16 PM
Sulfate	140	5.0		mg/L	10	1/14/2010 12:43:16 PM
EPA 6010B: HARDNESS						
						Analyst: SNV
Hardness (As CaCO3)	260	1.0		mg/L	1	1/24/2010
EPA METHOD 7470: MERCURY						
						Analyst: SNV
Mercury	ND	0.00020		mg/L	1	1/21/2010 4:38:56 PM
EPA 6010B: TOTAL RECOVERABLE METALS						
						Analyst: SNV
Strontium	0.78	0		mg/L	5	1/24/2010 5:56:05 PM
Aluminum	0.34	0.040		mg/L	1	1/24/2010 5:23:55 PM
Arsenic	ND	0.040		mg/L	1	1/24/2010 5:23:55 PM
Barium	0.43	0.040		mg/L	1	1/24/2010 5:23:55 PM
Cadmium	ND	0.0040		mg/L	1	1/24/2010 5:23:55 PM
Calcium	75	2.0		mg/L	1	1/24/2010 5:23:55 PM
Chromium	ND	0.012		mg/L	1	1/24/2010 5:23:55 PM
Copper	0.028	0.012		mg/L	1	1/24/2010 5:23:55 PM
Iron	22	2.0		mg/L	20	1/24/2010 5:49:03 PM
Lead	ND	0.010		mg/L	1	1/24/2010 5:23:55 PM
Magnesium	18	2.0		mg/L	1	1/24/2010 5:23:55 PM
Manganese	0.44	0.0040		mg/L	1	1/24/2010 5:23:55 PM
Potassium	59	2.0		mg/L	1	1/24/2010 5:23:55 PM
Selenium	ND	0.10		mg/L	1	1/24/2010 5:23:55 PM
Silver	ND	0.010		mg/L	1	1/24/2010 5:23:55 PM
Sodium	130	2.0		mg/L	1	1/24/2010 5:23:55 PM
Silica	38	11		mg/L	5	1/24/2010 5:56:05 PM
EPA METHOD 8260B: VOLATILES						
						Analyst: DAM
Benzene	ND	50		µg/L	50	1/19/2010 11:12:23 AM
Toluene	56	50		µg/L	50	1/19/2010 11:12:23 AM
Ethylbenzene	ND	50		µg/L	50	1/19/2010 11:12:23 AM
Acetone	600	500		µg/L	50	1/19/2010 11:12:23 AM
2-Butanone	ND	500		µg/L	50	1/19/2010 11:12:23 AM
Xylenes, Total	ND	75		µg/L	50	1/19/2010 11:12:23 AM
Surr: 1,2-Dichloroethane-d4	99.2	54.6-141		%REC	50	1/19/2010 11:12:23 AM
Surr: 4-Bromofluorobenzene	101	60.1-133		%REC	50	1/19/2010 11:12:23 AM
Surr: Dibromofluoromethane	108	78.5-130		%REC	50	1/19/2010 11:12:23 AM
Surr: Toluene-d8	97.5	79.5-126		%REC	50	1/19/2010 11:12:23 AM

Qualifiers:

- * Value exceeds Maximum Contaminant Level
- E Estimated value
- J Analyte detected below quantitation limits
- ND Not Detected at the Reporting Limit
- S Spike recovery outside accepted recovery limits

- B Analyte detected in the associated Method Blank
- H Holding times for preparation or analysis exceeded
- MCL Maximum Contaminant Level
- RL Reporting Limit

Hall Environmental Analysis Laboratory, Inc.

Date: 27-Jan-10

CLIENT: Gordon Environmental, Inc.	Client Sample ID: Tank
Lab Order: 1001152	Collection Date: 1/12/2010 3:10:00 PM
Project: SSI	Date Received: 1/13/2010
Lab ID: 1001152-02	Matrix: AQUEOUS

Analyses	Result	PQL	Qual	Units	DF	Date Analyzed
EPA METHOD 8260B: VOLATILES						Analyst: DAM
EPA METHOD 9060: TOC						Analyst: SCC
Total Organic Carbon	1500	25		mg/L	25	1/14/2010 2:39:39 PM
SM 2320B: ALKALINITY						Analyst: DAM
Alkalinity, Total (As CaCO3)	200	20		mg/L CaCO3	1	1/15/2010 5:04:00 PM
Carbonate	ND	2.0		mg/L CaCO3	1	1/15/2010 5:04:00 PM
Bicarbonate	200	20		mg/L CaCO3	1	1/15/2010 5:04:00 PM
EPA 120.1: SPECIFIC CONDUCTANCE						Analyst: DAM
Specific Conductance	1800	0.010		µmhos/cm	1	1/15/2010 5:04:00 PM
SM 4500 NH3: AMMONIA						Analyst: KS
Ammonia	11	1.0		mg/L	1	1/20/2010 10:59:00 AM
SM4500-H+B: PH						Analyst: DAM
pH	8.14	0.1		pH units	1	1/15/2010 5:04:00 PM
SM2540C MOD: TOTAL DISSOLVED SOLIDS						Analyst: MMS
Total Dissolved Solids	3250	20.0		mg/L	1	1/19/2010 8:35:00 AM

Qualifiers:	* Value exceeds Maximum Contaminant Level	B Analyte detected in the associated Method Blank
	E Estimated value	H Holding times for preparation or analysis exceeded
	J Analyte detected below quantitation limits	MCL Maximum Contaminant Level
	ND Not Detected at the Reporting Limit	RL Reporting Limit
	S Spike recovery outside accepted recovery limits	

Hall Environmental Analysis Laboratory, Inc.

Date: 27-Jan-10

CLIENT: Gordon Environmental, Inc.
Lab Order: 1001152
Project: SSI
Lab ID: 1001152-03

Client Sample ID: Field Blank
Collection Date: 1/12/2010 2:50:00 PM
Date Received: 1/13/2010
Matrix: AQUEOUS

Analyses	Result	PQL	Qual	Units	DF	Date Analyzed
EPA METHOD 8260B: VOLATILES						Analyst: DAM
Benzene	ND	1.0		µg/L	1	1/15/2010 12:43:34 AM
Toluene	ND	1.0		µg/L	1	1/15/2010 12:43:34 AM
Ethylbenzene	ND	1.0		µg/L	1	1/15/2010 12:43:34 AM
Acetone	ND	10		µg/L	1	1/15/2010 12:43:34 AM
2-Butanone	ND	10		µg/L	1	1/15/2010 12:43:34 AM
Xylenes, Total	ND	1.5		µg/L	1	1/15/2010 12:43:34 AM
Surr: 1,2-Dichloroethane-d4	98.8	54.6-141		%REC	1	1/15/2010 12:43:34 AM
Surr: 4-Bromofluorobenzene	101	60.1-133		%REC	1	1/15/2010 12:43:34 AM
Surr: Dibromofluoromethane	107	78.5-130		%REC	1	1/15/2010 12:43:34 AM
Surr: Toluene-d8	98.8	79.5-128		%REC	1	1/15/2010 12:43:34 AM

Qualifiers:

- * Value exceeds Maximum Contaminant Level
- E Estimated value
- J Analyte detected below quantitation limits
- ND Not Detected at the Reporting Limit
- S Spike recovery outside accepted recovery limits

- B Analyte detected in the associated Method Blank
- H Holding times for preparation or analysis exceeded
- MCL Maximum Contaminant Level
- RL Reporting Limit

Hall Environmental Analysis Laboratory, Inc.

Date: 27-Jan-10

CLIENT: Gordon Environmental, Inc.
Lab Order: 1001152
Project: SSI
Lab ID: 1001152-04

Client Sample ID: Trip Blank
Collection Date:
Date Received: 1/13/2010
Matrix: AQUEOUS

Analyses	Result	PQL	Qual	Units	DF	Date Analyzed
EPA METHOD 8260B: VOLATILES						Analyst: DAM
Benzene	ND	1.0		µg/L	1	1/15/2010 1:11:47 AM
Toluene	ND	1.0		µg/L	1	1/15/2010 1:11:47 AM
Ethylbenzene	ND	1.0		µg/L	1	1/15/2010 1:11:47 AM
Acetone	ND	10		µg/L	1	1/15/2010 1:11:47 AM
2-Butanone	ND	10		µg/L	1	1/15/2010 1:11:47 AM
Xylenes, Total	ND	1.5		µg/L	1	1/15/2010 1:11:47 AM
Surr: 1,2-Dichloroethane-d4	99.2	54.6-141		%REC	1	1/15/2010 1:11:47 AM
Surr: 4-Bromofluorobenzene	98.4	60.1-133		%REC	1	1/15/2010 1:11:47 AM
Surr: Dibromofluoromethane	109	78.5-130		%REC	1	1/15/2010 1:11:47 AM
Surr: Toluene-d8	98.7	79.5-126		%REC	1	1/15/2010 1:11:47 AM

Qualifiers:

- * Value exceeds Maximum Contaminant Level
- E Estimated value
- J Analyte detected below quantitation limits
- ND Not Detected at the Reporting Limit
- S Spike recovery outside accepted recovery limits

- B Analyte detected in the associated Method Blank
- H Holding times for preparation or analysis exceeded
- MCL Maximum Contaminant Level
- RL Reporting Limit



LABORATORY ANALYTICAL REPORT

Client: Hall Environmental
Project: 1001152
Lab ID: C10010437-001
Client Sample ID: Tank

Report Date: 01/21/10
Collection Date: 01/12/10 15:10
Date Received: 01/14/10
Matrix: Aqueous

Analyses	Result	Units	Qualifier	RL	MCL/ QCL	Method	Analysis Date / By
ORGANIC CHARACTERISTICS							
Oil & Grease (HEM)	1300	mg/L	*	9.2	10	E1664A	01/19/10 08:08 / bah

Report Definitions: RL - Analyte reporting limit.
QCL - Quality control limit.
* - The result exceeds the MCL.

MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.



QA/QC Summary Report

Client: Hall Environmental
 Project: 1001152

Report Date: 01/20/10
 Work Order: C10010437

Analyte	Result	Units	RL	%REC	Low Limit	High Limit	RPD	RPDLimit	Qual
Method: E1664A									Batch: 24980
Sample ID: C10010287-001BMS Oil & Grease (HEM)	Sample Matrix Spike 50	mg/L	5.1	94	78	114			01/19/10 08:06
Sample ID: C10010287-001BMSD Oil & Grease (HEM)	Sample Matrix Spike Duplicate 49	mg/L	5.0	94	78	114	1.2		01/19/10 08:07 18
Sample ID: MBLK1_100119A Oil & Grease (HEM)	Method Blank ND	mg/L	5.0						01/19/10 08:10
Sample ID: LCS1_100119A Oil & Grease (HEM)	Laboratory Control Sample 39	mg/L	5.0	98	78	114			01/19/10 08:10
Sample ID: LCSD_100119A Oil & Grease (HEM)	Laboratory Control Sample Duplicate 39	mg/L	5.0	98	78	114	0.3		01/19/10 08:10 18

Qualifiers:

RL - Analyte reporting limit.

ND - Not detected at the reporting limit.

QA/QC SUMMARY REPORT

Client: Gordon Environmental, Inc.
Project: SSI

Work Order: 1001152

Analyte	Result	Units	PQL	SPK Va	SPK ref	%Rec	LowLimit	HighLimit	%RPD	RPDLimit	Qual
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Method: EPA Method 300.0: Anions

Sample ID: MB MBLK Batch ID: R36967 Analysis Date: 1/15/2010 2:09:59 PM

Fluoride	ND	mg/L	0.10								
Chloride	ND	mg/L	0.50								
Nitrogen, Nitrate (As N)	ND	mg/L	0.10								
Phosphorus, Orthophosphate (As P)	ND	mg/L	0.50								
Sulfate	ND	mg/L	0.50								

Sample ID: LCS LCS Batch ID: R36967 Analysis Date: 1/15/2010 2:27:23 PM

Fluoride	0.5111	mg/L	0.10	0.5	0	102	90	110			
Chloride	4.935	mg/L	0.50	5	0	98.7	90	110			
Nitrogen, Nitrate (As N)	2.429	mg/L	0.10	2.5	0	97.2	90	110			
Phosphorus, Orthophosphate (As P)	4.937	mg/L	0.50	5	0	98.7	90	110			
Sulfate	9.692	mg/L	0.50	10	0	96.9	90	110			

Method: SM 2320B: Alkalinity

Sample ID: MB MBLK Batch ID: R36965 Analysis Date: 1/15/2010 3:22:00 PM

Alkalinity, Total (As CaCO3)	ND	mg/L Ca	20								
Carbonate	ND	mg/L Ca	2.0								
Bicarbonate	ND	mg/L Ca	20								

Sample ID: LCS LCS Batch ID: R36965 Analysis Date: 1/15/2010 3:28:00 PM

Alkalinity, Total (As CaCO3)	79.80	mg/L Ca	20	80	0	99.7	92.5	110			
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Qualifiers:

E	Estimated value	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
R	RPD outside accepted recovery limits	S	Spike recovery outside accepted recovery limits

QA/QC SUMMARY REPORT

Client: Gordon Environmental, Inc.

Project: SSI

Work Order: 1001152

Analyte	Result	Units	PQL	SPK Va	SPK ref	%Rec	LowLimit	HighLimit	%RPD	RPDLimit	Qual
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Method: EPA Method 8260B: VOLATILES

Sample ID: 5ml rb MBLK Batch ID: R36950 Analysis Date: 1/14/2010 8:46:37 AM

Benzene	ND	µg/L	1.0								
Toluene	ND	µg/L	1.0								
Ethylbenzene	ND	µg/L	1.0								
Acetone	ND	µg/L	10								
2-Butanone	ND	µg/L	10								
Xylenes, Total	ND	µg/L	1.5								
Surr: 1,2-Dichloroethane-d4	10.10	µg/L	0	10	0	101	54.6	141			
Surr: 4-Bromofluorobenzene	9.874	µg/L	0	10	0	98.7	60.1	133			
Surr: Dibromofluoromethane	10.97	µg/L	0	10	0	110	78.5	130			
Surr: Toluene-d8	9.927	µg/L	0	10	0	99.3	79.5	126			

Sample ID: b2 MBLK Batch ID: R37015 Analysis Date: 1/19/2010 8:51:19 AM

Benzene	ND	µg/L	1.0								
Toluene	ND	µg/L	1.0								
Ethylbenzene	ND	µg/L	1.0								
Acetone	ND	µg/L	15								
2-Butanone	ND	µg/L	10								
Xylenes, Total	ND	µg/L	1.5								
Surr: 1,2-Dichloroethane-d4	10.07	µg/L	0	10	0	101	54.6	141			
Surr: 4-Bromofluorobenzene	9.869	µg/L	0	10	0	98.7	60.1	133			
Surr: Dibromofluoromethane	10.82	µg/L	0	10	0	108	78.5	130			
Surr: Toluene-d8	9.830	µg/L	0	10	0	98.3	79.5	126			

Sample ID: 100ng lcs LCS Batch ID: R35950 Analysis Date: 1/14/2010 9:42:38 AM

Benzene	20.25	µg/L	1.0	20	0	101	76.7	114			
Toluene	21.63	µg/L	1.0	20	0	108	78.4	117			
Surr: 1,2-Dichloroethane-d4	9.806	µg/L	0	10	0	98.1	54.6	141			
Surr: 4-Bromofluorobenzene	10.06	µg/L	0	10	0	101	60.1	133			
Surr: Dibromofluoromethane	11.07	µg/L	0	10	0	111	78.5	130			
Surr: Toluene-d8	10.11	µg/L	0	10	0	101	79.5	126			

Sample ID: 100ng lcs LCS Batch ID: R37015 Analysis Date: 1/19/2010 9:47:57 AM

Benzene	19.43	µg/L	1.0	20	0	97.2	76.7	114			
Toluene	21.70	µg/L	1.0	20	0	109	78.4	117			
Surr: 1,2-Dichloroethane-d4	9.917	µg/L	0	10	0	99.2	54.6	141			
Surr: 4-Bromofluorobenzene	9.912	µg/L	0	10	0	99.1	60.1	133			
Surr: Dibromofluoromethane	8.731	µg/L	0	10	0	87.3	78.5	130			
Surr: Toluene-d8	10.12	µg/L	0	10	0	101	79.5	126			

Method: EPA Method 9060 TOC

Sample ID: MBLK MBLK Batch ID: R36955 Analysis Date: 1/14/2010 12:21:41 PM

Total Organic Carbon ND mg/L 1.0

Sample ID: LCS LCS Batch ID: R36955 Analysis Date: 1/14/2010 12:38:34 PM

Total Organic Carbon 4.793 mg/L 1.0 4.85 0 98.8 90 110

Qualifiers:

E	Estimated value	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
R	RPD outside accepted recovery limits	S	Spike recovery outside accepted recovery limits

QA/QC SUMMARY REPORT

Client: Gordon Environmental, Inc.
 Project: SSI

Work Order: 1001152

Analyte	Result	Units	PQL	SPK Va	SPK ref	%Rec	LowLimit	HighLimit	%RPD	RPDLimit	Qual
---------	--------	-------	-----	--------	---------	------	----------	-----------	------	----------	------

Method: EPA 120.1: Specific Conductance

Sample ID: 1001200-02C DUP Batch ID: R36985 Analysis Date: 1/15/2010 7:00:00 PM
 Specific Conductance 4.656 µmhos/c 0.010 35.9 20 R

Method: EPA Method 7470: Mercury

Sample ID: MBLK-21186 Batch ID: 21186 Analysis Date: 1/21/2010 4:14:01 PM
 Mercury ND mg/L 0.00020

Sample ID: LCS1-21166 Batch ID: 21186 Analysis Date: 1/21/2010 4:15:44 PM
 Mercury 0.004916 mg/L 0.00020 0.005 3E-05 97.6 80 120

Qualifiers:

- | | | | |
|---|--------------------------------------------|----|----------------------------------------------------|
| E | Estimated value | H | Holding times for preparation or analysis exceeded |
| J | Analyte detected below quantitation limits | ND | Not Detected at the Reporting Limit |
| R | RPD outside accepted recovery limits | S | Spike recovery outside accepted recovery limits |

QA/QC SUMMARY REPORT

Client: Gordon Environmental, Inc.

Project: SSI

Work Order: 1001152

Analyte	Result	Units	PQL	SPK Va	SPK ref	%Rec	LowLimit	HighLimit	%RPD	RPDLimit	Qual
---------	--------	-------	-----	--------	---------	------	----------	-----------	------	----------	------

Method: EPA 6010B: Total Recoverable Metals

Sample ID: MB-21166

MBLK

Batch ID: 21166 Analysis Date: 1/19/2010 1:22:12 PM

Aluminum	ND	mg/L	0.020								
Arsenic	ND	mg/L	0.020								
Barium	ND	mg/L	0.020								
Cadmium	ND	mg/L	0.0020								
Calcium	ND	mg/L	1.0								
Chromium	ND	mg/L	0.0060								
Copper	ND	mg/L	0.0080								
Iron	ND	mg/L	0.050								
Lead	ND	mg/L	0.0050								
Magnesium	ND	mg/L	1.0								
Manganese	ND	mg/L	0.0020								
Potassium	ND	mg/L	1.0								
Selenium	ND	mg/L	0.050								
Silver	ND	mg/L	0.0050								
Sodium	ND	mg/L	1.0								
Strontium	ND	mg/L	0.010								
Silica	ND	mg/L	1.1								

Sample ID: LCS-21166

LCS

Batch ID: 21166 Analysis Date: 1/19/2010 1:24:25 PM

Aluminum	0.5146	mg/L	0.020	0.5	0	103	80	120			
Arsenic	0.5020	mg/L	0.020	0.5	0	100	80	120			
Barium	0.4952	mg/L	0.020	0.5	0	99.0	80	120			
Cadmium	0.5006	mg/L	0.0020	0.5	0	100	80	120			
Calcium	48.91	mg/L	1.0	50	0	97.8	80	120			
Chromium	0.4962	mg/L	0.0060	0.5	0	99.2	80	120			
Copper	0.5309	mg/L	0.0060	0.5	0.0028	106	80	120			
Iron	0.4817	mg/L	0.050	0.5	0	96.3	80	120			
Lead	0.4919	mg/L	0.0050	0.5	0	98.4	80	120			
Magnesium	49.28	mg/L	1.0	50	0	98.6	80	120			
Manganese	0.4956	mg/L	0.0020	0.5	0	99.1	80	120			
Potassium	51.47	mg/L	1.0	50	0	103	80	120			
Selenium	0.4879	mg/L	0.050	0.5	0	97.6	80	120			
Silver	0.5098	mg/L	0.0050	0.5	0	102	80	120			
Sodium	52.39	mg/L	1.0	50	0	105	80	120			
Strontium	0.09881	mg/L	0.010	0.1	0	98.8	80	120			
Silica	5.754	mg/L	1.1	5.885	0.0262	97.3	80	120			

Method: SM 4500 NH3: Ammonia

Sample ID: MB

MBLK

Batch ID: R37029 Analysis Date: 1/20/2010 10:59:00 AM

Ammonia ND mg/L 1.0

Sample ID: LCS

LCS

Batch ID: R37029 Analysis Date: 1/20/2010 10:59:00 AM

Ammonia 9.660 mg/L 1.0 10 0 96.6 80 120

Qualifiers:

E	Estimated value	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
R	RPD outside accepted recovery limits	S	Spike recovery outside accepted recovery limits

QA/QC SUMMARY REPORT

Client: Gordon Environmental, Inc.

Project: SSI

Work Order: 1001152

Analyte	Result	Units	PQL	SPK Va	SPK ref	%Rec	LowLimit	HighLimit	%RPD	RPDLimit	Qual
---------	--------	-------	-----	--------	---------	------	----------	-----------	------	----------	------

Method: SM4500-H+B: pH

Sample ID: 1001165-08A DUP

DUP

Batch ID: R36985 **Analysis Date:** 1/15/2010 5:47:00 PM

pH 8.120

pH units 0.1

0.247

Method: SM2540C MOD: Total Dissolved Solids

Sample ID: MBLK-21144

MBLK

Batch ID: 21144 **Analysis Date:** 1/19/2010 8:35:00 AM

Total Dissolved Solids ND

mg/L 20.0

Sample ID: LCS1-21144

LCS

Batch ID: 21144 **Analysis Date:** 1/19/2010 8:35:00 AM

Total Dissolved Solids 1023

mg/L 20.0 1000 0 102 80 120

Qualifiers:

- | | |
|----------------------------------------------|------------------------------------------------------|
| E Estimated value | H Holding times for preparation or analysis exceeded |
| J Analyte detected below quantitation limits | ND Not Detected at the Reporting Limit |
| R RPD outside accepted recovery limits | S Spike recovery outside accepted recovery limits |

Hall Environmental Analysis Laboratory, Inc.

Sample Receipt Checklist

Client Name GEI
Work Order Number 1001152

Date Received: 1/13/2010

Received by: TLS

Sample ID labels checked by:

Checklist completed by:

[Signature]
Signature

01/13/10
Date

[Initials]
Initials

Matrix:

Carrier name Client drop-off

- Shipping container/cooler in good condition? Yes No Not Present
- Custody seals intact on shipping container/cooler? Yes No Not Present Not Shipped
- Custody seals intact on sample bottles? Yes No N/A
- Chain of custody present? Yes No
- Chain of custody signed when relinquished and received? Yes No
- Chain of custody agrees with sample labels? Yes No
- Samples in proper container/bottle? Yes No
- Sample containers intact? Yes No
- Sufficient sample volume for indicated test? Yes No
- All samples received within holding time? Yes No
- Water - VOA vials have zero headspace? No VOA vials submitted Yes No
- Water - Preservation labels on bottle and cap match? Yes No N/A
- Water - pH acceptable upon receipt? Yes No N/A
- Container/Temp Blank temperature? 3.5° <6° C Acceptable
If given sufficient time to cool.

Number of preserved bottles checked for pH:

5
2 → 12 unless noted below.

COMMENTS:

Client contacted _____ Date contacted: _____ Person contacted _____

Contacted by: _____ Regarding: _____

Comments: _____

Corrective Action _____

**APPLICATION FOR PERMIT
SUNDANCE WEST**

**VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 7: TENSILE STRESS ANALYSIS**

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LIST OF ATTACHMENTS

Attachment No.	Title
III.7.A	KOERNER, ROBERT M. 2005. <i>DESIGNING WITH GEOSYNTHETICS, 5TH EDITION</i> . NEW JERSEY: PEARSON PRENTICE HALL.
III.7.B	SHARMA, HARI D. AND LEWIS, SANGEETA, P. 1994. <i>WASTE CONTAINMENT SYSTEMS, WASTE STABILIZATION, AND LANDFILLS: DESIGN AND EVALUATION</i> . NEW YORK: JOHN WILEY AND SONS.
III.7.C	QIAN, XUEDE; KOERNER, ROBERT M.; AND GRAY, DONALD H. 2002. <i>GEOTECHNICAL ASPECTS OF LANDFILL DESIGN AND CONSTRUCTION</i> . NEW YORK: PRETENCE HALL.
III.7.D	CETCO® LINING TECHNOLOGIES, 2009. <i>BENTOMAT® GCL DIRECT SHEAR DATABASE (TR-114BM)</i>
III.7.E	KOERNER, ROBERT M. AND KOERNER, GEORGE R. 2007. <i>INTERPETATION(S) OF LABORATORY GENERATED INTERFACE SHEAR STRENGTH DATA FOR GEOSYNTHETIC MATERIALS WITH EMPHISIS ON THE ADHESION VALUE</i> . GRI WHITE PAPER #11. GEOSYNTHETICS INSTITUTE.
III.7.F	THIEL, RICHARD. <i>A TECHNICAL NOTE REGARDING INTERPRETATION OF COHESION (OR ADHESION) AND FRICTION ANGLE IN DIRECT SHEAR TESTS</i> . GEOSYNTHETICS, APRIL MAY 2009 VOLUME 27: PAGES 10-19.
III.7.G	THIEL, RICHARD. <i>PEAK VS RESIDUAL SHEAR STRENGTH FOR LANDFILL BOTTOM LINER STABILITY ANALYSES</i> . THIEL ENGINEERING, OREGON HOUSE, CA, USA.
III.7.H	BOWLES, JOSEPH E. 1977. <i>FOUNDATION ANALYSIS AND DESIGN, 2ND EDITION</i> . UNITED STATES: MCGRAW HILL BOOK COMPANY.
III.7.I	RICHARDSON, CLINTON P., PHD, PE. 2009. <i>MUNICIPAL LANDFILL DESIGN CALCULATIONS: AN ENTRY LEVEL MANUAL OF PRACTICE</i> . CALIFORNIA: UBUILDABOOK, LLC.
III.7.J	GSE LINING TECHNOLOGY, INC., <i>GSE HD TEXTURED PRODUCT DATA SHEET</i> .
III.7.K	GSE LINING TECHNOLOGY, INC., <i>WIDE WIDTH TENSILE STRENGTH TEST OF F42060060S GEOCOMPOSITE</i> .
III.7.L	CATERPILLAR, INC., <i>CATERPILLAR PERFORMANCE HANDBOOK, EDITION 42</i>

**APPLICATION FOR PERMIT
SUNDANCE WEST**

**VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 7: TENSILE STRESS ANALYSIS**

1.0 DESIGN CRITERIA

The liner system for the Sundance West Surface Waste Management Facility (Sundance West) is designed to meet the requirements of the New Mexico Energy, Minerals and Natural Resource Department, Oil Conservation Division Rules 19.15.36 NMAC. More specifically, 19.15.36.14.D(1)(b) NMAC requires:

“Liners shall be able to withstand projected loading stresses, settling and disturbances from overlying oil field waste, cover materials and equipment operations.”

and further 19.15.36.14.D.(2)(b) NMAC requires:

“Geosynthetic material the operator installs on a slope greater than 25 percent shall be designed to withstand the calculated tensile forces acting upon the material. The design shall consider the maximum friction angle of the geosynthetic with regard to a soil-geosynthetic or geosynthetic-geosynthetic interface and shall ensure that overall slope stability is maintained.”

2.0 PROJECT DESCRIPTION

The Sundance West site will be comprised of 320 acres ±, with a solid waste landfill footprint of 126 acres ±. The site is located in the South 1/2 Section 30 Township 21 South, Range 38 East, Lea County, New Mexico (NMPM).

The interior (excavation) sideslopes of the Sundance West Landfill are designed at 3H:1V. The liner design for the landfill sideslopes and floor (**Figure III.7.1**), from top to bottom, consists of the following components below the waste:

- 24-inch (in.) protective soil layer (soil classification “SC-SM”)
- 200-mil geocomposite (200-mil geonet/10 oz/yd² non-woven geotextile)
- Double-sided textured high density polyethylene (HDPE) liner
- 200-mil geonet
- Double-sided textured HDPE liner
- 6-in. prepared subgrade (CL) soil

3.0 CALCULATION OF TENSILE STRESSES IN GEOSYNTHETICS AND SIDESLOPE LINER STABILITY

External shear forces will develop on the 3H:1V sideslopes, assuming the placement of an initial 2-foot (ft) lift of protective soil and an 8-ft lift of waste, assuming the lifts are unsupported and no adhesion (**Attachment III.7A, Attachment III.7.B, Attachment III.7.C and Attachment III.7.D**). The unbalanced forces, due to the assumed unsupported placement of the 2-ft protective soil layer and 10-ft waste layer, must be supported by the liner components above the interface with the least amount of frictional resistance. Interface friction angles (Φ) and adhesion (as determined by direct shear testing) for geosynthetics will vary depending on the normal load applied to the geosynthetics. For the Sundance West Facility, the maximum normal load applied to the floor and sideslope varies. Based on the review of available literature, **Tables III.7.1 through III.7.5** present the interface friction angles and soil internal friction angles to be used to determine the tensile stresses in the geosynthetics that will be installed at the Sundance West Facility.

The interface friction angle and adhesion for the geosynthetic interfaces is determined for the floor and sideslope as follows.

**TABLE III.7.1
Geosynthetic Interface Friction Angles and Adhesion – Sideslope Normal Load
Sundance West**

Normal Load	Thickness (ft)	Unit Weight (lbs/ft ³)	Total Weight (lbs/ft ²)	Range of Shear Testing Loads ¹ per ASTM D 5321 (lbs/in ²)
1. Final Cover Soil	2	105	210	0.25 (28.1) = 7.0 0.50 (28.1) = 14.1 1.0 (28.1) = 28.1
2. Intermediate Cover Soils	1	105	105	
3. Oil Field Waste ²	50	74	3,700	
4. Protective Soil Layer	2	105	210	
Design Vertical Load:		Total:	4,225 lbs/ft ² (29.3 lbs/in ²)	
Design Normal Load: = [(29.3 lbs/in ²) (cos 18.43°)] = 28.1 lbs/in ²		Total:	28.1 lbs/in ²	7.0 14.1 28.1

Notes: 1. Shear testing loads based on ASTM D 5321 = 0.25 (maximum normal load); 0.5 (maximum normal load); 1.0 (maximum normal load)

2. Oil field waste on the sideslope varies from 0 to approximately 100 feet in depth; averaging 50 feet at the centroid of the sideslope waste mass.

**TABLE III.7.2
Geosynthetic Interface Friction Angles and Adhesion – Floor Normal Load
Sundance West**

Normal Load	Thickness (ft)	Unit Weight (lbs/ft ³)	Total Weight (lbs/ft ²)	Range of Shear Testing Loads ¹ per ASTM D 5321 (lbs/in ²)		
				0.25 (85.7) = 21.4	0.50 (85.7) = 42.9	1.0 (85.7) = 85.6
1. Final Cover Soil	2	105	210	21.4	42.9	85.6
2. Intermediate Cover Soils	1	105	105			
3. Oil Field Waste	161	74	11,914			
4. Protective Soil Layer	2	105	110			
Design Vertical/Normal Load:		Total:	12,339 lbs/ft ² (85.7 lbs/in ²)			

Note: 1. Shear testing loads based on ASTM D 5321 = 0.25 (maximum normal load); 0.5 (maximum normal load); 1.0 (maximum normal load).

**TABLE III.7.3
Geosynthetic Interface Friction Angles and Adhesion¹ – Sideslope Liner System
Sundance West**

Geosynthetic to Geosynthetic Interface	Normal Stresses (lbs/in ²)	Mohr-Coulomb Failure Envelope ²	
		Φ	Adhesion
Protective Soil Layer (SC-SM) ² to Nonwoven Geotextile of Geocomposite	Reference 1	26°	Unknown
HDPE Geonet to Double-Sided Textured HDPE FML	Reference 2	7.0° – 25° Assume =19°	Unknown
Double-Sided Textured HDPE FML to Nonwoven Geotextile of GCL	1.7 3.5 6.9 Reference 10	23.9°	0 lbs/ft ²
Woven Geotextile of GCL to Subgrade Soil (undrained)	2 5 10 Reference 10	19.9°	117 lbs/ft ²

Notes: 1. Values reported for Φ and Adhesion are based on review of available literature and are used to predict the performance of the liner system. Site-specific shear strength testing should be conducted using actual liner system components and soils as specified by the Engineer for the facility prior to construction.

2. As recommended in Reference 13, the values for Φ and Adhesion (when available in the literature) represent “Residual Shear Strength” values (**Attachment II.7.G**).

TABLE III.7.4
Geosynthetic Interface Friction Angles and Adhesion¹ – Floor Liner System
Sundance West

Geosynthetic to Geosynthetic Interface	Normal Stresses (lbs/in ²)	Mohr-Coulomb Failure Envelope ²	
		Φ	Adhesion
Protective Soil Layer (SC-SM) to Nonwoven Geotextile of Geocomposite	Reference 1	18°	Unknown
HDPE Geonet to Smooth HDPE FML	Reference 1	10°	Unknown
Smooth HDPE FML to Nonwoven Geotextile of GCL	Reference 2	8° – 12° Average = 10°	Unknown
Woven Geotextile of GCL to Subgrade Soil (undrained)	13.9 55.6 83.3 Reference 10	15.6°	561.1 lbs/ft ²

- Notes: 1. Values reported for Φ and Adhesion are based on review of available literature and are used to predict the performance of the liner system. Site-specific shear strength testing should be conducted using actual liner system components and soils as specified by the Engineer for the facility prior to construction.
2. As recommended in Reference 13, the values for Φ and Adhesion (when available in the literature) represent “Peak Shear Strength” values (**Attachment III.7.G**).

TABLE III.7.5
Soils Internal Friction Angle and Cohesion^{1,2}
Sundance West

Material	Density	Φ	Cohesion [Assumed]
Protective Soil Layer (Relative Density, Medium)	105 lbs/ft ³	33°	0 lbs/ft ²
Oil Field Stabilized Waste (Relative Density, Medium)	74 lbs/ft ³	33°	0 lbs/ft ²
Compacted Subgrade (Relative Density, Dense)	114 lbs/ft ³	30°	0 lbs/ft ²
Natural Foundation Soils (Relative Density, Medium to Dense)			
SC-SM Soils	90 lbs/ft ³	33°	0 lbs/ft ²
CL (Chinle Formation Soils)	115 lbs/ft ³	30°	0 lbs/ft ²

- Notes: 1. Values reported for Φ and Cohesion/Adhesion are based on review of available literature and are used to predict the performance of the liner system and soils. Site-specific shear strength testing should be conducted on soils and liner system components specified by the Engineer for the facility prior to construction.
2. Geotechnical laboratory testing of on-site soils show predominately SC-SM soils within the top 45 feet (**Volume IV**). For the purposes of this slope stability analysis, cohesion was assumed to be 0 lbs/ft³ providing an additional factor of safety to these calculations.

Based on the sideslope liner system design, the interface with the least amount of frictional resistance occurs at the geonet to double-sided textured interface ($\Phi = 19^\circ$) [Table III.7.3 as referenced in Attachment III.7.B, p. 149]. The unbalanced forces, due to the assumed unsupported oil field waste and protective soil layer, are based on the sideslope liner stability calculations presented in Reference 9; *Municipal Landfill Design Calculations: An Entry Level Manual of Practice* (Richardson, 2009) [Attachment III.7.I]:

Where:

- B = slope angle for 3H:1V sideslope = 18.43°
- F_X = Shear forces that are equal to the product of the normal force ($W_W \cos B$) and the tangent of the friction angle between the two neighboring materials.
- W_W = Weight of Waste.
- T_W = Friction force on edge of waste.
- W_{net} = Net weight of waste acting upon the liner system ($W_W - T_W$)
- h_{waste} = Height of waste layer = 10 feet
- h_{soil} = Height of protective soil layer = 2 feet
- Φ_{waste} = Waste internal angle of friction = 33°
- Φ_{soil} = Soil Internal angle of friction = 33°
- Density of waste = 74 lbs/ft³
- Density of protective soil = 105 lbs/ft³ Dry Density

A. Determine weight of waste and protective soil layer on sideslope

$W_{waste/soil} = 0.5 (h_{waste}) [(h_{waste})(\text{slope})] (\text{density of waste}) + 0.5 (h_{soil}) [(h_{soil})(\text{slope})] (\text{density of protective soil layer})$

$$W_{waste/soil} = 0.5 (10 \text{ ft}) [(10 \text{ ft})(3)] (74 \text{ lbs/ft}^3) + 0.5 (2 \text{ ft}) [(2 \text{ ft})(3)] (105 \text{ lbs/ft}^3)$$

$$W_{waste/soil} = 11,100 \text{ lbs/ft} + 630 \text{ lbs/ft} = 11,730 \text{ lbs/ft}$$

B. Determine friction force on edge of waste and protective soil layer

$$T_W = (K_o) (\sigma_v) (\tan (\Phi_{waste}) (h_{lift}) + (K_o) (\sigma_v) (\tan (\Phi_{soil}) (h_{lift}))$$

Where:

- $K_o = 1 - \sin (\Phi_{waste}) = 0.455$
- $K_o = 1 - \sin (\Phi_{soil}) = 0.455$
- $\sigma_v = (0.5) (h_{waste}) (\text{density of waste}) = 370 \text{ lbs/ft}^2$
- $\sigma_v = (0.5) (h_{soil}) (\text{density of soil}) = 105 \text{ lbs/ft}^2$
- Φ_{waste} = Internal friction angle of waste = 33°
- Φ_{soil} = Internal friction angle of protective soil = 33°
- h_{waste} = height of lift of waste = 10 ft
- h_{soil} = height of lift of soil = 2 ft

$$T_W = (0.455)(370 \text{ lbs/ft}^2)(\tan (33^\circ) (10 \text{ ft}) + (0.455)(105 \text{ lbs/ft}^2)(\tan (33^\circ) (2 \text{ ft}))$$

$$T_W = 1,093.3 \text{ lbs/ft} + 62.05 \text{ lbs/ft}$$

$$T_W = 1,155.4 \text{ lbs/ft}$$

C. Net weight of waste and protective soil layer

$$W_{\text{net}} = W_{\text{waste/soil}} - T_W$$

$$W_{\text{net}} = 11,730 \text{ lbs/ft} - 1,155.4 \text{ lbs/ft}$$

$$W_{\text{net}} = 10,574.6 \text{ lbs/ft}$$

D. Determine weight force component

$$N_A = (W_{\text{net}}) (\cos (\text{slope angle}))$$

Where: N_A is the normal force perpendicular to the sideslope (**Figure III.7.2**)

$$N_A = 10,574.6 \text{ lbs/ft} (\cos 18.43^\circ)$$

$$N_A = 10,032.2 \text{ lbs/ft}$$

E. Calculate shear forces on geosynthetics (Figure III.7.2)

Determine friction forces:

1. Interface friction angle between 200-mil geocomposite nonwoven geotextile and protective soil layer, $\Phi = 26^\circ$ (**Table III.7.3**).

$$F_1 = N_A (\tan 26^\circ)$$

$$F_1 = 10,032.3 \text{ lbs/ft} (0.488)$$

$$F_1 = 4,895.8 \text{ lbs/ft}$$

2. Interface friction angle between double-sided textured HDPE liner and 200-mil geocomposite (HDPE geonet), $\Phi = 19^\circ$ (**Table III.7.1**).

$$F_2 = N_A (\tan 19^\circ)$$

$$F_2 = 10,032.3 \text{ lbs/ft} (0.308)$$

$$F_2 = 3,086.3 \text{ lbs/ft}$$

$F_1 > F_2$, therefore the geocomposite is in tension.

$$\text{Geocomposite tension} = 4,895.8 \text{ lbs/ft} - 3,086.3 \text{ lbs/ft.}$$

$$\text{Geocomposite tension} = 1,809.5 \text{ lbs/ft} = 150.8 \text{ lbs/in.}$$

3. $F_3 = F_2 = 3,086.3$ lbs/ft for static no-slip condition.
4. Interface friction angle between double-sided textured HDPE liner and 200-mil geonet, $\Phi = 19^\circ$ (**Table III.7.3**).

$$F_4 = N_A (\tan 19^\circ)$$

$$F_4 = 10,032.3 \text{ lbs/ft (0.308)}$$

$$F_4 = 3,086.3 \text{ lbs/ft}$$

$F_4 = F_3$, therefore double-sided textured HDPE liner not in tension.

5. $F_5 = F_4 = 3,086.3$ lbs/ft for static no-slip condition.
6. Interface friction angle between 200-mil geonet and double-sided textured HDPE liner, $\Phi = 19^\circ$ (**Table III.7.3**).

$$F_6 = N_A (\tan 16^\circ)$$

$$F_6 = 10,032.3 \text{ lbs/ft (0.308)}$$

$$F_6 = 3,086.3 \text{ lbs/ft}$$

$F_6 = F_5$, therefore 200-mil geonet not in tension.

7. $F_7 = F_6 = 3,086.3$ lbs/ft for static no-slip condition.
8. Interface friction angle between double-sided textured HDPE liner and nonwoven geotextile of GCL, $\Phi = 23.9^\circ$ (**Table III.7.3**).

$$F_8 = N_A (\tan 23.9^\circ)$$

$$F_8 = 10,032.3 \text{ lbs/ft (0.443)}$$

$$F_8 = 4,444.3 \text{ lbs/ft}$$

$F_8 > F_7$, therefore double-sided textured HDPE liner not in tension.

9. $F_9 = F_8 = 4,444.3$ lbs/ft for static no-slip condition.
10. Interface friction angle between woven geotextile and compacted subgrade, $\Phi = 19.9^\circ$ (**Table III.7.3**).

$$F_{10} = N_A (\tan 19.9^\circ)$$

$$F_{10} = 10,032.3 \text{ lbs/ft (0.362)}$$

$$F_{10} = 3,631.6 \text{ lbs/ft}$$

$F_9 > F_{10}$, therefore, theoretically the geosynthetic clay liner (GCL) is in tension assuming no consideration for adhesion as listed in **Table III.7.3**. If the adhesion is included in the analysis, the GCL is likely not to be in tension and liner system slip plane occurs between the primary geocomposite and double-sided textured HDPE liner as indicated by the, $\Phi = 19^\circ$ (**Table III.7.3**).

F. Summary

1. Tensile stress, 200-mil geocomposite = $F_1 - F_2 = 4,895.8 - 3,086.3 = 1,809.5$ lbs/ft
2. Tensile stress, double-sided HDPE liner = $F_3 - F_4 = 3,086.3 - 3,086.3 = 0.0$ lbs/ft
3. Tensile stress, 200-mil geonet = $F_5 - F_6 = 3,086.3 - 3,086.3 = 0.0$ lbs/ft
4. Tensile stress, double-sided HDPE liner = $F_7 - F_8 = 3,086.3 - 4,444.3 < 0.0$ lbs/ft
5. Tensile stress, GCL including laboratory measured adhesion = 0.0 lbs/ft

G. Conclusion

The tensile stress in the 200-mil geocomposite is 1,809.5 lbs/ft, or 150.8 lbs/in. This positive value indicates that the 200-mil geocomposite is in wide width tension. The wide width tensile strength for the specified 200-mil geocomposite is not available from a manufacturer. However, GSE Lining Technology, Inc. has conducted wide width tensile testing for a 200-mil/6 oz/yd² geocomposite which typically has an allowable wide tensile rating of 270 lbs/in (**Attachment III.7.K**). Per GSE Lining Technology, Inc., the 200-mil/10 oz/yd² geocomposite specified for the Sundance West Facility should perform equal to or better than the 200-mil/6 oz/yd² geocomposite. Therefore a geocomposite with a wide width tensile strength of 270 lbs/in or greater will not be adversely affected if a 10-ft lift of waste is placed on the sideslope with a factor of safety equal to $270 \text{ lbs/in} / 150.8 \text{ lbs/in} = 1.79$. The zero and negative values for tensile stress in the other geosynthetics indicate that they are not in tension. Therefore, the proposed liner system design is compatible with calculated external forces.

4.0 CALCULATION OF TENSILE STRESSES IN GEOSYNTHETICS DUE TO EQUIPMENT LOADING

A Caterpillar D6E dozer or equivalent will be used to place the protective soil layer up the sideslope in approximately 12-ft lifts. The maximum unsupported length of protective soil will be 38 ft for a 3H:1V sideslope. Parameters to be used in the analysis include:

- Unit weight of protective soil = 105 lbs/ft³ Dry Density (**Table III.7.1**).
- Internal friction angle of protective soil = 33° (**Table III.7.1**)
- Critical liner interface friction angle occurs between the geocomposite and the textured HDPE liner = 16° (**Table III.7.3**).
- Equipment loading assuming a D6E dozer: (CAT Performance Handbook, Edition 42)
 - Weight = 32,000 lbs.
 - Track width = 22 inches = 1.83 feet.
 - Pressure distribution: Assume a 2H:1V distribution, therefore width acting on geomembrane = 3.83 feet.

- Tensile forces acting on geocomposite:
 - Protective soil layer, F_{soil} .
 - D6E dozer, F_{dozer} .
- Total resisting forces:
 - Geocomposite interface friction, $F_{\text{geocomposite}}$.
 - Soil buttress friction at toe of slope, F_{buttress} .

The minimum interface friction angle for the liner system is 19° and occurs between the geocomposite and double-sided textured HDPE geomembrane (**Table III.7.3**).

Tensile forces acting on geocomposite:

$$F_{\text{soil}} = h_{\text{lift}} (\text{unsupported slope length}) (\text{unit weight of protective soil}) (\sin (\text{slope angle}))$$

$$F_{\text{soil}} = (2 \text{ ft}) (38 \text{ feet}) (105 \text{ lbs/ft}^3) (\sin (18.43^\circ))$$

$$F_{\text{soil}} = 2,522.8 \text{ lbs/ft}$$

$$F_{\text{dozer}} = [0.5 (\text{dozer weight}) / (\text{width acting on geomembrane})] (\sin (18.43^\circ))$$

$$F_{\text{dozer}} = [0.5 (32,000 \text{ lbs}) / 3.83 \text{ ft}] (\sin (18.43^\circ))$$

$$F_{\text{dozer}} = 1,320.7 \text{ lbs/ft}$$

$$\text{Total tensile force acting on geocomposite} = 2,522.8 \text{ lbs/ft} + 1,320.7 \text{ lbs/ft} = 3,843.5 \text{ lbs/ft}$$

Total Resisting Forces acting on geocomposite:

$$F_{\text{geocomposite}} = (\text{Weight of protective soil} + \text{Weight of Dozer}) (\cos (\text{slope angle})) (\tan (\text{interface friction angle}))$$

$$F_{\text{geocomposite}} = [(2 \text{ ft}) (38 \text{ ft}) (105 \text{ lbs/ft}^3) + (16,000 \text{ lbs}/3.83 \text{ feet})] (\cos 18.43^\circ) (\tan 19^\circ)$$

$$F_{\text{geocomposite}} = (7,980 \text{ lbs/ft} + 4,177.5 \text{ lbs/ft}) (0.949) (0.308)$$

$$F_{\text{geocomposite}} = 3,553.5 \text{ lbs/ft}$$

$$F_{\text{buttress}} = \left[\frac{\cos (\text{internal friction angle of soil})}{\cos (\text{internal friction angle of soil} + \text{slope angle})} \right] \left[\frac{(\text{Unit weight of soil}) (\text{thickness of soil})^2}{\sin^2 (\text{slope angle})} \right] \tan (\text{internal friction angle of soil})$$

$$F_{\text{buttress}} = \left[\frac{\cos (33^\circ)}{\cos (33^\circ + 18.43^\circ)} \right] \left[\frac{(105 \text{ lbs/ft}^3 (2 \text{ ft})^2)}{\sin^2 (18.43^\circ)} \right] [\tan (33^\circ)]$$

$$F_{\text{buttress}} = [0.839 / 0.623] [420 \text{ lbs/ft}/0.600] [0.649]$$

$$F_{\text{buttress}} = 611.8 \text{ lbs/ft}$$

Total resisting force acting on geomembrane = 3,553.5 lbs/ft + 611.8 lbs/ft = 4,165.3 lbs/ft

Tensile forces < Resisting forces, therefore the geocomposite is not in tension.

Summary:

Tensile stress in geocomposite = 3,553.5 lbs/ft – 4,165.3 lbs/ft = -611.8 lbs/ft. The negative tensile stress indicates that the geocomposite is not in tension. Therefore, placing the protective soil layer up the sideslope will not adversely impact the geocomposite.

5.0 PUNCTURE RESISTANCE OF LINER SYSTEM IN LEACHATE COLLECTION TRENCH DUE TO EQUIPMENT LOADING

After construction of the leachate collection trench that includes installation of the liner system, nonwoven geotextile and gravel, a protective soil layer will be placed over the trench. The purpose of this calculation is to determine the factor of safety against puncture of the liner system due to the operation of a Cat 627H scraper placing protective soil overtop the leachate collection trench.

5.1 Analytic Method

Stress distribution can be obtained by the shallow-foundation theory of geotechnical engineering. This theory assumes a 2V:1H distribution of the stress below the assumed Cat 627H scraper tire; which is a reasonably accurate approximation of the decrease in stress with depth due to the applied surficial load of the scraper.

The geometry of the stress distribution on the geotextile and gravel within the leachate collection trench is shown on **Figure III.7.5** and can be calculated using the following equation (**Attachment III.7.A, Equation 2.34, page 180**):

$$p = \frac{P}{2 (B + 2h \tan \alpha) (L + 2h \tan \alpha)} + [\gamma_s h_o (\text{soil}) + \gamma_{tr} h_o (\text{leachate gravel})]$$

Where:

p = stress on the geotextile in the leachate collection trench

P = axle load (lbs)

$$= \frac{90,213 \text{ lbs} + 57,610 \text{ lbs}}{2} = 73,912 \text{ lbs} \text{ (Attachment III.7.L, page 8-4)}$$

B = width of tire contact = 1.5 feet

h = depth of surficial load on geotextile = 3.8 feet

α = assumed angle of stress distribution = 26.6°

L = length of tire contact = 0.5 feet

γ_s = unit weight of overlying protective soil = $105 \frac{\text{lbs}}{\text{ft}^3}$

h_o (soil) = 2 feet

γ_{lr} = unit weight of overlying leachate gravel = $130 \frac{\text{lbs}}{\text{ft}^3}$

h_o (leachate gravel) = 1.8 feet

$$p = \frac{P}{2 (B + 2h \tan \alpha) (L + 2h \tan \alpha)} + [\gamma_s h_o (\text{soil}) + \gamma_{lr} h_o (\text{leachate gravel})]$$

$$p = \frac{73,912 \text{ lbs}}{2 [(1.5 \text{ ft} + 2(3.8 \text{ ft})(\tan 26.6^\circ)) (0.5 \text{ ft} + 2(3.8 \text{ ft}) \tan 26.6^\circ)]} + [(2 \text{ ft}) (120 \frac{\text{lbs}}{\text{ft}^3}) + [(1.8 \text{ ft}) (130 \frac{\text{lbs}}{\text{ft}^3})]$$

$$p = \frac{73,912 \text{ lbs}}{2 [(5.30 \text{ ft})(4.30 \text{ ft})]} + 474 \frac{\text{lbs}}{\text{ft}^2}$$

$$p = \frac{73,912 \text{ lbs}}{2 [(22.79 \text{ ft}^2)]} + 474 \frac{\text{lbs}}{\text{ft}^2}$$

$$p = 1,621 \frac{\text{lbs}}{\text{ft}^2} + 474 \frac{\text{lbs}}{\text{ft}^2}$$

$$p = 1,795.6 \frac{\text{lbs}}{\text{ft}^2} = 12.5 \frac{\text{lbs}}{\text{in}^2}$$

Puncture calculation assuming largest leachate gravel rock diameter of 2.0 inches (**Volume II.7, pg. II.7-38**)

The vertical force exerted on the geotextile assuming a maximum leachate gravel rock diameter of 2.0 inches; and assuming an angular shape and relatively large object is given by the following equation (**Attachment III.7.A, pg. 171**):

$$F_{\text{required}} = p' d_a^2 S_1 S_2 S_3$$

Where:

F_{required} = required vertical puncturing force to be resisted

d_a = maximum diameter of leachate gravel = 2.0 inches

p' = pressure exerted on geotextile (from above) = $12.5 \frac{\text{lbs}}{\text{in}^2}$

S_1 = protrusion factor of the puncturing object = 0.9 for an angular and relatively large object.

S_2 = scale factor to adjust the ASTM D4833 puncture test value that uses a 8.0 mm diameter puncture probe to the actual puncturing object = 0.8 for an angular and relatively large object.

S_3 = shape factor to adjust the ASTM D4833 flat puncture probe to the actual shape of the puncturing object = 0.9 for an angular and relatively large object.

$$F_{\text{required}} = (12.5 \frac{\text{lbs}}{\text{in}^2})(2 \text{ in})^2 (0.9) (0.8) (0.9)$$

$$F_{\text{required}} = (50 \text{ lbs}) (0.9) (0.8) (0.9)$$

$$F_{\text{required}} = 32.4 \text{ lbs}$$

Assuming a strength-reduction factor of 2.0 to account for long-term performance of the nonwoven geotextile, the factor of safety against puncture due to a 2.0-inch diameter rock is as follows:

$$FS = 0.5 \left[\frac{F_{\text{allowable}}}{F_{\text{required}}} \right]$$

$$F_{\text{allowable}} = 180 \text{ lbs (Attachment II.7, pg. II.7-42)}$$

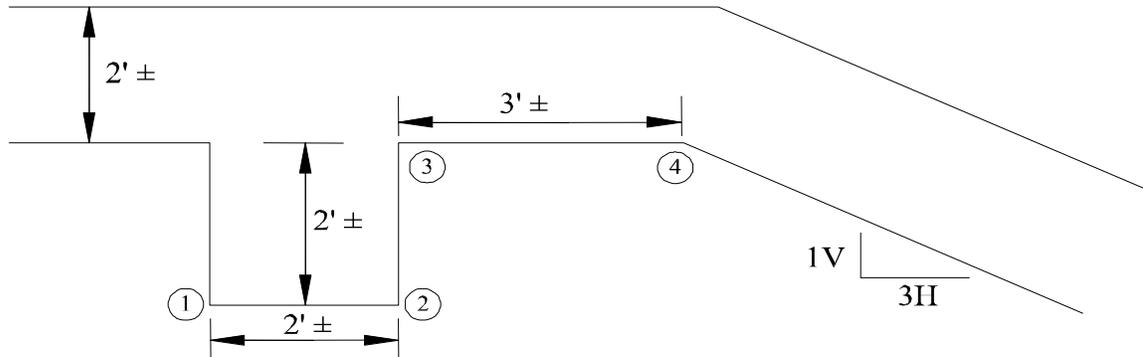
$$F_{\text{required}} = 32.4 \text{ lbs (from above)}$$

$$FS = 0.5 \left[\frac{180 \text{ lbs}}{32.4 \text{ lbs}} \right]$$

$$FS = 2.8, \text{ which is acceptable}$$

6.0 ANCHOR TRENCH PULLOUT ANALYSIS

Anchor trench configuration:



The anchor trench consists of extending the geosynthetics along the trench bottom to increase resistance force. In order to establish the static equilibrium equation, two imaginary and frictionless pulleys are assumed at the top edge and the bottom corner of the anchor trench (**Attachment III.7.C, page 111, Equation 4-28**). The friction force above a runout geosynthetic system is always neglected in the anchor trench design, since the cover soil moves together with the liner system as it deforms.

6.1 Geocomposite – Double-Side Textured Geomembrane Interface

$\Sigma F_H = 0$ yields the following equation for the calculation of T (where T = geocomposite tensile force (i.e., anchor trench resistance force) per unit width:

$$T = \frac{(q_b)(L_{Ro})(\tan\delta_c) + [K_o(\sigma_{vave})(d_{AT}) + (\sigma_v)(L_{AT})](\tan\delta_c + \tan\delta_f)}{\cos\beta + (\sin\beta)(\tan\delta_c)}$$

Where:

L_{Ro} = runout length = 3 ft

L_{AT} = width of anchor trench = 2.0 ft

d_{cs} = depth of cover soil = 2.0 ft

d_{AT} = depth of anchor trench = 2.0 ft

γ_s = unit weight of cover and backfill soil = 105 lbs/ft³ (**Table III.7.1**)

Φ = friction angle of backfill soil in anchor trench = 33° (**Table III.7.1**)

δ_c = friction angle between the geocomposite and underlying geomembrane = 19° (**Table III.7.3**)

δ_f = friction angle between the geocomposite and the backfill soil = 26° (**Table III.7.3**)

β = sideslope angle, measured from horizontal = 18.43°

$$K_o = 1 - \sin \Phi = 1 - 0.545 = 0.455$$

$$\sigma_{vave} = (\gamma_s)(d_{cs} + 0.5d_{AT}) = 105 \text{ lbs/ft}^3 (2.0 \text{ ft} + 0.5(2.0 \text{ ft})) = 315 \text{ lbs/ft}^2$$

$$\sigma_{vB} = (\gamma_s)(d_{cs} + d_{AT}) = 105 \text{ lbs/ft}^3 (2.0 \text{ ft} + 2.0 \text{ ft}) = 420 \text{ lbs/ft}^2$$

$$q_b = (\gamma_s)(d_{cs}) = 105 \text{ lbs/ft}^3 (2.0 \text{ ft}) = 210 \text{ lbs/ft}^2$$

$$T = \frac{(q_b)(L_{RO})(\tan \delta_c) + [K_o(\sigma_{vave})(d_{AT}) + (\sigma_{vB})(L_{AT})](\tan \delta_c + \tan \delta_f)}{\cos \beta - (\sin \beta)(\tan \delta_c)}$$

$$T = \frac{(210 \frac{\text{lbs}}{\text{sf}})(3 \text{ ft})(\tan 19^\circ) + [(0.455)(315 \frac{\text{lbs}}{\text{sf}})(2.0 \text{ ft}) + (420 \frac{\text{lbs}}{\text{sf}})(2.0 \text{ ft})](\tan 19^\circ + \tan 26^\circ)}{\cos 18.43^\circ - (\sin 18.43^\circ)(\tan 19^\circ)}$$

$$T = \frac{193.8 \frac{\text{lbs}}{\text{ft}} + [286.65 \frac{\text{lbs}}{\text{ft}} + 840 \frac{\text{lbs}}{\text{ft}}](0.704)}{0.871}$$

$$T = \frac{193.8 \frac{\text{lbs}}{\text{ft}} + 776.3 \frac{\text{lbs}}{\text{ft}}}{0.871}$$

$$T = \frac{1,126.7 \frac{\text{lbs}}{\text{ft}}}{0.871}$$

$$T = 1,293.6 \frac{\text{lbs}}{\text{ft}}$$

$$T = 1,293.6 \frac{\text{lbs}}{\text{ft}} = 107.8 \frac{\text{lbs}}{\text{in}} \div 0.20 \text{ in (geocomposite thickness)} = 539 \frac{\text{lbs}}{\text{in}^2}$$

Ultimate Strength > Anchor Trench Resistance > Allowable Strength

Assume Allowable Strength = Ultimate Strength ÷ Factor of Safety

Assumed Factor of Safety = 3.0

$$\text{Geocomposite Ultimate Strength} = 270 \frac{\text{lbs}}{\text{in}} \div 0.20 \text{ in (geocomposite thickness)} = 1,350 \frac{\text{lbs}}{\text{in}^2}$$

$$\text{Allowable Strength} = 1,350 \frac{\text{lbs}}{\text{in}^2} \div 3.0 = 450 \frac{\text{lbs}}{\text{in}^2}$$

$$1,350 \frac{\text{lbs}}{\text{in}^2} > 539 \frac{\text{lbs}}{\text{in}^2} > 450 \frac{\text{lbs}}{\text{in}^2}$$

Conclusion:

The results indicate that the anchor trench, as designed, provides sufficient capacity such that the anchor trench capacity lies between the geocomposite yield stress and assumed allowable stress.

7.0 GEOSYNTHETIC SLIPPAGE ANALYSIS

In order to determine the factor of safety for slippage and subsequent tension in the liner geosynthetics, the method of active and passive wedges developed by Qian et. al. (2002) was used (**Attachment III.7.C, pg. 520**). This calculation utilizes the passive wedge that supports the active wedge on the sideslope, consistent with actual conditions in the field. These calculations were performed along the largest geomembrane covered slope, which is found at the cross section shown on **Figure III.7.4**. **Figure III.7.4** also shows the approximate location of the deepest waste over a sidewall slope. To be conservative, the lowest internal and interface friction angles were used. These values, taken from **Tables III.7.1, III.7.3 and III.7.4**, are $\delta = 19^\circ$, for the interface friction angle between the geonet component of the geocomposite and double-sided textured HDPE liner, and $\delta = 10^\circ$ for the interface friction angle between the smooth HDPE liner and the geonet component of the geocomposite. The total height of the active wedge is the maximum height of waste over the sloped portion of geomembrane.

For the purposes of this calculation, the following assumptions and nomenclature (**Table III.7.6**) were used from the literature (**Attachment III.7.C, pg. 521**):

TABLE III.7.6
Translational Failure Analysis
Sundance West

$W_P =$	total weight of the passive wedge
$N_P =$	normal force acting on the bottom of the passive wedge
$F_P =$	Frictional force acting on the bottom of the passive wedge (parallel to the bottom of the passive wedge)
$E_{HP} =$	normal force from the active wedge acting on the passive wedge
$E_{VP} =$	frictional force acting on the side of the passive wedge
$FS_P =$	Factor of safety for the passive wedge
$\delta_P =$	Minimum interface friction angle of multi-layer liner components beneath the passive wedge = 10°
$\Phi_S =$	friction angle of the solid waste = 33°
$\alpha =$	angle of the solid waste slope, measured from horizontal
$\theta =$	angle of the landfill cell subgrade, measured from horizontal = 1.15°
$W_A =$	weight of the active wedge
$W_T =$	total weight of active and passive wedges
$N_A =$	normal force acting on the bottom of the active wedge
$F_A =$	Frictional force acting on the bottom of the active wedge (parallel to the bottom of the active wedge)
$E_{HA} =$	normal force from the active wedge acting on the active wedge, $E_{HA} = E_{HP}$
$E_{VA} =$	frictional force acting on the side of the active wedge, $E_{VA} = E_{VP}$
$FS_A =$	factor of safety for the active wedge
$\delta_A =$	minimum interface friction angle of multi-layer liner components beneath the active wedge = 19°
$\beta =$	angle of sideslope, measured from the horizontal = 18.43°
$FS =$	factor of safety for the entire solid waste mass

Figure III.7.4 also shows measured values for b , b_p , and h_t .

The active wedge is considered first:

$$W_A = \frac{1}{2}((b * h_a * \gamma) + (b * h_b * \gamma))$$

$$W_A = \frac{1}{2} \left(180' * 45' * 74 \left(\frac{lbs}{ft^3} \right) + 180' * 60' * 74 \left(\frac{lbs}{ft^3} \right) \right) = 699,300 \frac{lbs}{ft}$$

The passive wedge is then considered, by multiplying the cross sectional area by the unit weight of waste.

$$W_P = \frac{1}{2}(b_P * h_t * \gamma) = W_P = \frac{1}{2} \left(315 * 105 * 74 \left(\frac{lbs}{ft^3} \right) \right) = 1,223,775 \frac{lbs}{ft}$$

$$W_T = 699,300 \frac{lbs}{ft} + 1,223,775 \frac{lbs}{ft} = 1,923,075 \frac{lbs}{ft}$$

From **Attachment III.7.C, equation 13.62, pg. 524**, the equation is used to determine the factor of safety. Where:

$$aFS^3 + bFS^2 + cFS + d = 0$$

$$a = W_A \sin \beta \cos \theta + W_P \cos \beta \sin \theta$$

$$b = (W_A \tan \delta_P + W_P \tan \delta_A + W_T \tan \phi_s) \sin \beta \sin \theta - (W_A \tan \delta_A + W_P \tan \delta_P) \cos \beta \cos \theta$$

$$c = - [W_P \tan \phi_s (\sin \beta \cos \theta \tan \delta_P + \cos \beta \sin \theta \tan \delta_A) + (W_A \cos \beta \sin \theta + W_P \sin \beta \cos \theta) \tan \delta_A \tan \delta_P]$$

$$d = W_T \cos \beta \cos \theta \tan \delta_A \tan \delta_P \tan \phi_s$$

Where:

$$\beta = 18.43^\circ - \text{sideslope angle; } \sin 18.43^\circ = 0.316, \cos 18.43^\circ = 0.949$$

$$\theta = 1.60^\circ - \text{subgrade angle; } \sin 1.60^\circ = 0.028, \cos 1.60^\circ = 1.000$$

$$\delta_P = 10^\circ - \text{minimum friction angle of bottom liner system; } \tan 10^\circ = 0.176$$

$$\delta_A = 19^\circ - \text{minimum friction angle of sideslope liner system; } \tan 19^\circ = 0.308$$

$$\phi_s = 33^\circ - \text{friction angle of waste; } \tan 33^\circ = 0.649$$

Compute values for a, b, c and d:

$$a = W_A \sin \beta \cos \theta + W_P \cos \beta \sin \theta$$

$$a = 699,300 (0.316)(1.000) + 1,223,775 (0.949)(0.028)$$

$$\mathbf{a = 253,497 \text{ lbs/ft}}$$

$$b = (W_A \tan \delta_P + W_P \tan \delta_A + W_T \tan \phi_s) \sin \beta \sin \theta - (W_A \tan \delta_A + W_P \tan \delta_P) \cos \beta \cos \theta$$

$$b = [699,300(0.176) + 1,223,775(0.308) + 1,923,075(0.649)](0.316)(0.028) - [699,300(0.308) + 1,223,775(0.176)] (0.949) (1.00)$$

$$b = 1,748,075.2(0.316)(0.028) - 430,768.8(0.949)(1.00)$$

$$b = 15,466.9 \text{ lbs/ft} - 445,963.2 \text{ lbs/ft}$$

$$\mathbf{b = - 430,496.3 \text{ lbs/ft}}$$

$$c = - [W_P \tan \phi_s (\sin \beta \cos \theta \tan \delta_P + \cos \beta \sin \theta \tan \delta_A) + (W_A \cos \beta \sin \theta + W_P \sin \beta \cos \theta) \tan \delta_A \tan \delta_P]$$

$$c = - [[1,223,775(0.649) [(0.316)(1.00)(0.176) + (0.949)(0.028)(0.308)] + [699,300(0.949)(0.028) + 1,223,775(0.316)(1.00)](0.308)(0.176)]$$

$$c = - [1,223,775(0.649)[0.056 + 0.008] + [18,581.8 + 386,712.9](0.308)(0.176)]$$

$$c = - [794,230[0.064] + [405,294.7](0.308)(0.176)]$$

$$c = - [50,830.7 + [405,294.7(0.308)(0.176)]]$$

$$c = - [50,830.7 \text{ lbs/ft} + 21,970.2 \text{ lbs/ft}]$$

$$\mathbf{c = - 72,800.9 \text{ lbs/ft}}$$

$$d = W_T \cos \beta \cos \theta \tan \delta_A \tan \delta_P \tan \phi_s$$

$$d = 1,923,075(0.949)(1.00)(0.308)(0.176)(0.649)$$

$$\mathbf{d = 64,205.2 \text{ lbs/ft}}$$

$$aFS^3 + bFS^2 + cFS + d = 0$$

$$253,497 FS^3 - 430,496.3 FS^2 - 72,800.9 FS + 64,205.2 = 0$$

$$253,497 FS^3 + 64,205.2 = 430,496.3 FS^2 + 72,800.9 FS$$

This equation is then solved by trial and error as provided in **Table III.7.7**.

TABLE III.7.7
Geosynthetic Slippage Analysis Factor of Safety Summary
Sundance West

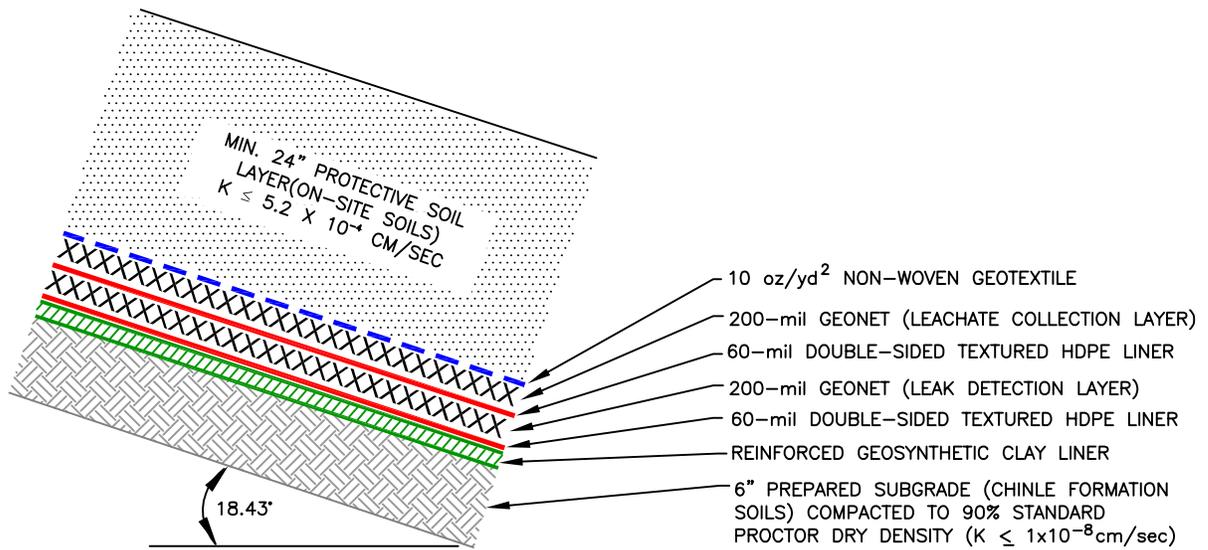
Assumed FS	$253,497FS^3+64,205.2$	$430,496.3FS^2+72,800.9FS$	Closure
(1)	(2)	(3)	(2) – (3)
2.0	2,092,181.2	1,867,587.0	224,594.2
1.7	1,309,635.9	1,367,894.9	-58,259.0
1.75	1,422,790.7	1,445,796.5	-23,005.8
1.8	1,542,599.7	1,525,849.6	16,750.1
1.78	1,493,865.4	1,493,570.1	295.3
1.77	1,469,905.1	1,477,559.5	-7,654.4

The factor of safety is 1.77, which indicates that the passive wedge will more than adequately support the active wedge on the sideslopes without slipping and the geosynthetic liner system is not in tension. Therefore, the proposed liner system design is compatible with calculated external forces.

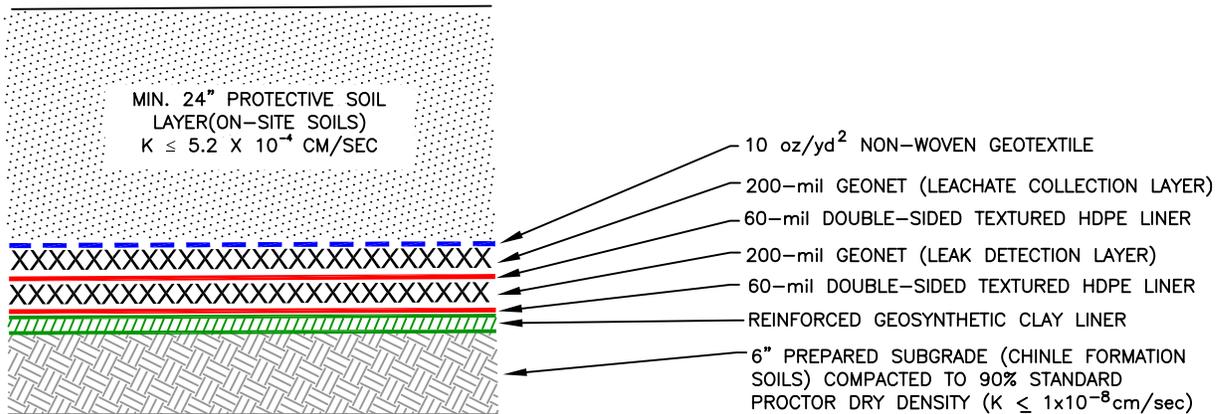
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SIDEWALL LINER SYSTEM



FLOOR LINER SYSTEM

SIDEWALL & FLOOR LINER SYSTEM DETAIL

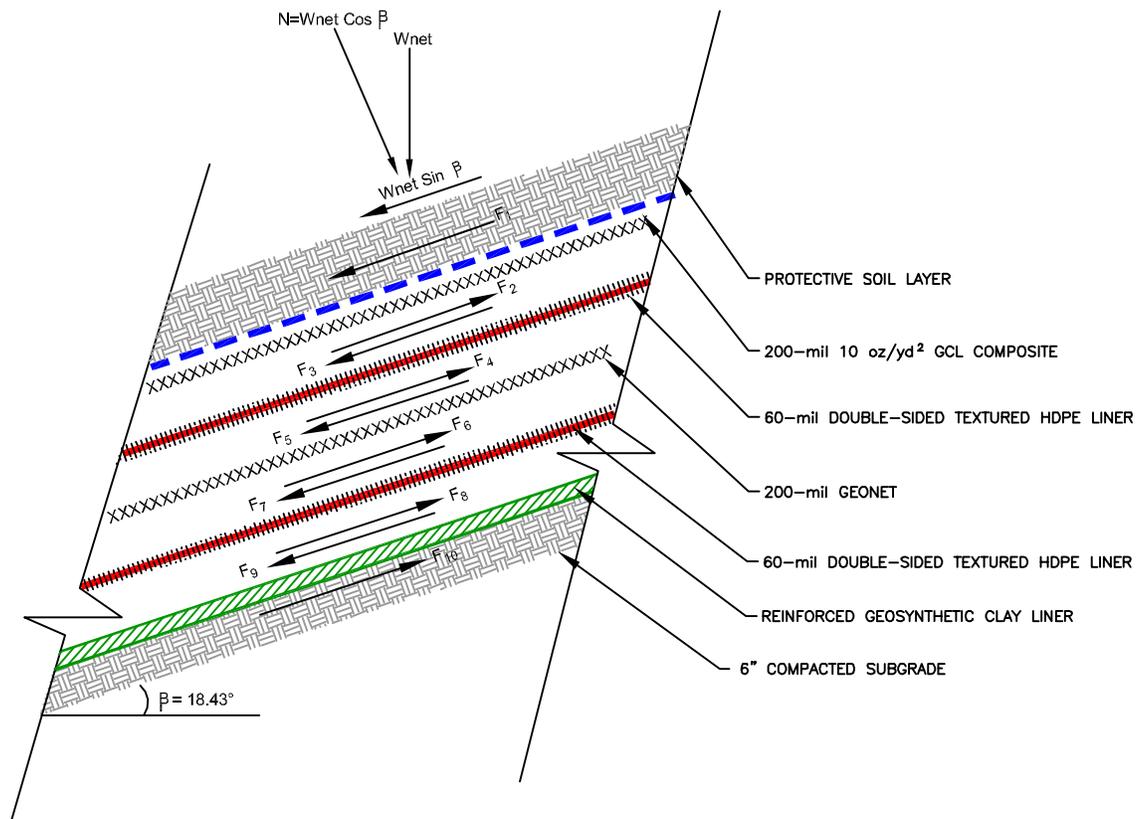
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LEA COUNTY, NEW MEXICO



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FREE BODY DIAGRAM
NOT TO SCALE

GEOSYNTHETIC FRICTION FORCES

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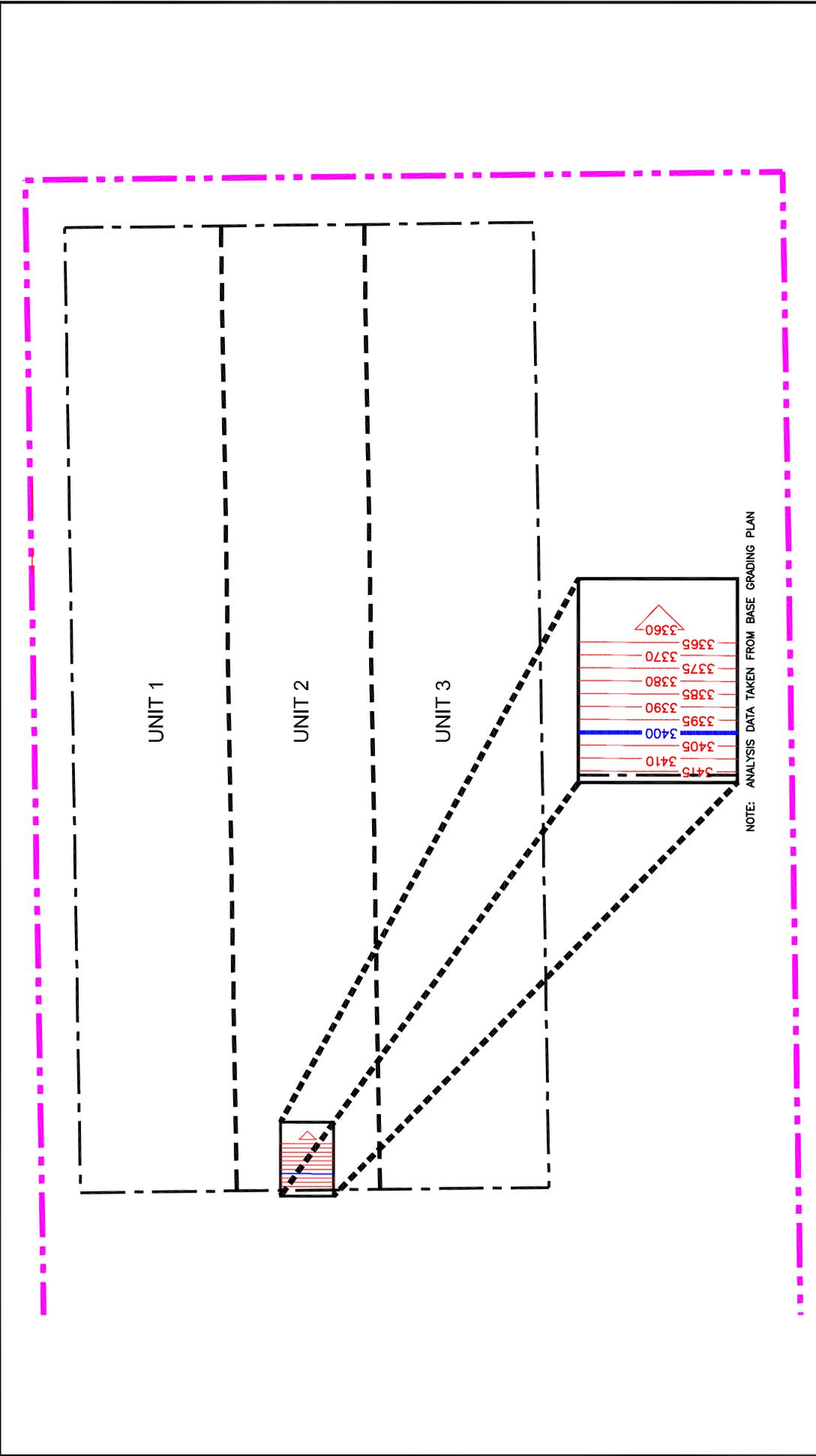


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SLIPPAGE ANALYSIS LOCATION

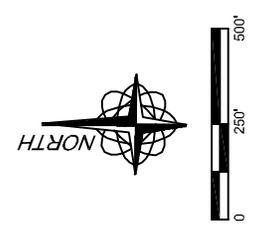
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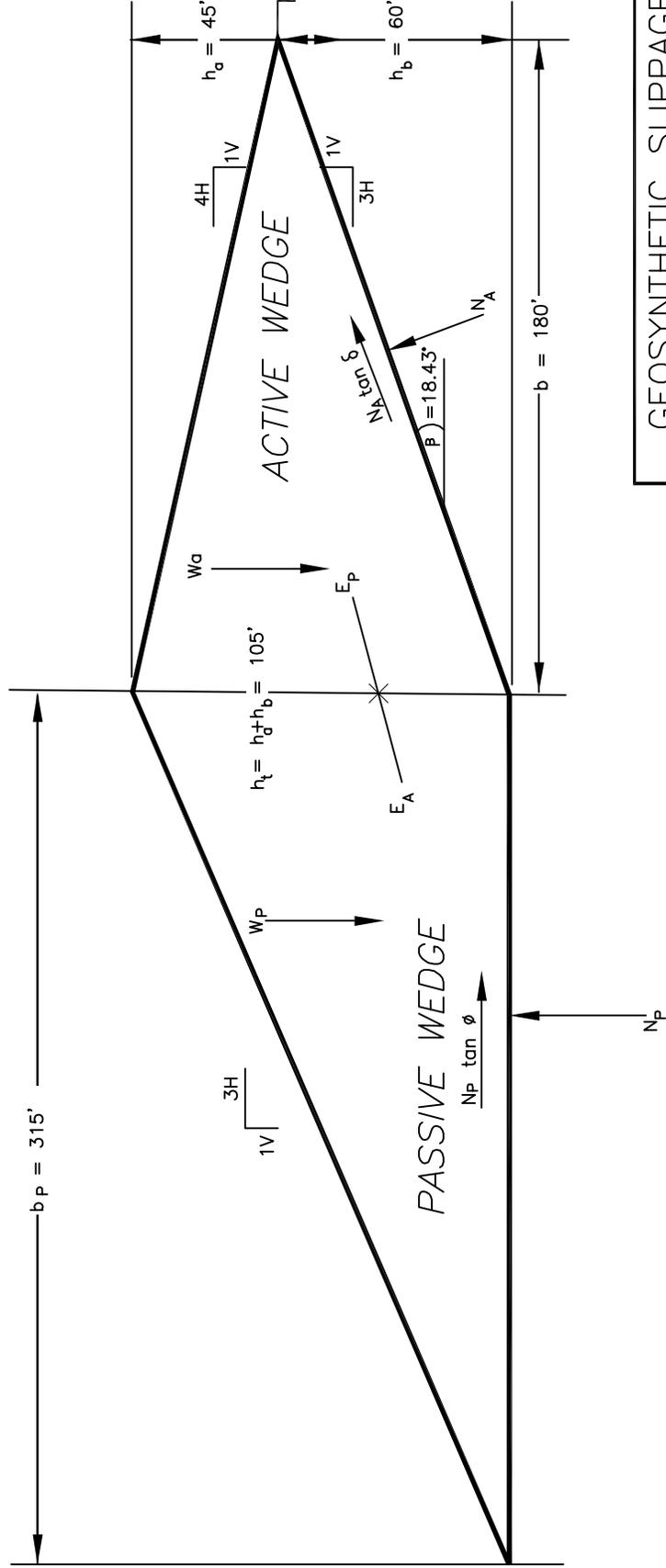
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FIGURE III.7.3



- LEGEND**
- FACILITY BOUNDARY
 - LIMIT OF WASTE
 - UNIT BOUNDARY



GEOSYNTHETIC SLIPPAGE ANALYSIS

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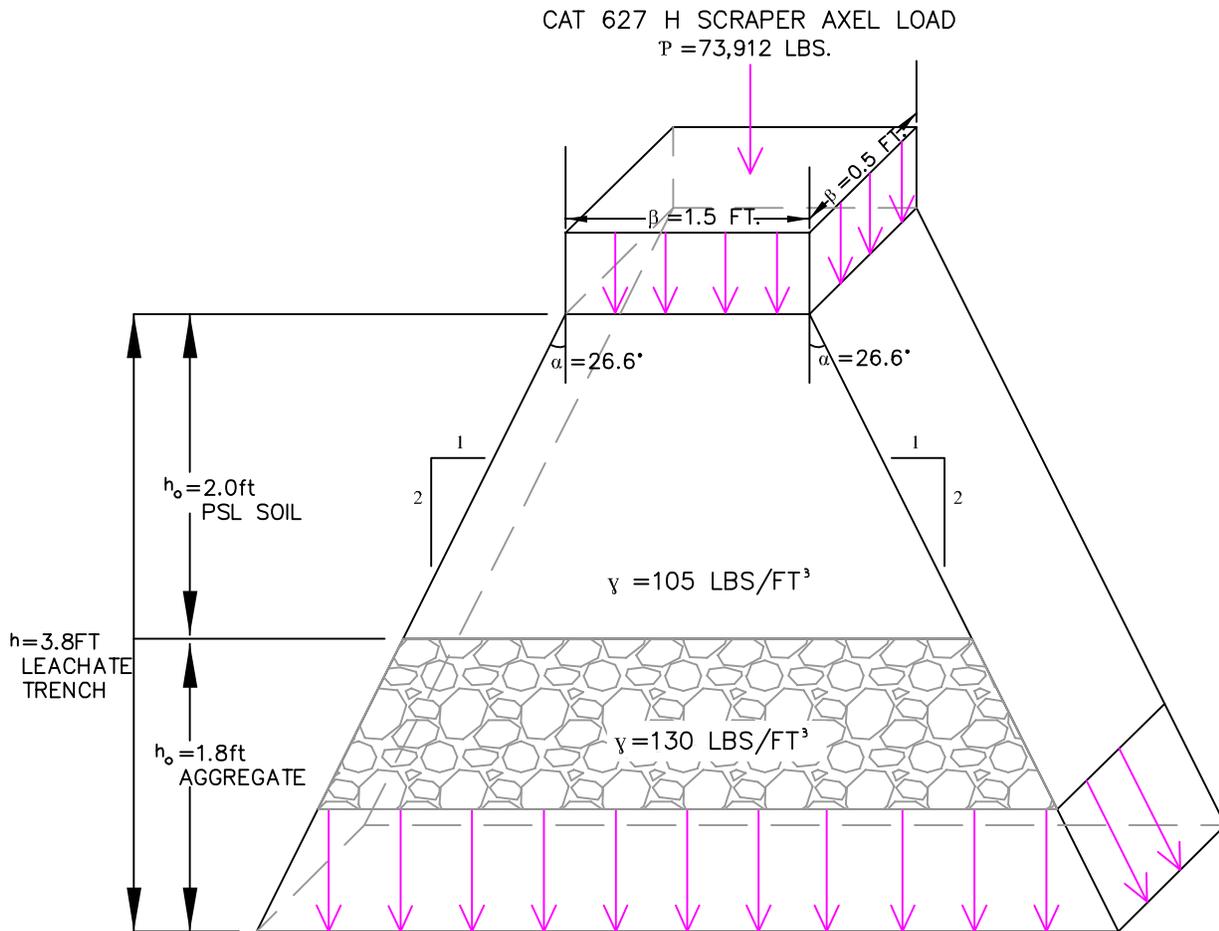


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NO SCALE

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FIGURE III.7.5