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PART 36
PERMIT
APPLICATION

Volume III Part 3

November 7, 2013

PVC PIPE DIMENSIONS

Nominal Pipe Size	Wall Thickness		Outside Diameters		
				Tolerance	
	Minimum	Tolerance	Average OD	Average	Out-of-Roundness
ASTM D 1785, PVC PIPE, SCHEDULE 40					
1	0.133	+0.020	1.315	±0.005	±0.010
1¼	0.140	+0.020	1.660	±0.005	±0.012
1½	0.145	+0.020	1.900	±0.006	±0.012
2	0.154	+0.020	2.375	±0.006	±0.012
2½	0.203	+0.024	2.875	±0.007	±0.015
3	0.216	+0.026	3.500	±0.008	±0.015
3½	0.226	+0.027	4.000	±0.008	±0.050
4	0.237	+0.028	4.500	±0.009	±0.050
5	0.258	+0.031	5.563	±0.010	±0.050
6	0.280	+0.034	6.625	±0.011	±0.050
8	0.322	+0.039	8.625	±0.015	±0.075
10	0.365	+0.044	10.750	±0.015	±0.075
12	0.406	+0.049	12.750	±0.015	±0.075
ASTM D 1785, PVC PIPE, SCHEDULE 80					
1	0.179	+0.021	1.315	±0.005	±0.010
1¼	0.191	+0.023	1.660	±0.005	±0.012
1½	0.200	+0.024	1.900	±0.006	±0.012
2	0.218	+0.026	2.375	±0.006	±0.012
2½	0.276	+0.033	2.875	±0.007	±0.015
3	0.300	+0.036	3.500	±0.008	±0.015
3½	0.318	+0.038	4.000	±0.008	±0.015
4	0.337	+0.040	4.500	±0.009	±0.015
5	0.375	+0.045	5.563	±0.010	±0.030
6	0.432	+0.052	6.625	±0.011	±0.035
8	0.500	+0.060	8.625	±0.015	±0.075
10	0.593	+0.071	10.750	±0.015	±0.075
12	0.687	+0.082	12.750	±0.015	±0.075
ASTM D 2241, PVC PIPE (SDR-PR), SDR 21 (200)					
1	0.063	+0.020	1.315	±0.005	±0.015
1¼	0.079	+0.020	1.660	±0.005	±0.015
1½	0.090	+0.020	1.900	±0.006	±0.030
2	0.113	+0.020	2.375	±0.006	±0.030
2½	0.137	+0.020	2.875	±0.007	±0.030
3	0.167	+0.020	3.500	±0.008	±0.030
3½	0.190	+0.023	4.000	±0.008	±0.050
4	0.214	+0.026	4.500	±0.009	±0.050
5	0.265	+0.032	5.563	±0.010	±0.050

APPLICATION FOR PERMIT
DNCS ENVIRONMENTAL SOLUTIONS

VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 5: PIPE LOADING CALCULATIONS

ATTACHMENT III.5.D

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 moire 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 chlorine (PVC) d. Thermoset plastic pipe
      - Reinforced plastic mortar (RPM)

- Reinforced thermosetting resin (RTR)

Within the rigid pipe classification, the suitability of cast iron arid 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, arid 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 arid 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 lover 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 later method appears to be an adequately conservative approach. If Lp equals the cumulative length of the perforations per unit length of the pipe, L, then thelactual load on the pipe should be increased as follows:

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

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.

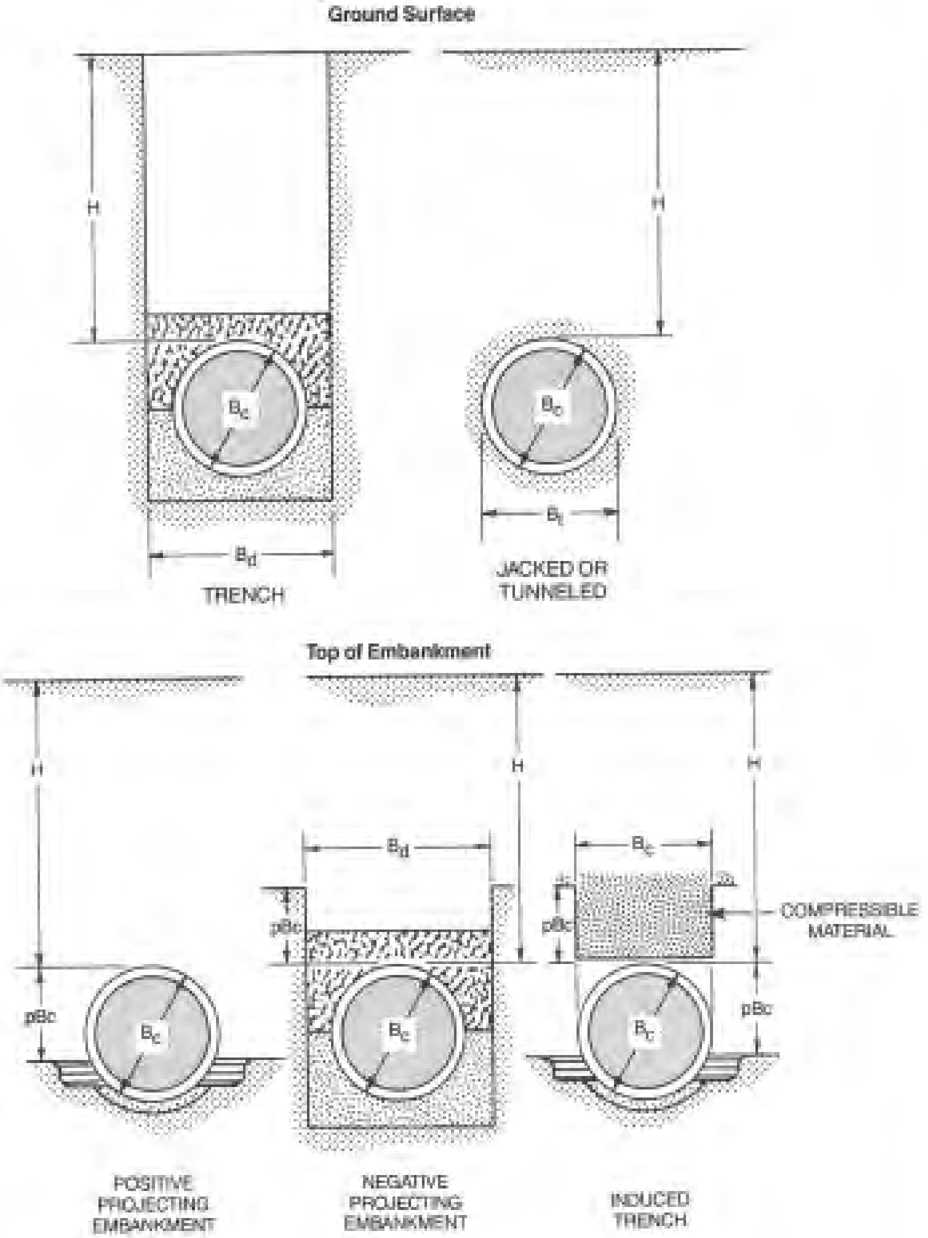
The supporting strength of a leachate collection pipe is a function of installation conditions as well as the strength of the pipe itself. Structural analysis and design of the collection system are problems of soilstructure interaction. This section presents general procedures for determining the structural 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.



Adapted From: American Concrete Pipe Association, 1980

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:

$$W = CWB2 \qquad (4C\text{-}2)$$

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, Of, at the base of the fill. The magnitude of Qf is given by the expression:

$Q_f = (w_f)(H_f)$ (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:

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

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, Pvf (in lbs/sq ft), is determined from the following:

$Pvf = ({}^{Q}f)({}^{C}us)$ (4C-5)

where: Cus = 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.

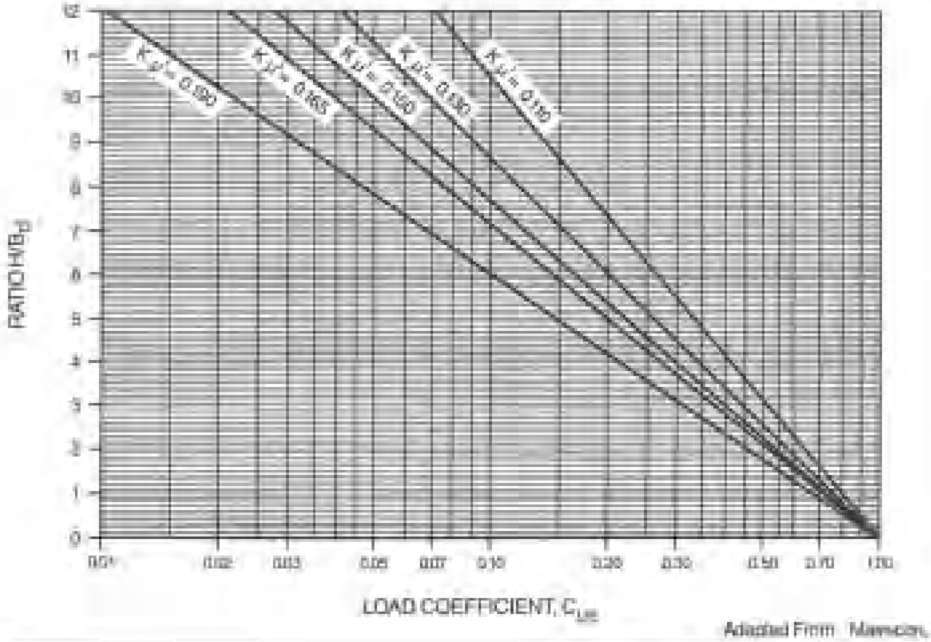
The load coefficient, C_{us}, may be calculated from the following equation or obtained from Figure 4C.2:

${}^{C}us = e^{-2KU'(H/Bd)}$ (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



Adapted From Mansion, Inc., 1983

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 (f t)

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

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

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

Type of Soil	Maximum Value of Ku'
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):

$$Pvt = (Bd)(w)(Cd) \qquad (4C\text{-}7)$$

where:

$Pvt =$ 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:

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

in which the terms are as previously defined.

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

$$Pv = P_{vf} + P_{vt} \qquad (4C\text{-}9)$$

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

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

$$we = P_v B_d \qquad (4C\text{-}11)$$

or:

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

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

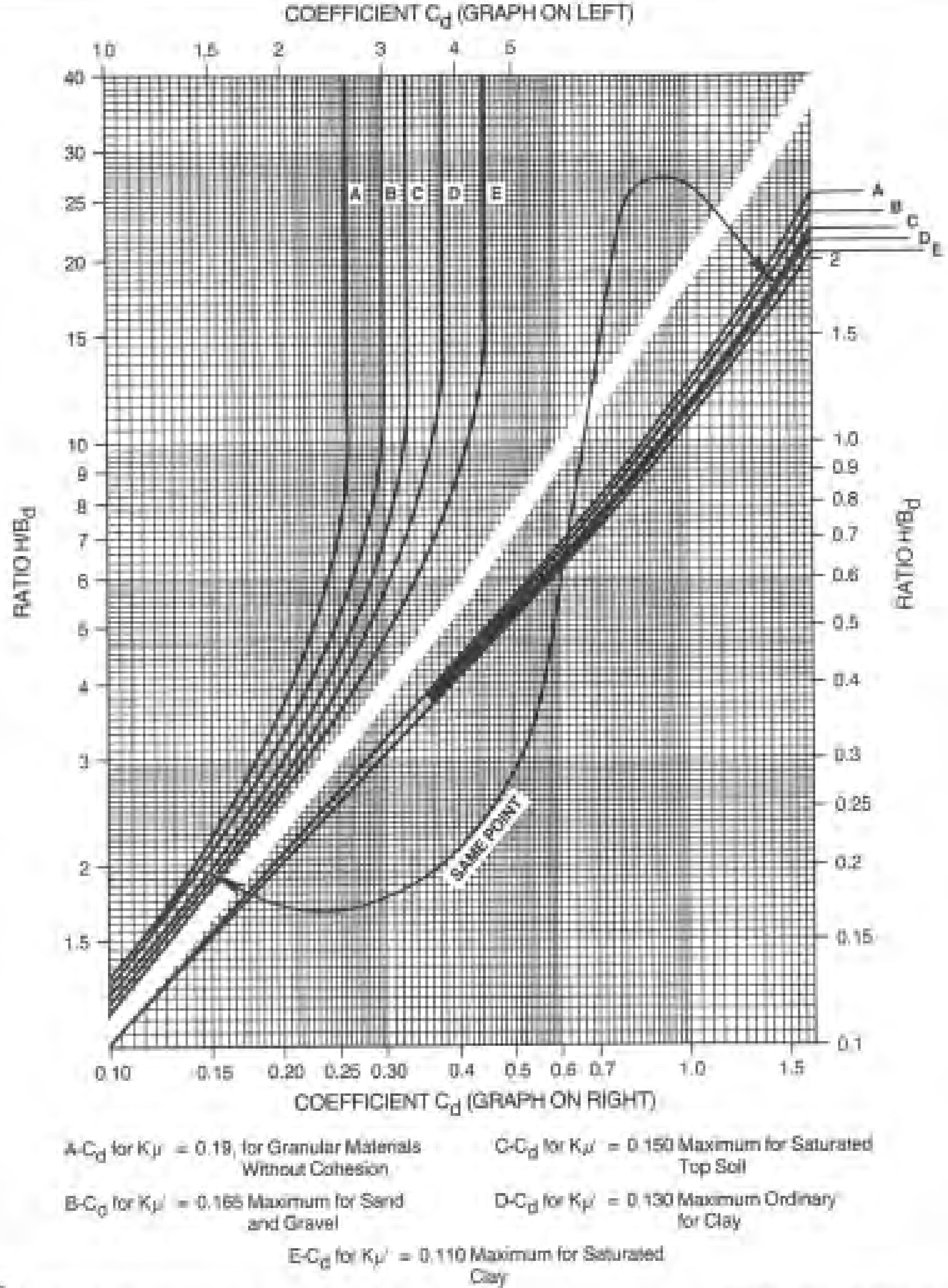
For flexible pipe in the trench condition, the load as given by Marston's formula would be:

$$w_c = P_v B_c \qquad (4C\text{-}13)$$

or:

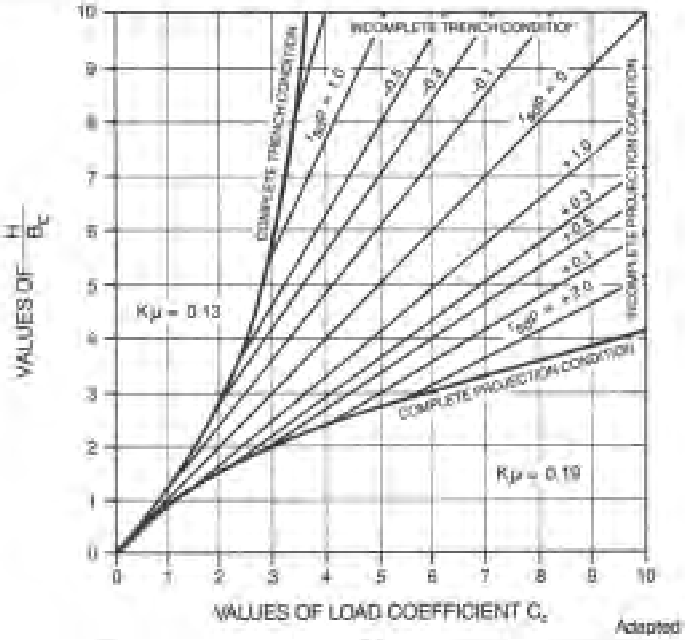
$$w_c = (B)(Q_f)(C_{us}) + (B_d)(w)(C_d)(B_c) \qquad (4C\text{-}14)$$

where: $B_c =$ Outside diameter of pipe (ft)



Adapted From: Matrecon, Inc., 1983

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



Adapted From: ASCE and WPCF, 1982

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:

$$W_c = C_c{}^{w}fB_c^2 \qquad (4C\text{-}15)$$

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 Sever Design and Construction published by the ASCE and WPCF (1982). Values of Cc may be obtained from Figure 4C.4.

Table 4C.2. Recommended Design Values of rsd (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:

$$W_c = (H)(w_f)(B_c) \qquad (4C\text{-}16)$$

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 Ku for use in Figure 4C.4.

For a positive settlement ratio: Ku = 0.19
For a negative settlement ratio: Ku = 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:

$$W_c = C_n{}^{wB}d^2 \qquad (4C\text{-}17)$$

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 sever 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 WPCE (1982). Values of C_n may be obtained from Figure 4C.5.

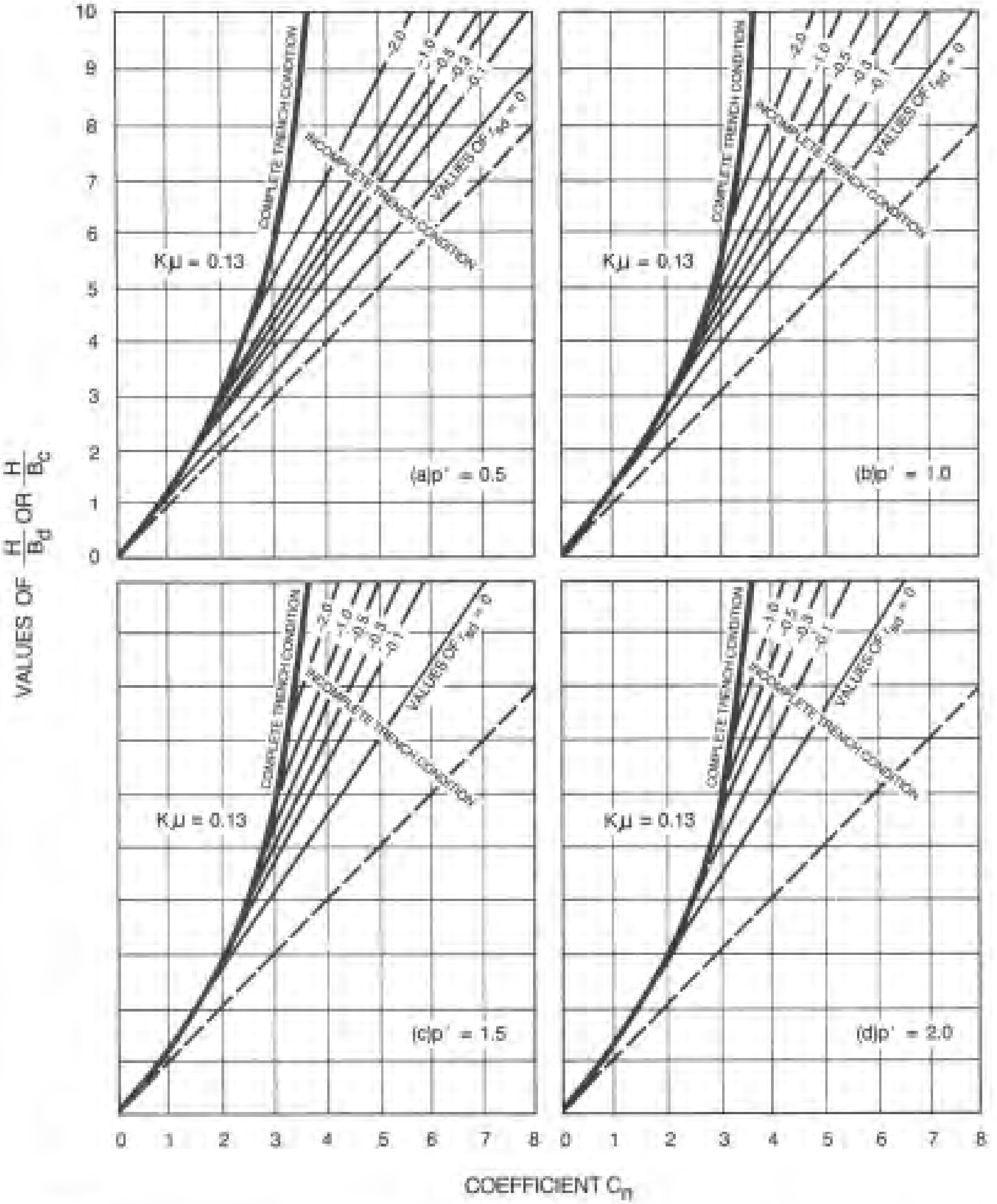
As in the case of the positive projecting embankment condition, the fill load is influenced by the product of the settlement ratio (r_{sd}) and the projection ratio (p'). The settlement ratio for the negative projecting embankment condition is the quotient obtained by taking the difference between the 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 05 (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



Adapted From: ASCE and WPCF, 1982

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):

$$W_{sc} = \frac{PF}{C_S L} \qquad (4C\text{-}18)$$

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):

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

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_S, for Concentrated and Distributed Superimposed Loads Vertically Centered over Sewer Pipe.

$\frac{D}{2H}$ or $\frac{B_C}{2H}$	$\frac{M}{2H}$ 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

Equipment	Operating Weight (lbs)	Ground Contact	Track or Wheel Load (lbs)
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 ASTSM 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 indicatedt 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.

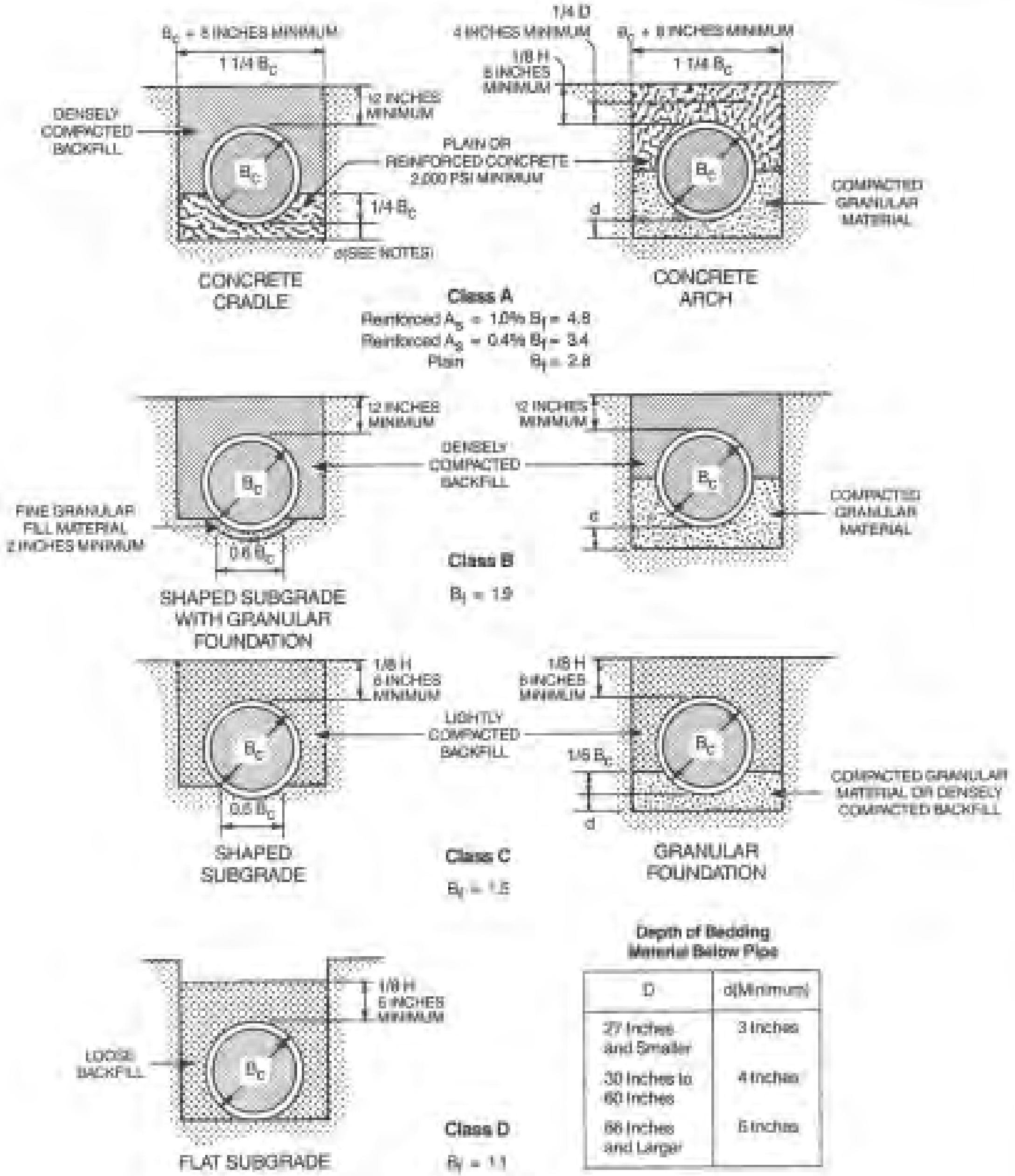
4C.3.1.2 Embankment Beddings

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, Lf, for this type of installation is computed by the equation:

$$Lf \qquad \frac{A}{N-xq} \qquad (4C\text{-}20)$$

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.



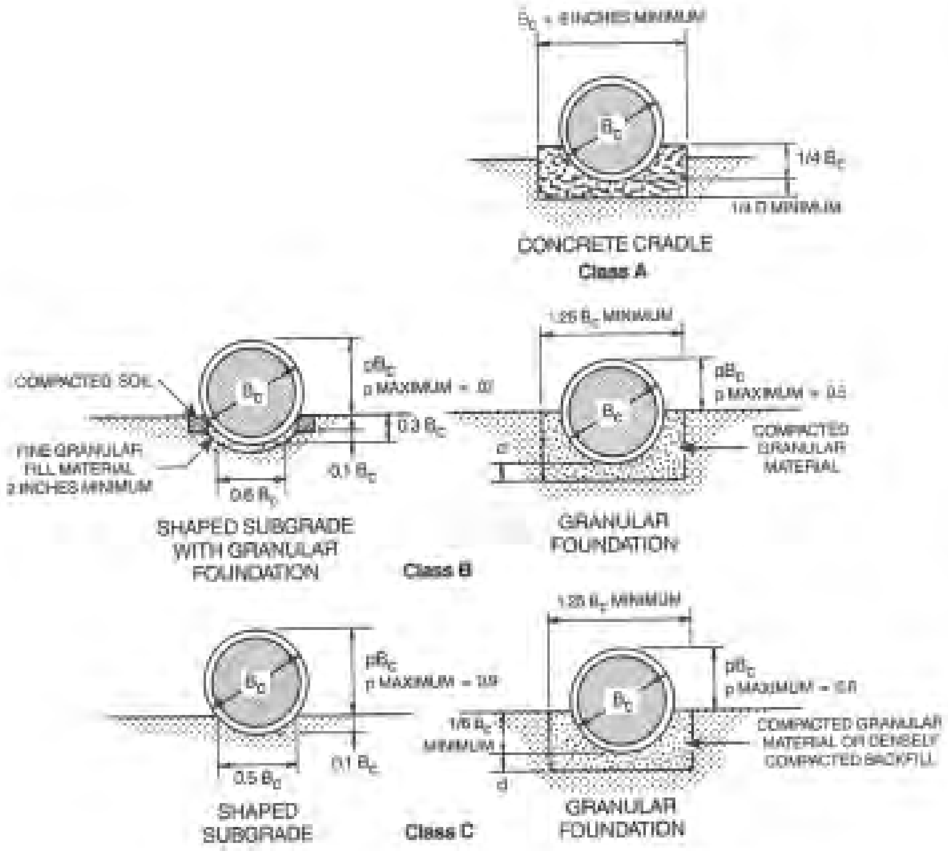
Depth of Bedding Material Below Pipe

D	d(Minimum)
27 Inches and Smaller	3 Inches
30 Inches to 60 Inches	4 Inches
66 Inches and Larger	6 Inches

Adapted From: American Concrete Pipe Association, 1980

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



Depth of Bedding Material Below Pipe

D	d(Minimum)
27 Inches and Smaller	3 Inches
30 Inches to 60 Inches	4 Inches
66 Inches and Larger	6 Inches

Adapted From: American Concrete Pipe Association, 1980

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

Class of Bedding	N
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:

$$q \qquad \frac{mk}{C_c}\left[\frac{H}{B_c} + \frac{m}{2}\right] \tag{4C-21}$$

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

Fraction of Pipe Subjected to Lateral Pressure, m	Class A Bedding	Other Than Class A Bedding
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):

$$Y = \frac{D_l K_b W_c r^3}{EI + 0.061\, E' r^3} \qquad \text{(4C-22)}$$

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

D_l = 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 (in0n)
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, Bc, and relate it to the vertical stress on the pipe, Pv, as follows:

$$\frac{W_C}{B_c} = P_v = \frac{Y(EI + 0.061\, E'n^3)}{B_c(D_l K_b r^3)} \qquad (4C\text{-}23)$$

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, Kb, are listed in Table 4C.8. Spangler's data suggested a Kb value of 0.10 for pipe embedded in native soil with no bedding and a Kb 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 Kb value of 0.083 should therefore be used in lieu of actual field data.

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

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, El, 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 El is not realistic for leachate collection pipes in many localites (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, aa 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 Eld, 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:

$$PS = \frac{F}{Y} \qquad \text{(4C-.24)}$$

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

$$SF = EI = 0.149r3(PS) \qquad (4C\text{-}25)$$

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:

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

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:

$$\text{Coefficient of uniformity, } C_u, \quad = \frac{D60}{D_{10}} \qquad \text{(4C-27)}$$

and

$$\text{Coefficient of curvature, } C_c, \quad = \frac{(D30)_2}{(D_{10})(D_{60})} \qquad \text{(4C-28)}$$

where: D_{10}, D_{30}, and D — 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
DNCS ENVIRONMENTAL SOLUTIONS

VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 5: PIPE LOADING CALCULATIONS

ATTACHMENT III.5.E

POLY PIPE INDUSTRIES, INC. 2008.

DESIGN AND ENGINEERING GUIDE FOR POLYETHYLENE PIPING.

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PolyPipe®

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.**	**Actual mm.**		**in.**	**mm.**	**in.**	**mm.**	**lb. per foot**	**kg. per meter**
			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.

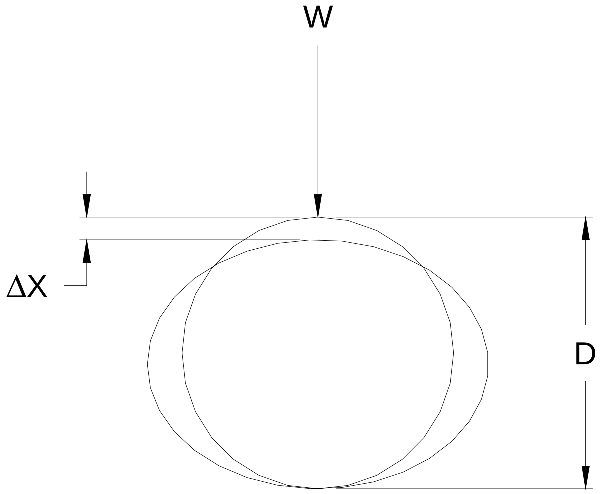
RING DEFLECTION

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 formula[5]:

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

Where W = Earthload per unit length of pipe, lbs/in
C_d = Trench Coefficient, (dimensionless) (See Figure C-2)
ρ = Soil density, lbs/ft^3
D = Outside diameter, inches
B_d = Trench width at top of pipe, feet

---

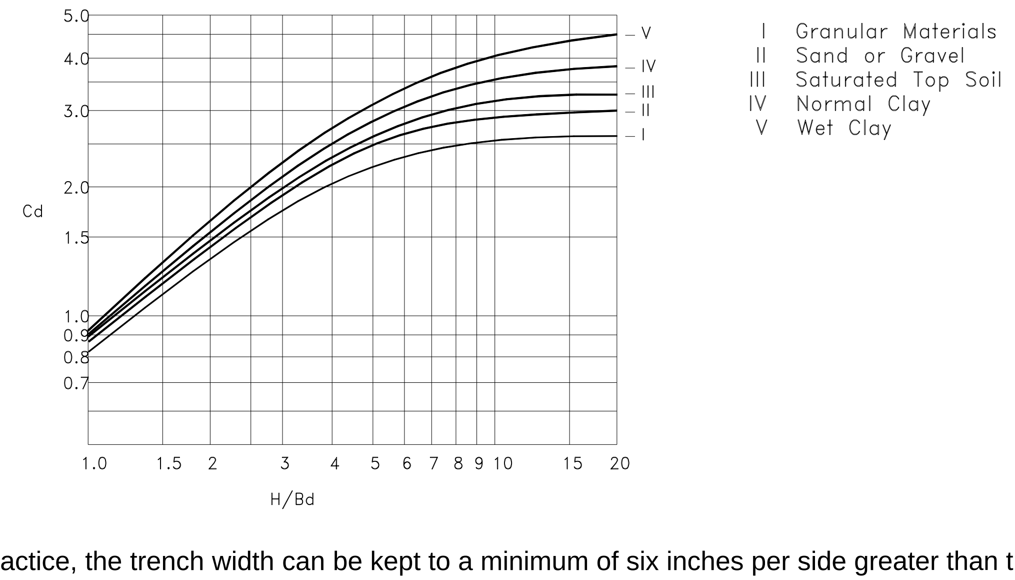
[5] Moser, A.P. Buried Pipe Design. 2nd Edition. New York: McGraw-Hill, 2001.

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

Class	Comments
Class I - 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.
Class II - 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.
Class III - Fine sand and clay gravel, including fine sands, sand-clay mixtures, and gravel-clay mixtures.	140 - 150 pounds per cubic foot.
Class IV - Silt, silty clays, and clays, including inorganic clays and silts of medium to high plasticity and liquid limits.	150 - 180 pounds per cubic foot.
Class V - 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 equation[6]:

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

Where Δx = Horizontal deflection or change in diameter, inches
D_l = 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 formula[6]:

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

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

---

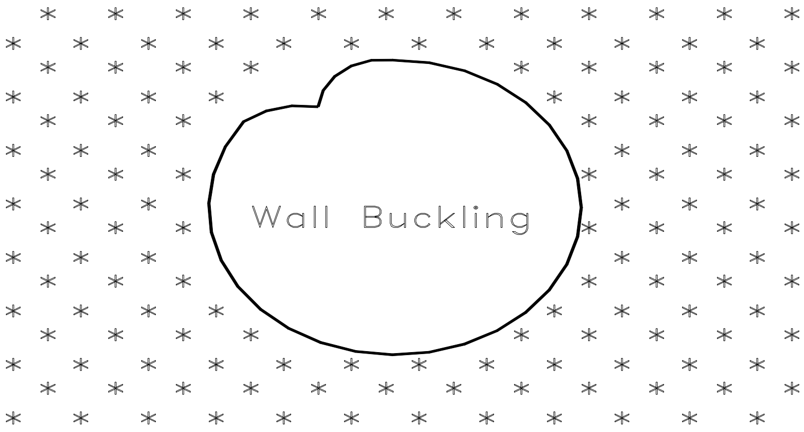
[6] Plastics Pipe Institute. Underground Installation of Polyethylene Pipe, 1996.

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 LOAD[1]

$$P_b = \frac{\rho_{soil} \cdot H}{144} \tag{20}$$

Where P_b = Backfill load, psi
ρ_{soil} = Backfill density, lbs/ft^3
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 Boussinesq[17] formulation:

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

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,

---

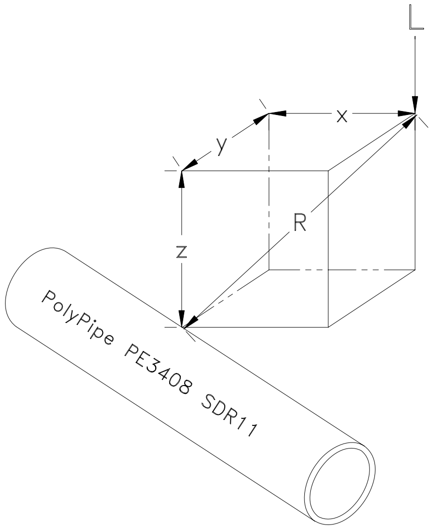
[1] Nayyar, Mohinder L. Ed. Piping Handbook. 6th Edition. New York: McGraw-Hill, Inc., 1992.

[17] Chen, W. F., Liew, Richard L. Y. The Civil Engineering Handbook. New York: CRC Press, 2003. 2nd Edition.

$$R = \sqrt{x^2 + y^2 + z^2} \tag{22}$$

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)

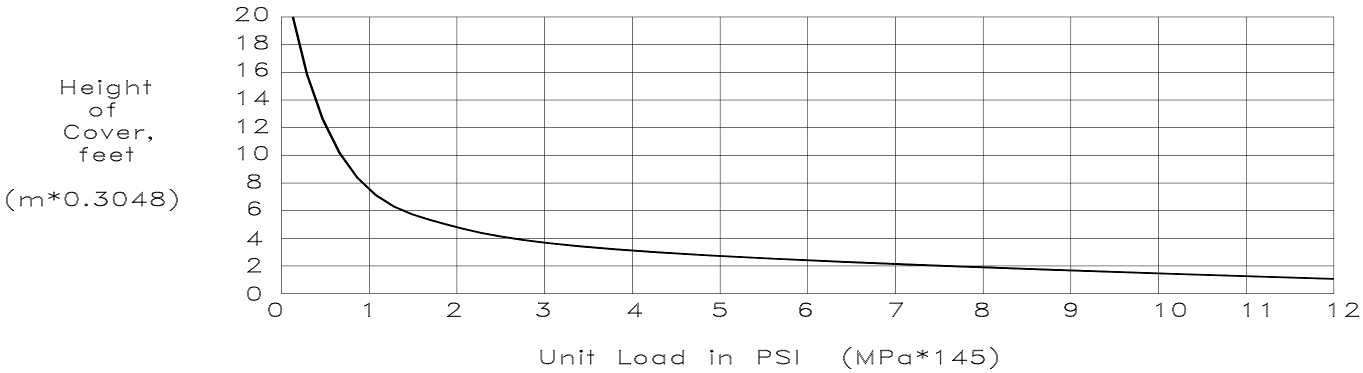
Figure C-4
RESULTANT SURFACE LOAD



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.

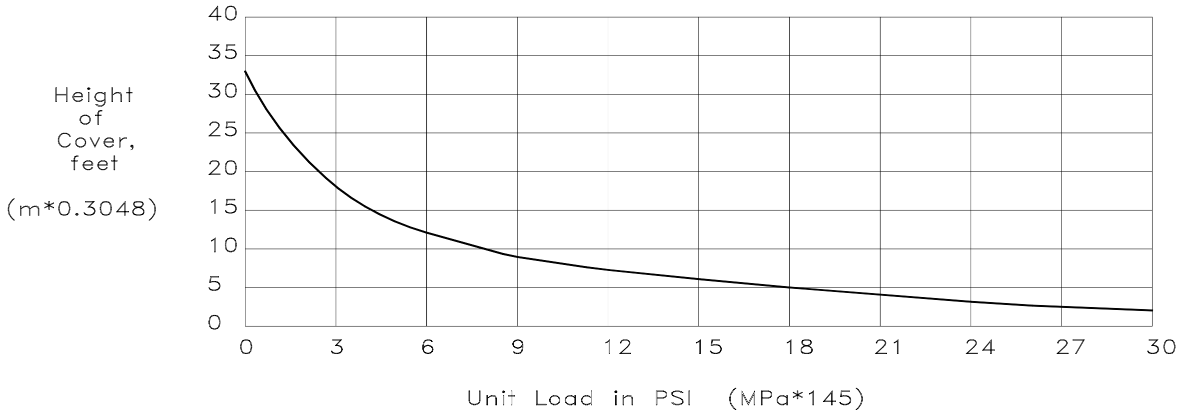
Figure C-5
H20 HIGHWAY LOADING



***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,

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

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:

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

or

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

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SECTION 5: PIPE LOADING CALCULATIONS

ATTACHMENT III.5.F

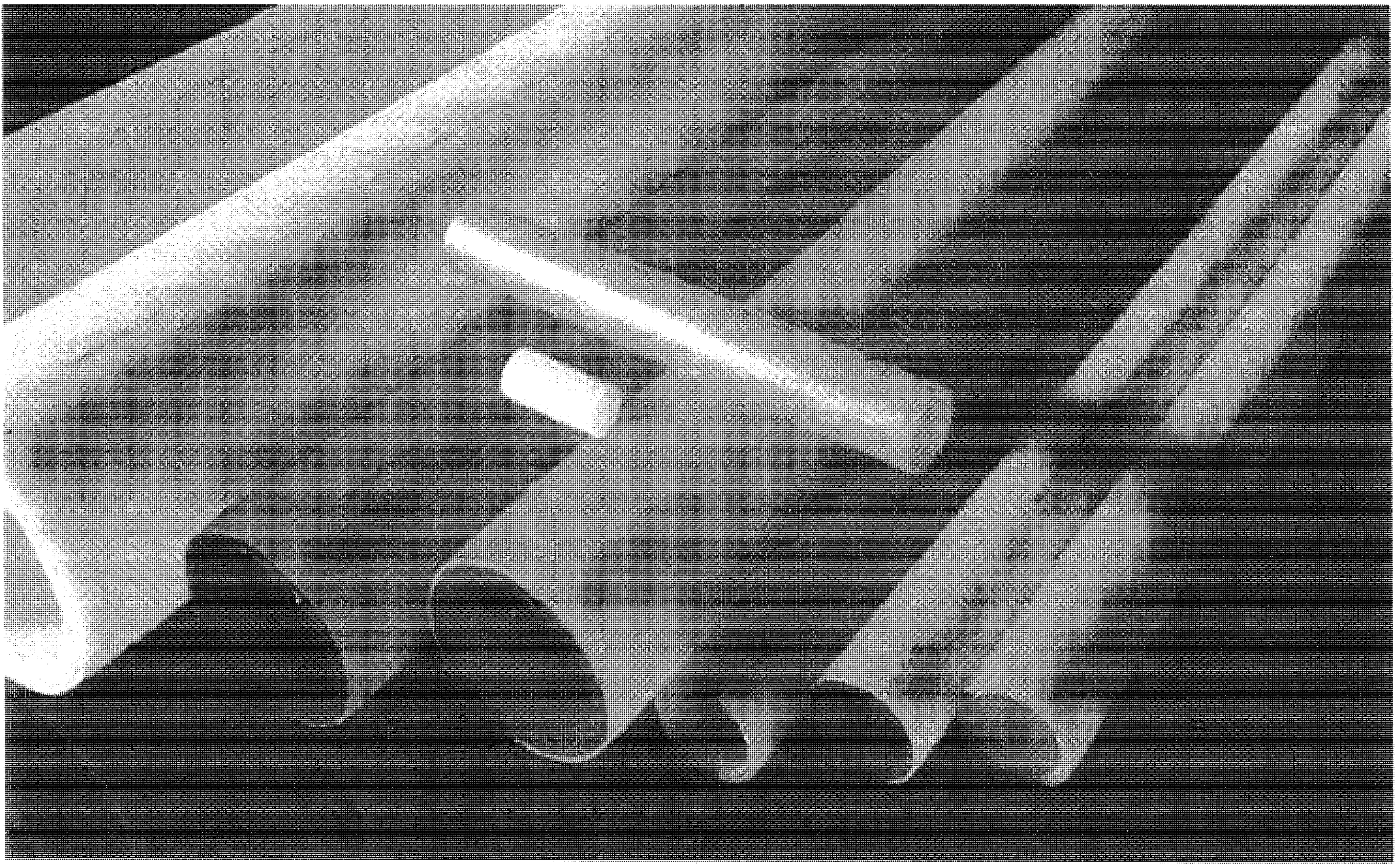
DRISCOPIPE, INC. 2008.

POLYETHYLENE PIPING SYSTEMS MANUAL

www.driscopipe.com

DRISCOPIPE®

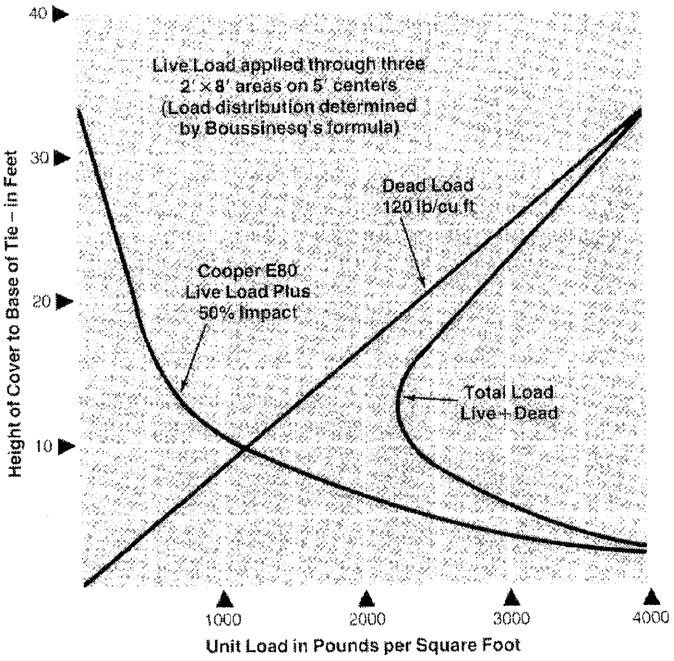
Polyethylene Piping Systems Manual



Innovative Supplier of Quality Piping Systems.

PHILLIPS 66

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_I 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_I is positive. P_I 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

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

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.

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SECTION 5: PIPE LOADING CALCULATIONS

ATTACHMENT III.5.G

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:

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

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

$$C = h - z \qquad \textbf{(7-40)}$$

For DriscoPlex™ OD Controlled pipe

$$C = 0.5\,(1.06\,t) \qquad \textbf{(7-41)} \; \leftarrow$$

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 $\boxed{f_D = 6.0.}$

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.

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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

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1.0 INTRODUCTION

DNCS Environmental Solutions (DNCS Facility) is a proposed Surface Waste Management Facility for oil field waste processing and disposal services. The proposed DNCS 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, DNCS Properties, LLC.

1.1 Description

The DNCS site is comprised of a 562-acre ± tract of land located south of NM 529 in portions of Section 31, Township 17 South, Range 33 East; and in the northern half of Section 6, Township 18 South, Range 33 East, Lea County, NM. A portion of the 562-acre tract is a drainage feature that will be excluded from development. The drainage feature includes a 500-ft setback and totals 67 acres ±. The DNCS Facility will include two main components; a liquid oil field waste Processing Area (177 acres ±), and an oil field waste Landfill (318 acres ±); therefore the DNCS Facility comprises 495 acres ±. Oil field wastes are anticipated to be delivered to the DNCS 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 x 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 x 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, primarily over the past 30 years. Fluid Containment design provides a unique opportunity to incorporate a range of engineered materials that exceed the equivalent performance of soils. The design of the DNCS Facility includes several examples of geosynthetics and plastics deployed for their superior characteristics, usually applied in conjunction with soil layers:

- Geomembranes (flexible membrane liners) provided as barrier layer in the primary and secondary liner system (**Attachment III.6.A**).
- Geotextiles serving as cushioning layers and as filters to maintain flow (**Attachment III.6.B**).
- Geonets deployed as drainage layers and in leak detection systems (**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 environmental setting. These materials must be able to withstand the physical forces that they will experience, as documented in this section. **Attachment III.6.A** includes recent research results that indicate the functional longevity of HDPE liners in similar installations is in the hundreds of years.

This section provides demonstrations, as required by 19.15.36.14.D.1 and 19.15.36.17.B NMAC 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
DNCS Environmental Solutions

MATERIAL	FUNCTION	ATTACHED REFERENCE DOCUMENTATION	
HDPE Geomembrane	Primary and secondary barrier layer for landfill liner.	III.6.A	*Geomembrane Lifetime Prediction: Unexposed and Exposed Conditions*
			Chemical Compatibility of Poly-Flex Liners
			Chemical Resistance Table Low Density and High Density Polyethylene
			NSC, Contaminant Solutions for Industrial Waste; HDPE Geomembrane
			Liner Longevity Article: Geosynthetics Magazine, Oct/Nov 2008
Geotextile	Filter layer around leachate collection piping.	III.6.B	*Amoco Technical Note No. 7, Chemical Resistance of Amoco Polypropylene Geotextiles*
			Amoco Technical Note No. 14, Geotextile Polymers for Waste Applications
Geonet	Drainage layer between primary and secondary liner	III.6.C	*Evaluation on Stress Cracking Resistance of Various HDPE Drainage Geonets*
GCL	Secondary layer in composite liner.	III.6.D	*The Effects of Leachate on the Hydraulic Conductivity of Bentomat*
			Bench-scale Hydraulic Conductivity Tests of Bentonitic Blanket Materials for Liner and Cover Systems (Thesis by Paula Estornell)
HDPE Pipe	Solid and slotted piping, leachate collection system and GCCS.	III.6.E	*Chemical Resistance of Plastics and Elastomers Used in Pipeline Construction*
			Driscopipe Engineering Characteristics
			Plexco Chemical Resistance Information
PVC Pipe	Solid and slotted piping, leachate collection system and GCCS.	III.6.F	*Certainteed - PVC Chemical Resistance*

Acronyms used:

GCL:	Geosynthetic Clay Liner
FML:	Flexible Membrane Liner
PVC:	Polyvinyl Chloride
HDPE:	High Density Polyethylene

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ATTACHMENT III.6.A

HDPE GEOMEMBRANES REFERENCE DOCUMENTATION

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475 Kedron Avenue
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
LLDPE = linear low density polyethylene
fPP = flexible polypropylene
PVC = polyvinyl chloride (plasticized)
CSPE = chlorsulfonated polyethylene
EPDM = ethylene propylene diene terpolymer

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* 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 (Halflife)

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.

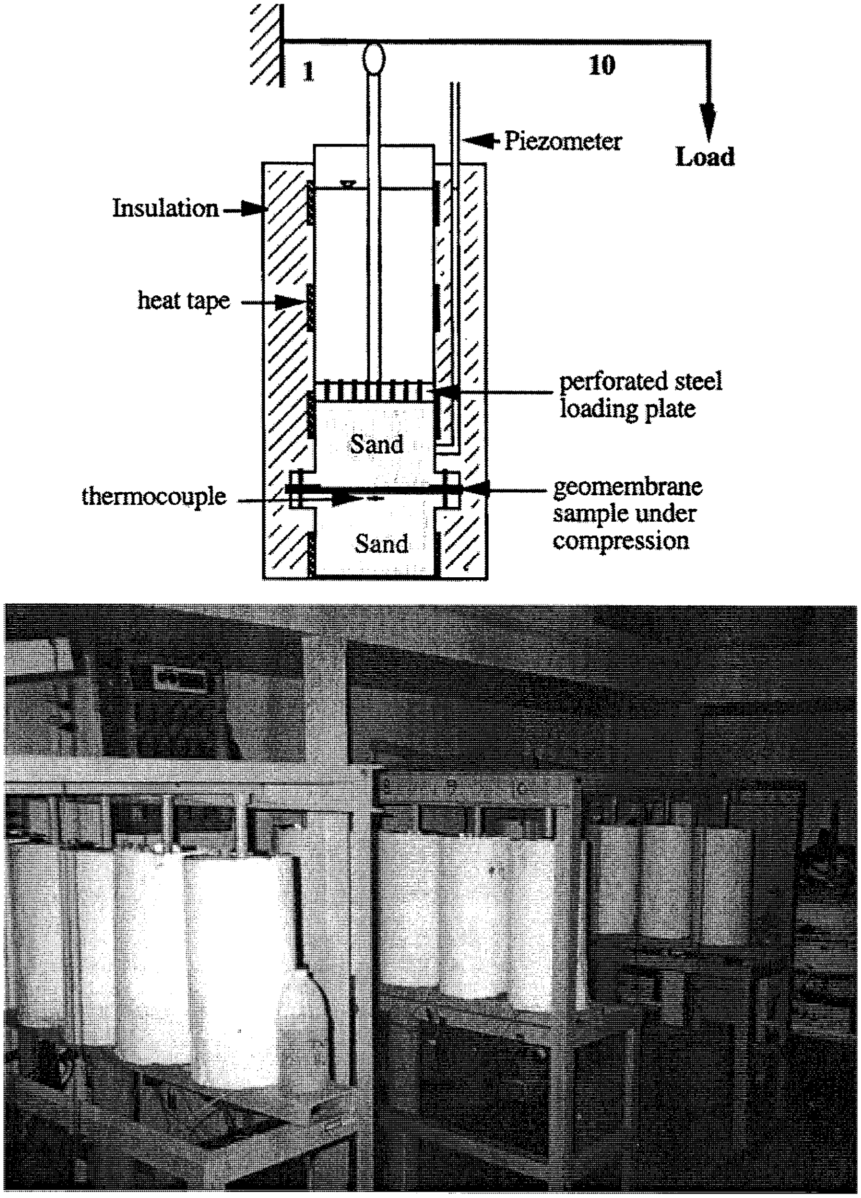


Figure 1. Incubation schematic and photograph of multiple cells maintained at various constant temperatures.

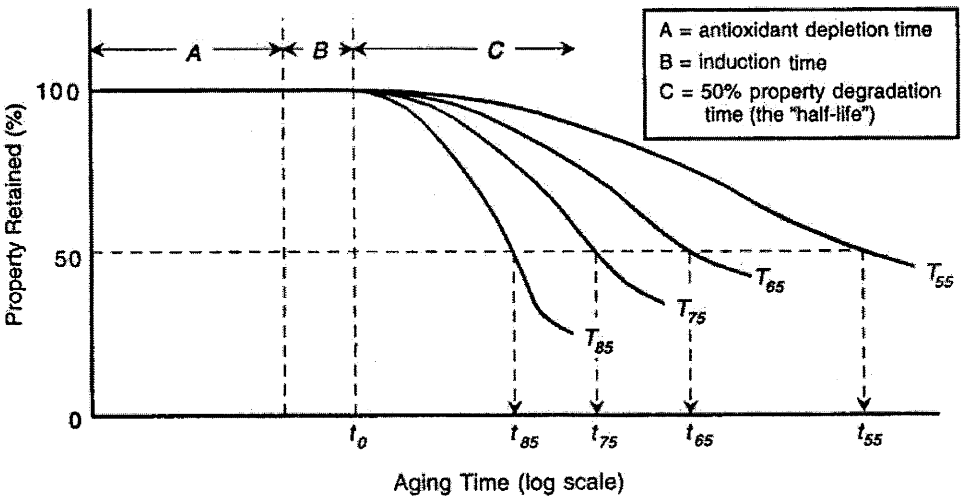


Figure 2. Three conceptual stages in chemical aging of polyolefin geomembranes.

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).

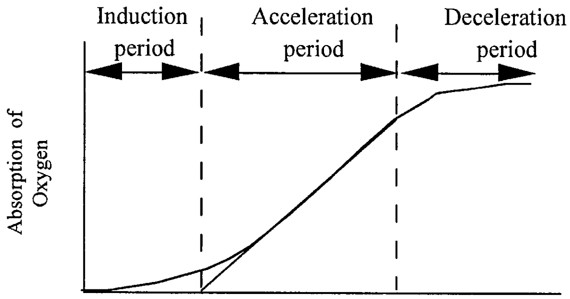
$$\mathrm{RH} \rightarrow \mathrm{R}\bullet + \mathrm{H}\bullet \qquad (1)$$

(aided by energy or catalyst residues in the polymer)

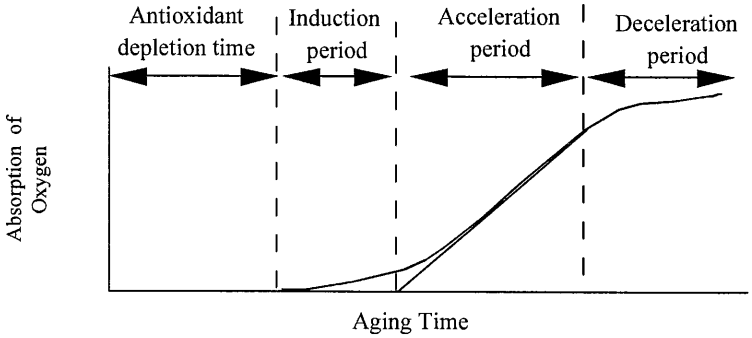
$$R\bullet + O2 \rightarrow ROO\bullet \quad (2)$$

$$ROO\bullet + RH \rightarrow ROOH + R\bullet \quad (3)$$

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 (Halflife)

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, Rapopport and Zaikov (1986). This indicates that the concentration of ROOH has a critical control on the duration of the induction period.

$$\mathrm{ROOH} \rightarrow \mathrm{RO}\bullet\ \mathrm{OH}\bullet \text{ (aided by energy)} \tag{4}$$

$$\mathrm{RO}\bullet + \mathrm{RH} \rightarrow \mathrm{ROH} + \mathrm{R}\bullet \tag{5}$$

$$\mathrm{OH}\bullet + \mathrm{RH} \rightarrow \mathrm{H2O} + \mathrm{R}\bullet \tag{6}$$

A series of oxidation reactions produces a substantial amount of free radical polymer chains (R•), 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 halflife time, or simply the "halflife". It should be noted that even at halflife, 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	Stage "A" (yrs.)		Stage "B" (yrs.)	Stage "C" (yrs.)		Total Lifetime
°F	(°C)	Std OIT	HP-OIT	Field Data	(max.)	(min.)	(ave. values)
68	20	200	215	30	255	149	449
77	25	135	144	25	132	77	270
86	30	95	98	20	70	41	173
95	35	65	67	15	38	22	111
104	40	45	47	10	21	12	73

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 halflife 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 halflife 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).

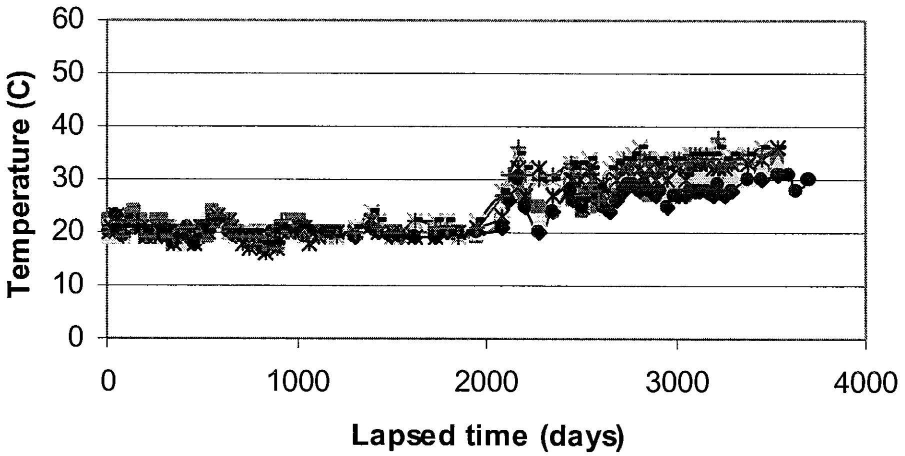


Figure 4. Long-term monitoring of an HDPE liner beneath a municipal solid waste landfill in Pennsylvania.

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 geomembrnaes

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).

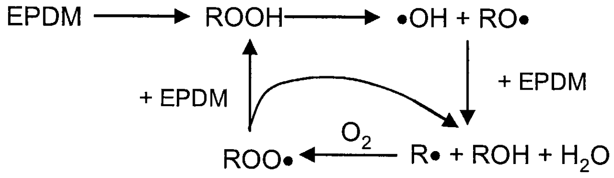
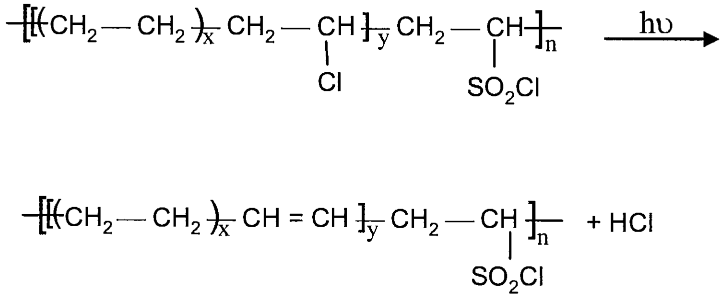


Figure 5. Oxidative degradation of crosslinked EPDM geomembranes, (Wang and Qu, 2003).

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.



$$\left[\left[\left(CH_2-CH_2\right)_x CH_2-\underset{Cl}{\underset{|}{CH}}\right]_y CH_2-\underset{SO_2Cl}{\underset{|}{CH}}\right]_n \xrightarrow{h\upsilon}$$

$$\left[\left[\left(CH_2-CH_2\right)_x CH=CH\right]_y CH_2-\underset{SO_2Cl}{\underset{|}{CH}}\right]_n + HCl$$

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 form 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/m^2 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/m^2.

The time of exposure to reach 50% elongation at break

= 2745 hr. of light
= 9,882,000 seconds

Total energy in MJ/m^2 = 68.25 W/m^2 × 9,882,000
= 674.4 MJ/m^2

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/m^2 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/m^2, with the average value being 517.8 W/m^2.

The time of exposure to reach 50% elongation at break
= 4416 hr. of light
= 15,897,600 seconds

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

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/m^2, 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:

Field vs. Xenon Arc : Thus, the acceleration factor is 4.3.
= 26 Months = 6.1 Months

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.

Poly-Flex, Inc. • 2000 W. Marshall Dr. • Grand Prairie, TX 75051 U.S.A. • 888-765-9359

CHEMICAL RESISTANCE INFORMATION

CHEMICAL CLASS	CHEMICAL EFFECT	PRIMARY CONTAINMENT (LONG TERM CONTACT) HDPE	PRIMARY CONTAINMENT (LONG TERM CONTACT) LLDPE	SECONDARY CONTAINMENT (SHORT TERM CONTACT) HDPE	SECONDARY CONTAINMENT (SHORT TERM CONTACT) 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. Hydrocloric 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.
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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
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- Aliphatic (e.g. Ethyl alcohol)		A	A	A	A
- Aromatic (e.g. Phenol)		A	C	A	B
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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

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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 ìcoefficient of chemical resistanceî 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 och 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 ìsatisfactoryî 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 equel 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 hydocarbons	–	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
Aromaitic 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 20	°C 60	HD 20	°C 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
Dibuthyl 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
Dioctyl 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
Mecury (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

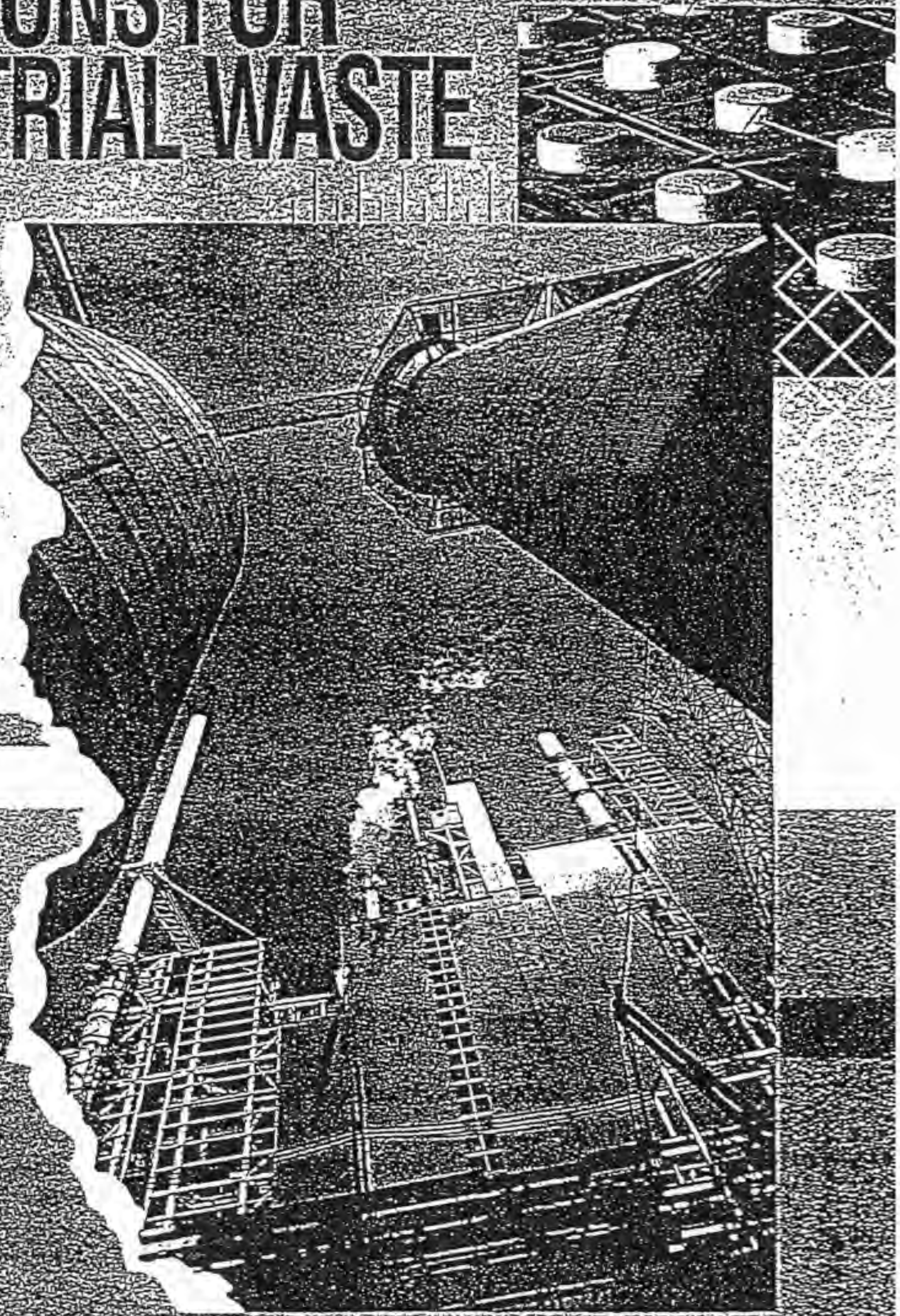
Chemical or product	Concentration	LD	°C	HD	°C
		20	60	20	60
Sodium chlorate	Sat.sol	S	S	S	S
Sodium chloride	Sat.sol	S	S	S	S
Sodium chlorite	Sat.sol	L	–	–	–
Sodium cyanide	Sat.sol	S	S	S	S
Sodium dichromate	Sat.sol	S	S	S	S
Sodium fluoride	Sat.sol	S	S	S	S
Sodium hexacyanoferrate (III)	Sat.sol	–	–	S	S
Sodium 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 ortophosphate	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



NSC

NSC

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 ±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)
Landfill caps
Lagoon liners
Pond liners
Floating covers
Secondary containment for above ground storage tanks
Retention ponds for mining applications
Wastewater treatment facilities
Potable water reservoirs
Tank linings
Canal linings
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	$^{\circ}C^{-1}$	1.5×10^{-4}	1.2×10^{-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	2.3×10^{-14}	8.1×10^{-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 (hot wedge fusion)	ASTM D 4437, NSF mod.	psi	1500	1870
		ppi	90	115
Peel Strength (fillet extrusion)	ASTM D 4437, NSF mod.	psi	1300	1590
		ppi	78	98

STANDARD ROLL DIMENSIONS

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

6H-0893

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

NSC

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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.

Final Inspection continued from page 56

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, Koerner/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 Iyr 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.

... 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.

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 environmental 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 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

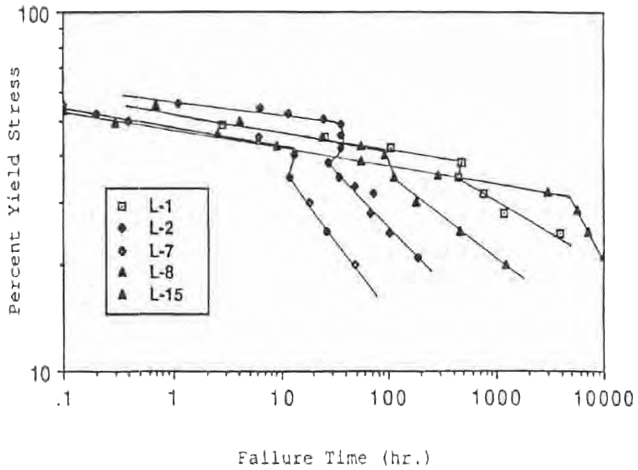

Figure 1 | Standard stress rupture curves for five HDPE geomembranes (Hsuan, et al. 1992)

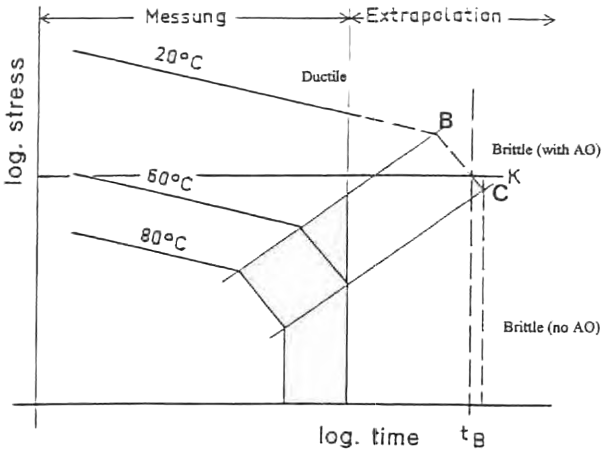

Figure 2 | Stress rupture curves showing third stage (Brittle no AO) oxidized limit. (Gaube, et al. 1985)

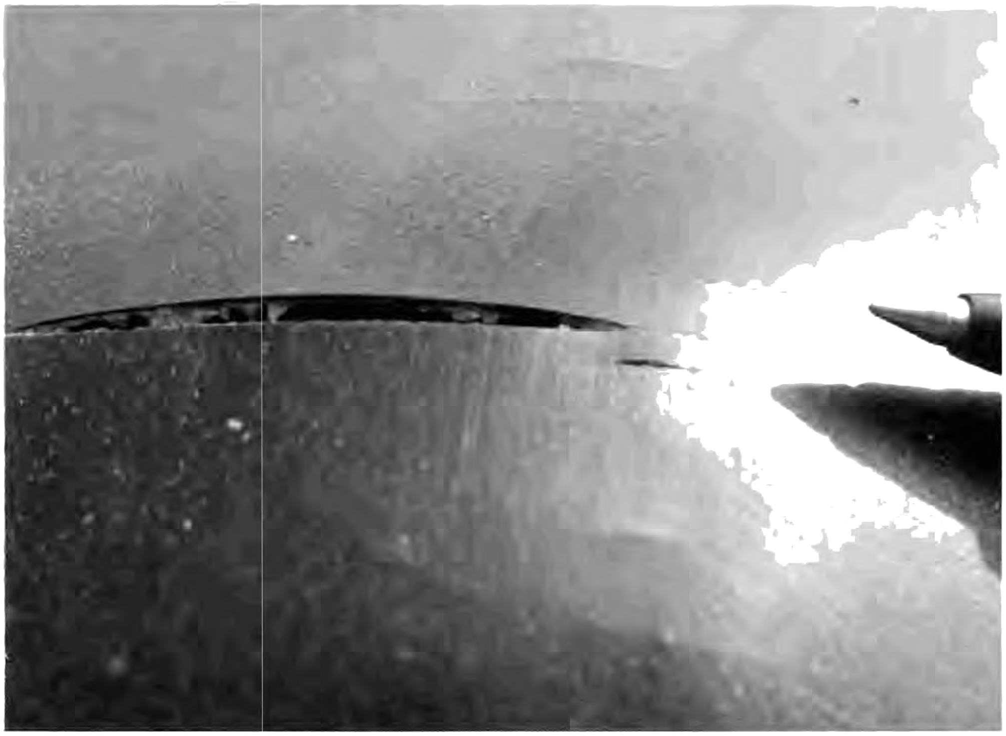

Figure 3 | Stress crack initiated by extruder die line at stone protrusion

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)

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 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.

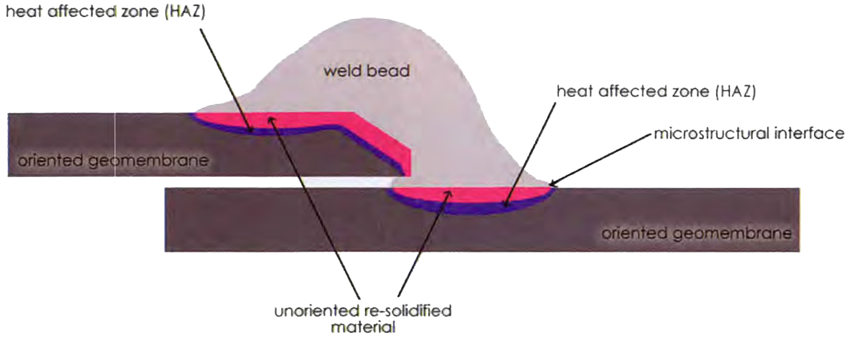

Figure 4 | Schematic of microstructure at extrusion weld

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

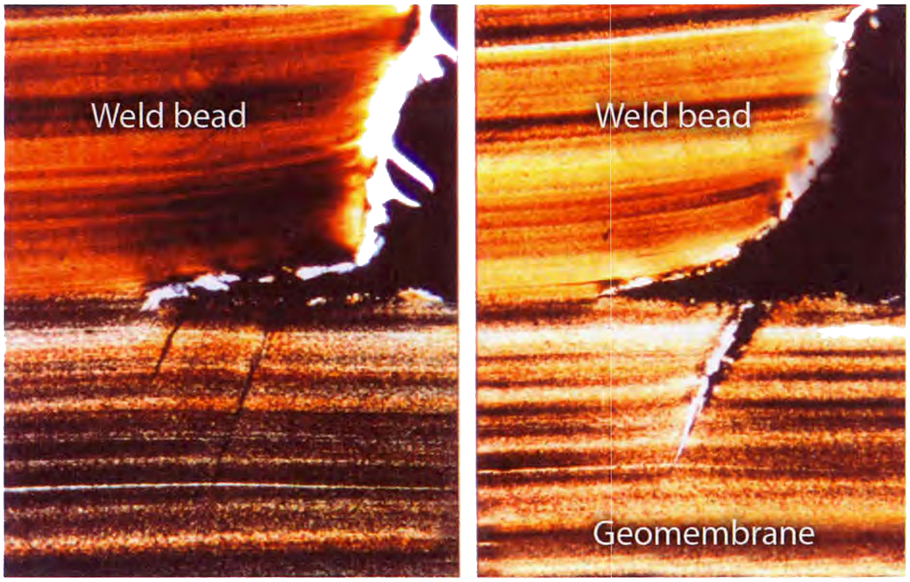

Figure 5 | Typical off-normal angle of precursor crazes (left) and stress crack (right) at edge of extrusion weld.

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
DNCS ENVIRONMENTAL SOLUTIONS

VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 6: GEOSYNTHETICS APPLICATION 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 achates, mildew, and insects.

How is the chemical resistance of polypropylene geotextiles determined?

Numerous laboratory test programs have subjected polypropylene to severe chemical environments 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 etremely 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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Technical Note No. 14

AMOCO GEOTEXTILES

Amoco Fabrics and Fibers Company

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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Note: This technical note is believed to be an accurate representation of information available from public sources; however, because the conditions in which such information may be used are beyond the control of Amoco Fabrics and Fibers Company, Amoco does not guarantee the suggestions and recommendations contained herein. Amoco assumes no responsibility for the use of information presented herein and hereby disclaims all liabilities which may arise in connection with such use. Final determination of the suitability of information and suggested uses is the sole responsibility of the user.

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ATTACHMENT III.6.C
GEONET REFERENCE DOCUMENTATION

Proceedings of the 4th Asian Regional Conference on Geosynthetics
June 17 - 20, 2008 Shanghai, China

EVALUATION ON STRESS CRACKING RESISTANCES OF VARIOUS HDPE DRAINAGE GEONETS

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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.

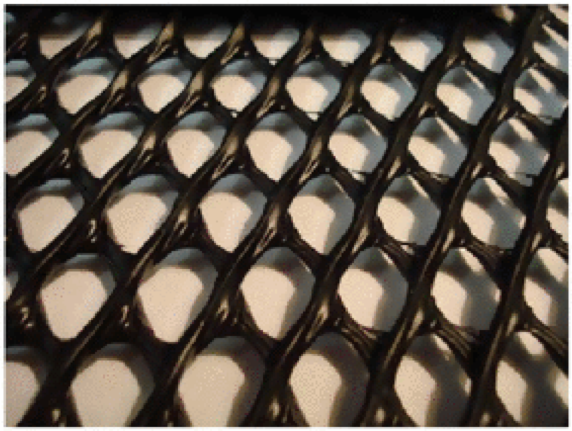
The specimens were immersed in a solution of 90% water and 10% I-gepal CO630 at a temperature of 50°C. The solution level was checked daily and de-ionized water used to keep the bath at a constant level.

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.

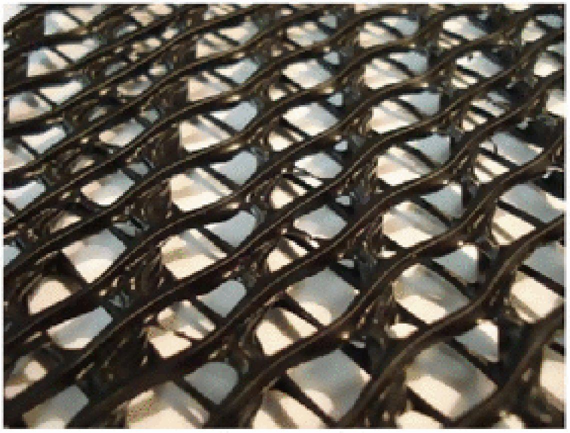
The immersion duration was 500 hours and during and after the test apparent observation and microscopic morphology was evaluated for the specimen.

Table 1 Typical specification of the samples

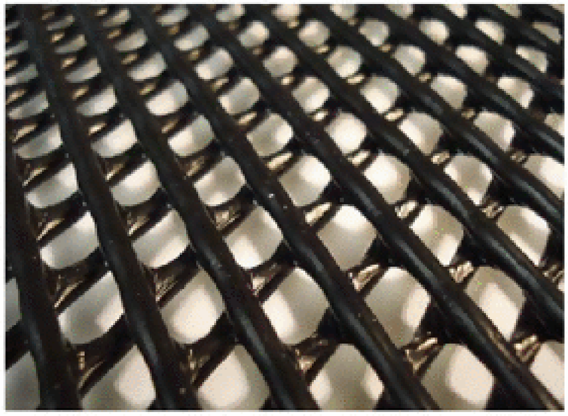
Property	Test method	Unit	Sample		
			A	B	C
Thickness	ASTM D5199	mm	5.6	8.6	8.2
Mass per unit area	ASTM D5261	g/m^2	920	1700	2300
Carbon black	ASTM D4218	%	2.3	2.2	2.3
Density	ASTM D1505	g/cm^3	0.942	0.944	0.940
Crystallinity	ASTM D2910	%	56	55	61



(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.

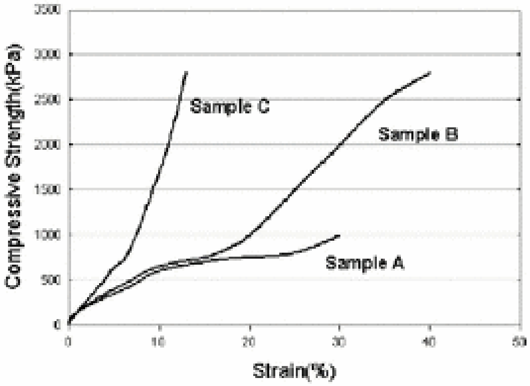


Fig. 3 Short-term compression test results

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.

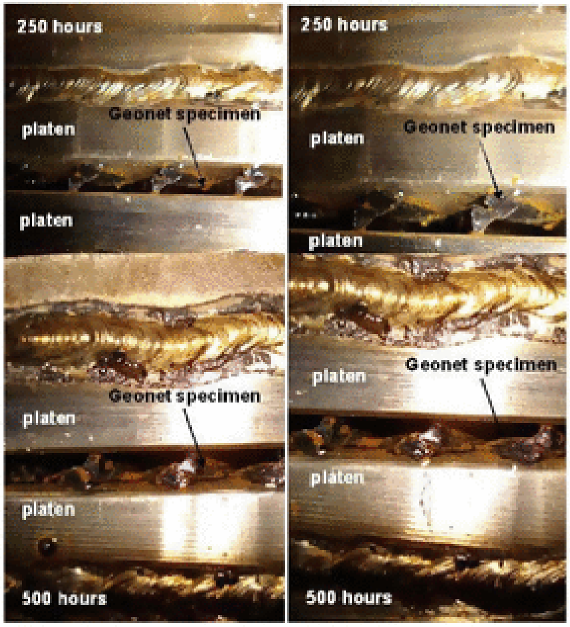


Fig. 4 Apparent observation during and end of the test for sample A (200kPa)

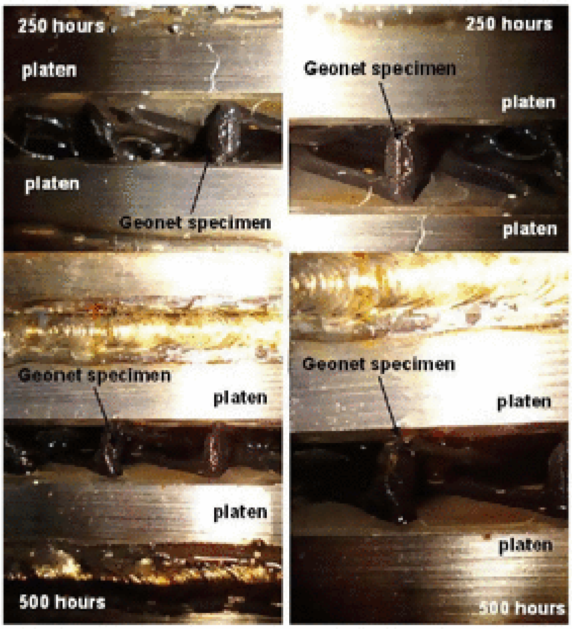


Fig. 5 Apparent observation during and end of the test for sample B (700 kPa)

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.

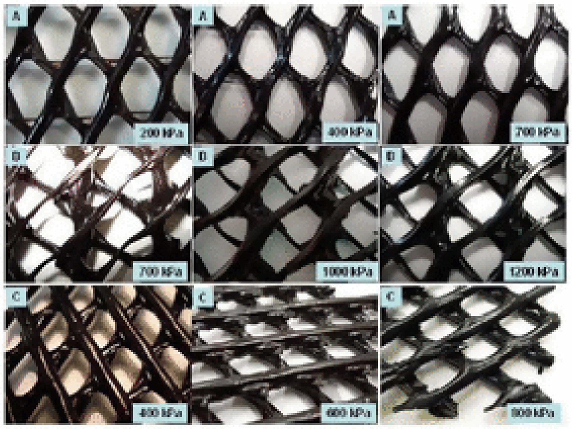


Fig. 6 Apparent observations end of the test for samples under various normal pressures

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

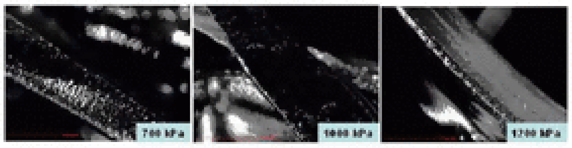


Fig. 8 Microscopic morphologies of Sample B after the test for various normal pressures

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 week to environmental stress cracking with increasing normal pressure

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APPLICATION FOR PERMIT
DNCS ENVIRONMENTAL SOLUTIONS

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

ATTACHMENT III.6.D

GEOSYNTHETIC CLAY LINER REFERENCE DOCUMENTATION

geosynthetic clay liners • geosynthetic clay liners • geosynthetic clay liners

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LINING TECHNOLOGIES

Laboratory Data Reports

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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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 #EL005

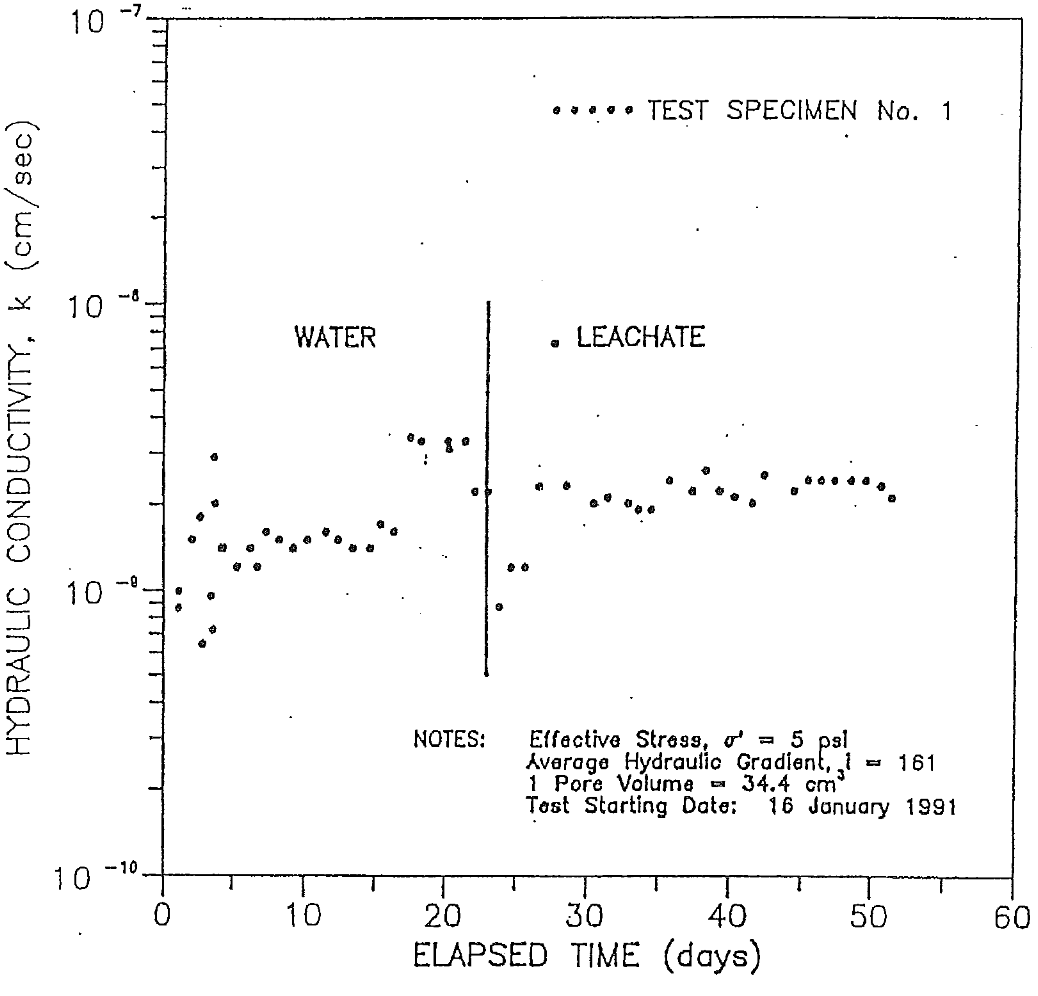

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FIGURE NO.	3.1-1
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91066
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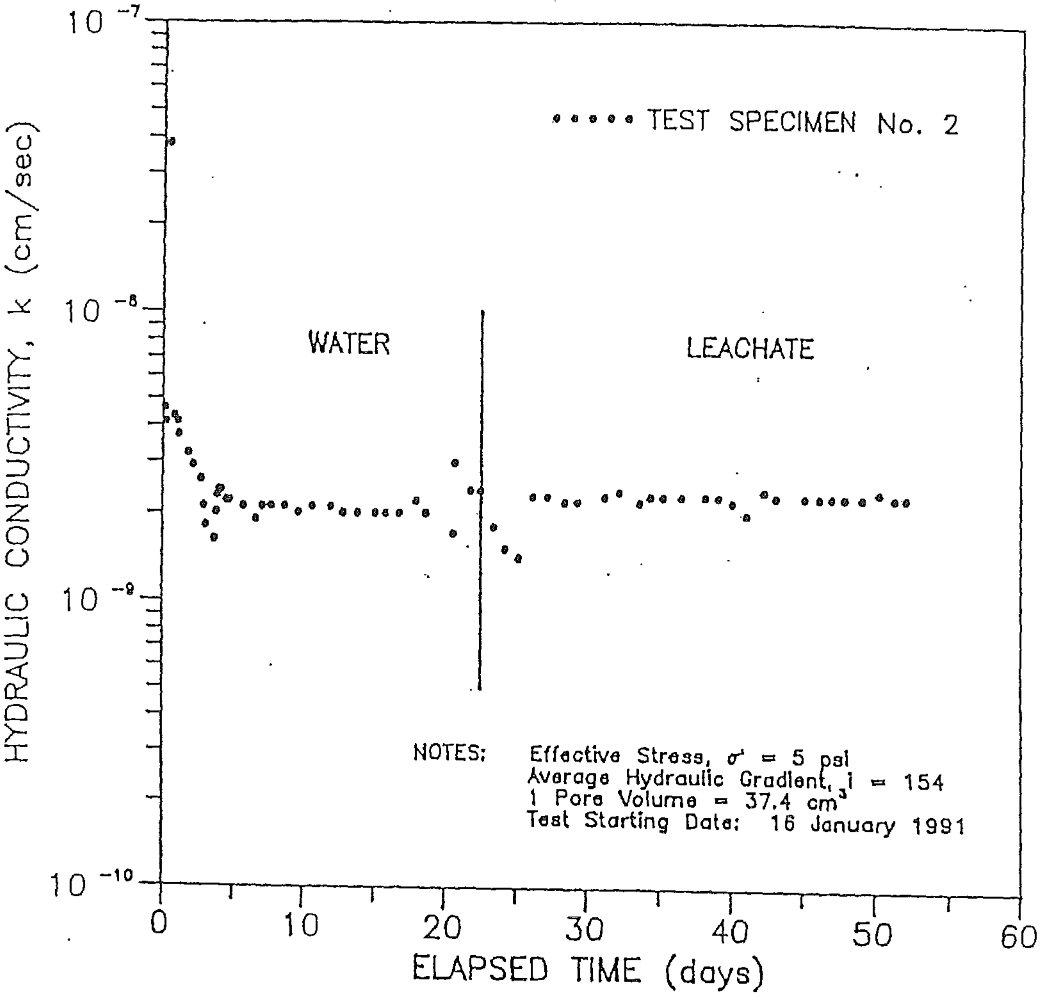
EPA 9100 COMPATIBILITY TESTING
BENTOMAT SAMPLE #EL005



NOTES: Effective Stress, σ' = 5 psi
Average Hydraulic Gradient, i = 154
1 Pore Volume = 37.4 cm^3
Test Starting Date: 16 January 1991

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FIGURE NO. 3.1-2
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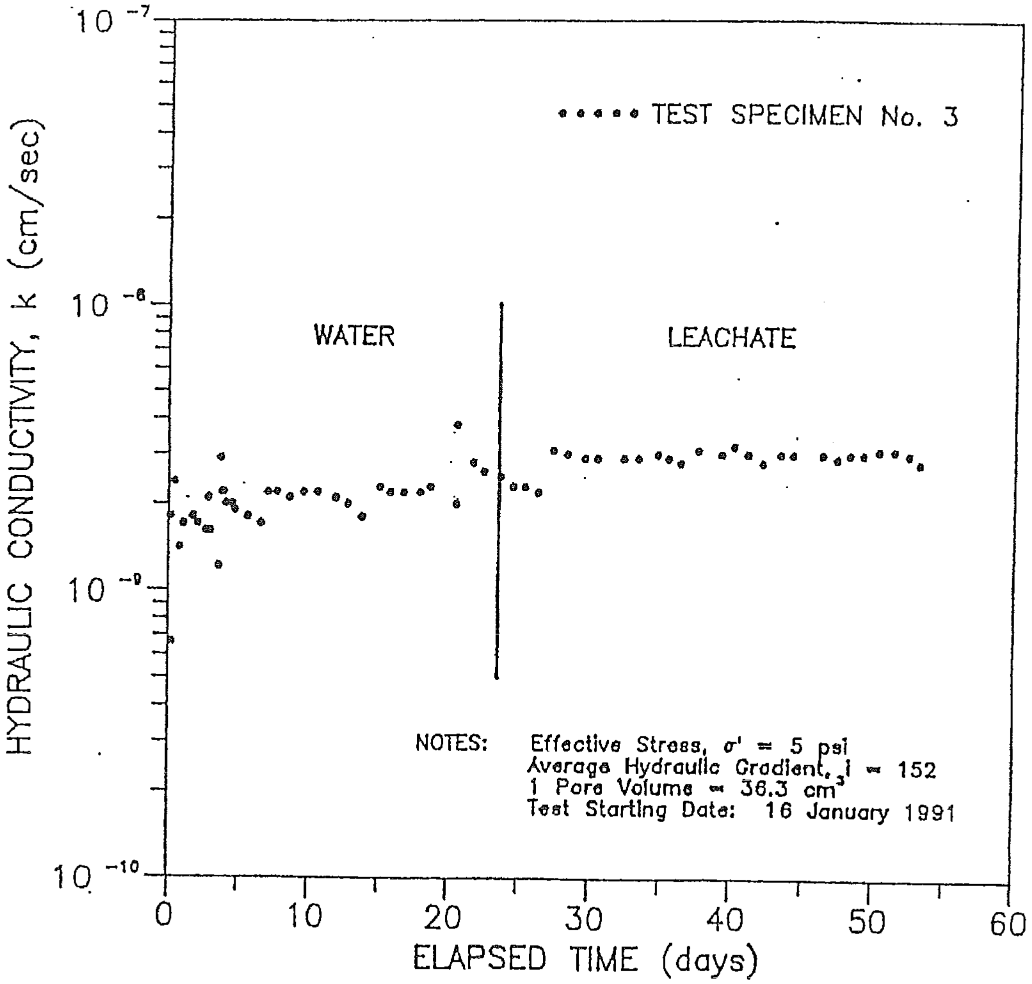
EPA 9100 COMPATIBILITY TESTING
BENTOMAT SAMPLE #EL005



NOTES: Effective Stress, $\sigma' = 5$ psi
Average Hydraulic Gradient, $i = 152$
1 Pore Volume = 36.3 cm^3
Test Starting Date: 16 January 1991

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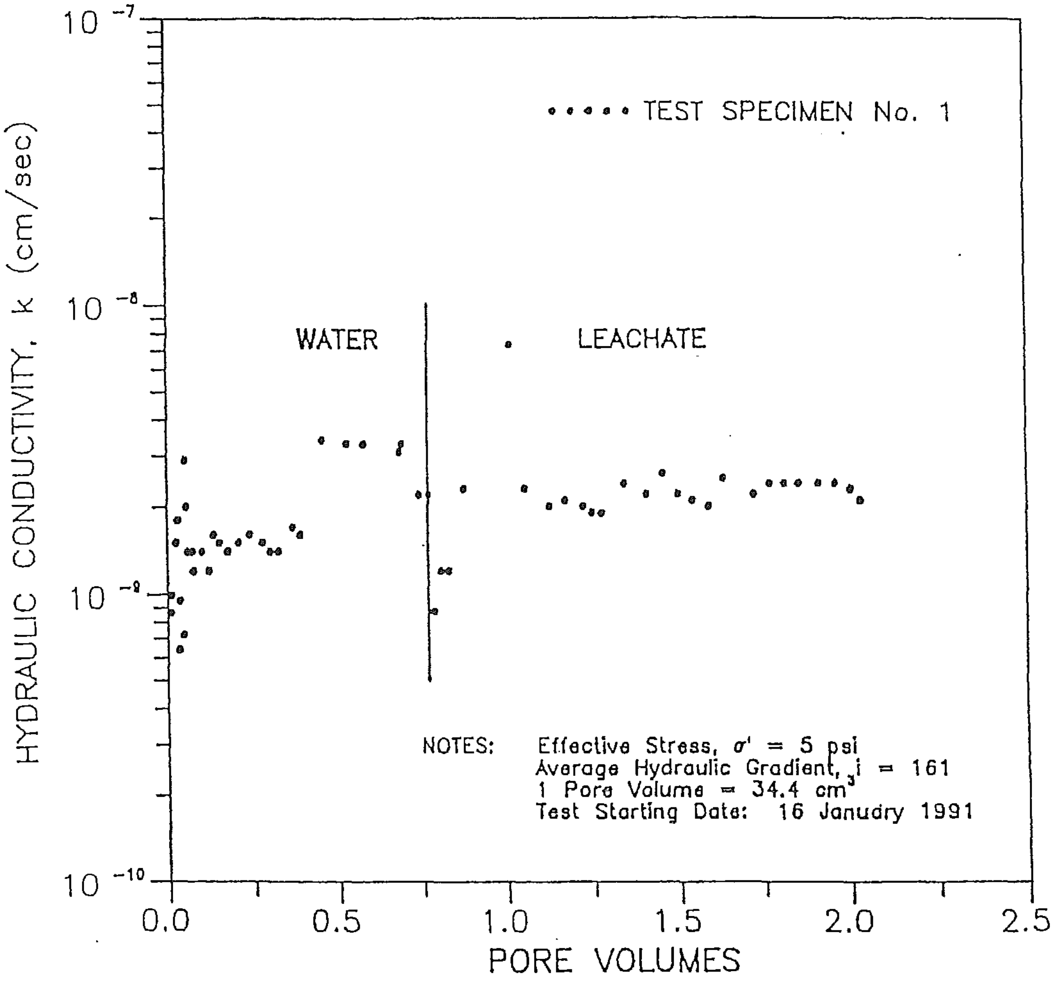
FIGURE NO.	3.1-3
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91066

EPA 9100 COMPATIBILITY TESTING
BENTOMAT SAMPLE #EL005



NOTES: Effective Stress, σ' = 5 psi
Average Hydraulic Gradient, i = 161
1 Pore Volume = 34.4 cm^3
Test Starting Date: 16 January 1991

GeoSyntec Consultants GEOMECHANICS AND ENVIRONMENTAL LABORATORY	FIGURE NO.	3.1-4
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	DOCUMENT NO.	GEL91066
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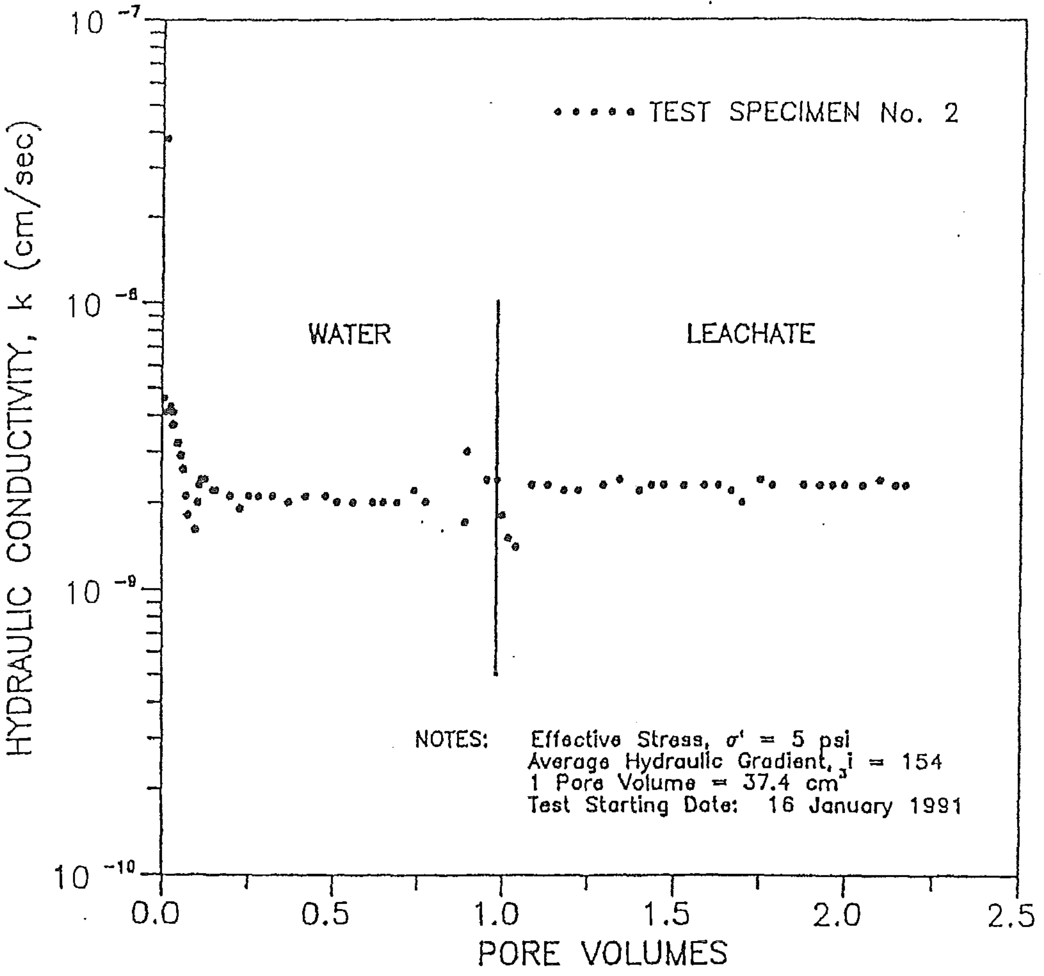
EPA 9100 COMPATIBILITY TESTING
BENTOMAT SAMPLE #EL005



NOTES: Effective Stress, σ' = 5 psi
Average Hydraulic Gradient, i = 154
1 Pore Volume = 37.4 cm^3
Test Starting Date: 16 January 1991

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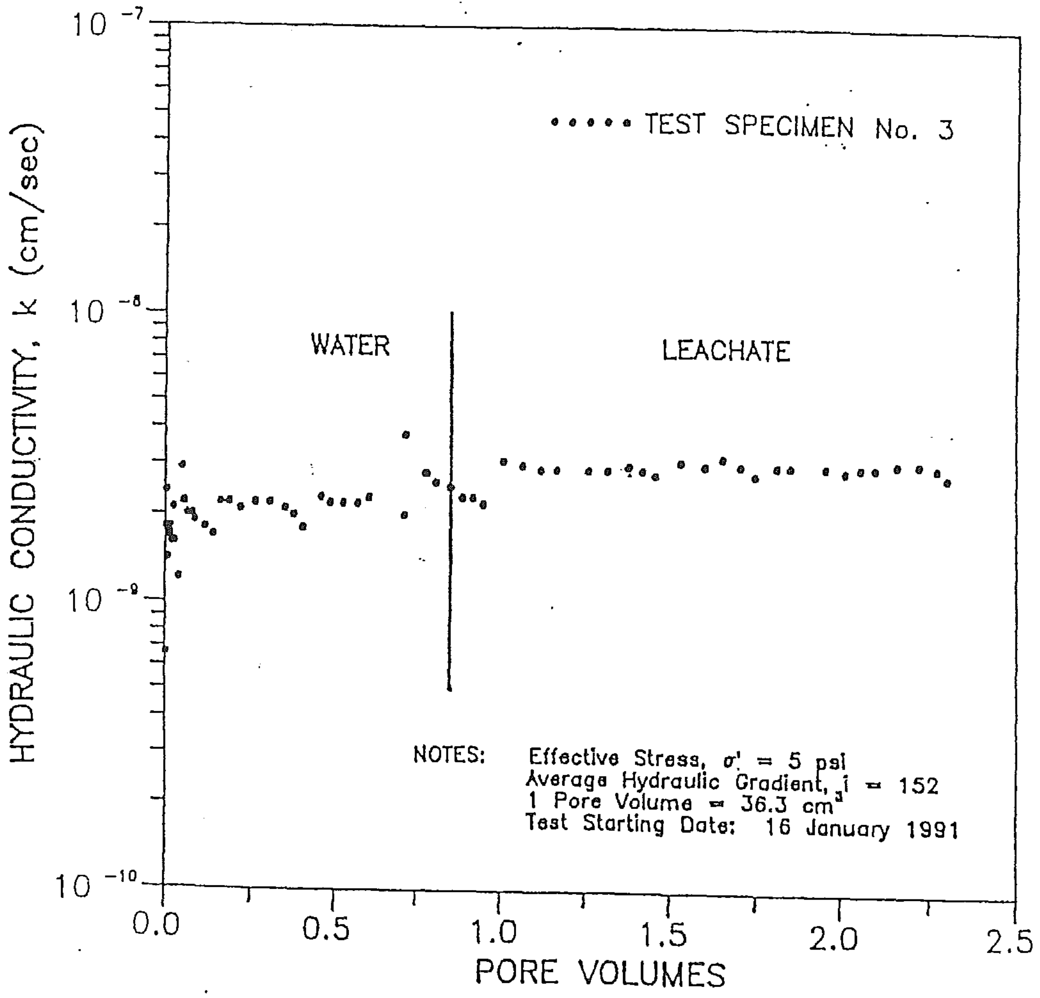
FIGURE NO. 3.1-5
PROJECT NO. GL1614
DOCUMENT NO. GEL91066
PAGE NO.

EPA 9100 COMPATIBILITY TESTING
BENTOMAT SAMPLE #EL005



NOTES: Effective Stress, σ' = 5 psi
Average Hydraulic Gradient, i = 152
1 Pore Volume = 36.3 cm^3
Test Starting Date: 16 January 1991

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FIGURE NO.	3.1-6
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91066
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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

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THESIS

Presented to the Faculty of the Graduate School of
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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 x 10^{-10} cm/s to 6 x 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)

Grade of Bentonite	Stress (psi) Cell	Stress (psi) Headwater	Stress (psi) Tailwater	Stress (psi) Maximum Effective	Hydraulic Conductivity (cm/s)
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}

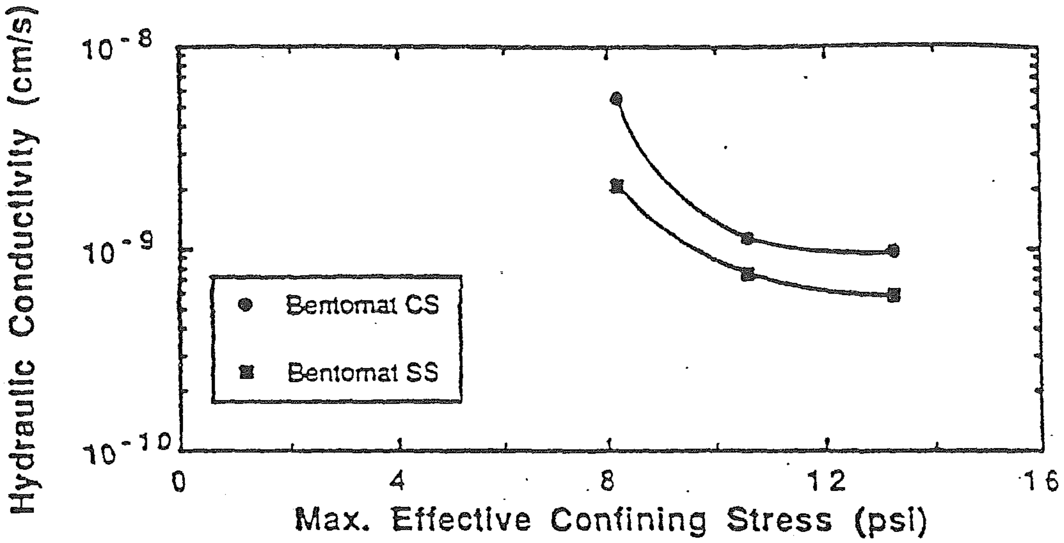

Fig. 2.2 Results of Flexible-Wall Hydraulic Conductivity Tests on Bentomat® (J&L Testing Company, 1990)

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 x 10^{-9} cm/s using the de-aired water and approximately 2.5 x 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 x 10^{-9} cm/s and 3 x 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 (psi)	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	12	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}

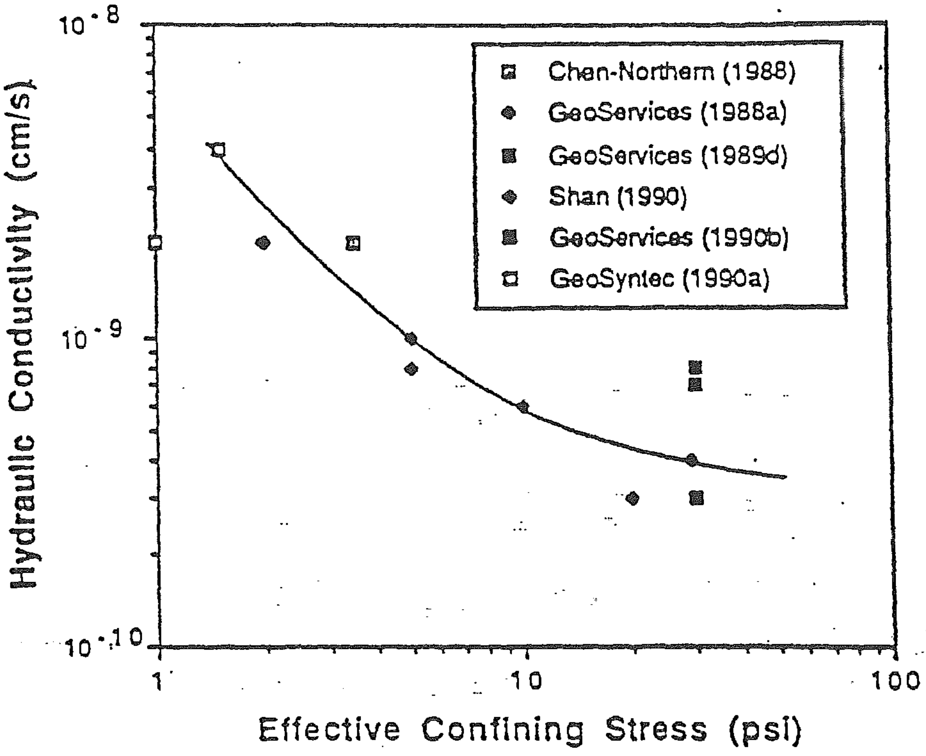

Fig. 2.5 Results of Hydraulic Conductivity Tests on Claymax® Permeated with Water

Table 2.5 Hydraulic Conductivity of Claymax® Permeated with Various Liquids

Source of Information	Permeant Liquid	Hydration Liquid	Pore Volumes of Flow	Effective Stress (psi)	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)	Sulfiric 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	24	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 ≤ 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 x 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 geomebrane, 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 x 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 x 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 consise form.

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

	Bentomat®			Claymax®			Paraseal/Gundseal		
Sample	Reference	Effective Stress (psi)	Hydraulic Conductivity (cm/s)	Reference	Effective Stress (psi)	Hydraulic Conductivity (cm/s)	Reference	Effective Stress (psi)	Hydraulic Conductivity (cm/s)
Sample Permeated with Desired 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}
Deslocated Sample	GeoSyntec (1991a)	5.0	1.0×10^{-9} to 3.0×10^{-9}	Shan (1990)	2.0	2.0×10^{-9}	GeoSyntec (1991c)	5.0	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)	- -	1.0×10^{-9}
Damaged Sample									
1-in diameter hole	GeoSyntec	- -	1.3×10^{-4}	Shan	2.0	5.0×10^{-9}	GeoSyntec	- -	1.0×10^{-3}
2-in diameter hole	(1991a)	- -	1.7×10^{-4}	(1990)(1)	- -	- -	(1991c)	- -	1.0×10^{-3}
3-in long slit		- -	3.0×10^{-5}		- -	- -		- -	1.0×10^{-3}
Composite Sample	GeoSyntec (1991a)	- -	3.0×10^{-9}	Shan (1990)	2.0	4.0×10^{-9}	GeoSyntec (1991c)	- -	2.0×10^{-9}
Overlapped Seam Sample	GeoSyntec (1991a)	- -	6.0×10^{-7} to 2.0×10^{-5}	GeoSyntec (1990b)	1.0	2.0×10^{-9}	GeoSyntec (1991c)	- -	5.0×10^{-8}

(1) The damaged Claymax® sample tested by Shan (1090) was punctured with 3 - 1 inch diameter holes.

18903

Report

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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 Pfingsten 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.

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 incrimentally increased until obtaining testing pressures of 4.125 KSC cell pressure and 4.00 KSC back pressure.

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 x 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

Permeant	Parkton Landfill	Eastern Sanitary Landfill
Sample No.	1	2
Classification	Claymax with 6" Silica Sand	Claymax with 6" Silica Sand
y Unit ght (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}

Rev: 12/87

Dennis F. Rasmussen
County Executive

BALTIMORE COUNTY
WASTEWATER MONITORING AND ANALYSIS DIVISION
INDUSTRIAL DISCHARGE CONTROL PROGRAM

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: Polyseed)

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	123 mg/L	3013	0.01	Silver	BDL
5012		FOG - A&V					
5013		FOG - Petr		*		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				

Rev: 12/87

Dennis F. Rasmussen
County Executive

BALTIMORE COUNTY
WASTEWATER MONITORING AND ANALYSIS DIVISION
INDUSTRIAL DISCHARGE CONTROL PROGRAM
SAMPLING/ANALYSIS FORM

Sample No.: 9 02104

Industry Name: PARKTON

Facility No.:

Address:

Telephone:

Requested by: R. Much

Sampling Site Location: Cell 03

Special Instructions: pH, BOD, COD, TSS, Alkalinity, Chloride, Metals

FIELD

Date and Time of Sampling: Start 2/9/89 Finish

Sampled by: R. Much, B. 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

ode	BDL	Parameter	Conc. (mg/L)	Code	BDL	Parameter	Conc. (mg/L)
		pH	6.1	3011	0.05	Ni (Nickel)	1.44 mg/L
		BOD	38,888 mg/L	3015	0.01	Zn (Zinc)	5.45 mg/
		COD	60,831 mg/L	3130		Phenols	
		TSS	691 mg/L	3013	0.01	Silver	0.03 mg/L
012		FOG - A&V					
013		FOG - Petr		*		GRAB pH	
026		P(Phosphorus)	interference				
006	0.01	Cd(Cadmium)	0.10 mg/L			Total Fe	736.00 mg/L
007	0.05	Cr(Chromium)	0.22 mg/L			Total alkalinity	15,000 mg/L
008	0.02	Cu(Copper)	0.17 mg/L			Chloride	1,500 mg/L
002		Cn(Cyanide)					
009	0.10	Pb (Lead)	0.60 mg/L				

APPLICATION FOR PERMIT
DNCS ENVIRONMENTAL SOLUTIONS

VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 6: GEOSYNTHETICS APPLICATION 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.

(Courtesy George Fischer Engineering Handbook)

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 (SYGEF®) 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».

(Courtesy George Fischer Engineering Handbook)

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 (SYGEF®)	Resistant to acids, solutions of salts, aliphatic, aromatic and chlorinated hydrocarbons, alcohols and halogens. Conditionally suitable for ketones, esters, organic bases and alkaline 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®)	PTFE	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	IIR 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 (Spannungsrissbildung) = 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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Acetaldehyde	CH_3-CHO (C_2H_4O)	21	technically pure	20	-	-	-	+	O	-		+	O	-	-	O
				40				O	-			O	-			-
				60								-				
				80												
				100												
				120												
				140												
Acetaldehyde			40%, aqueous solution	20	O	-	-	+	+	-		+	+	-	+	+
				40	-			+	+			+	+		+	+
				60				O	+			+	O		O	+
				80					O			+	-		-	+
				100					-							
				120												
				140												
Acetic acid (SpRB)	CH_3COOH	118	technically pure, glacial	20	O	-	-	+	+	+		O	-	-	O	O
				40	-			+	+	O						
				60				O	O	-						
				80					-							
				100												
				120												
				140												
Acetic acid (SpRB)	CH_3COOH		10%, aqueous	20	+	+	+	+	+	+		+	O	+	+	O
				40	+	+	+	+	+	+		+	-	O	+	-
				60	O	+	O	+	+	+		O			O	
				80		+			+	+						
				100					+	+						
				120						+						
				140												
Acetic acid (SpRB)			50%, aqueous	20	+	+	-	+	+	+		+	O	-	O	O
				40	+			+	+	+						
				60	O			+	+	+						
				80						O						
				100						O						
				120												
				140												
Acetic acid (SpRB)	CH_3COOH		60%	20	+	-	-	+	+	+		+				
				40												
				60												
				80												
				100												
				120												
				140												
Acetic acid (SpRB)		118	98%	20	-	-	-	+	+	+		O	-			
				40												
				60												
				80												
				100												
				120												
				140												
Acetic acid anhydride (SpRB)	$(CH_3\text{-}CO)_2O$	139	technically pure	20	-	-	-	+	+	-		O	-	-	-	+
				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	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Acetic acid isobutyl ester	$(CH_2)_2\text{-}CH\text{-}(CH_2)_2\text{-}CO_2H$		technically pure	20						-						
				40												
				60												
				80												
				100												
				120												
				140												
Acetone	$CH_3\text{-}CO\text{-}CH_3$	56	technically pure	20	-	-	-	+	+	-		+	-	-	-	○
				40				+	+			+				○
				60				+	+			+				○
				80												
				100												
				120												
				140												
Acetone			up to 10%, aqueous	20	-	-	○	+	+	○		+	○	-	+	○
				40				+	+	○		+	○		○	○
				60				+	+	○		+	-		-	○
				80												
				100												
				120												
				140												
Acetonitrile	CH_3CN	81.6	100%	20	-	-	-			-						
				40												
				60												
				80												
				100												
				120												
				140												
Acetophenone	$CH_3\text{-}CO\text{-}C_6H_5$		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												
Acrylic ester	$CH_2{=}CH\text{-}COO\ CH_2CH_3$	100	technically pure	20	-	-	-		-	-		○	-	-	○	+
				40												
				60												
				80												
				100												
				120												
				140												
Acrylonitrile	$CH_2{=}CH\text{-}CN$	77	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Adipic acid	$HOOC-(CH_2)_4-COOH$	Fp 153	saturated, aqueous	20	+	+	-	+	+	+		+	+	+	+	+
				40	+	+		+	+			+	+	+	+	+
				60	-	+		+	+			+	+	+	+	+
				80		+			+							
				100												
				120												
				140												
Aluni	see Potassium/ aluminium sulphate															
Alcoholic spirits (Gin, Whisky,etc.)			approx. 40% ethyl alcohol	20	+	O	-	+	+	+		+	+	+	+	+
				40												
				60												
				80												
				100												
				120												
				140												
Allyl alcohol	$H_2C=CH-CH_2-OH$	97	96%	20	O	O	-	+	+			O	O	+	O	+
				40	-			+	+			O	-	+	-	+
				60				+	+			O		+		+
				80								-		+		-
				100												
				120												
				140												
Aluminium chloride	$AlCl_3$		10%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	O	+	+
				80		+				+		+	+			+
				100						+		+	+			
				120						+						
				140												
Aluminium chloride	$AlCl_3$	115	saturated	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	+
				80		+			+	+			+	O	+	+
				100					O	+			+	-		+
				120						+						
				140												
Aluminium fluoride	AlF_3		saturated	20		+				+						
				40		+				+						
				60		+				+						
				80						+						
				100												
				120												
				140												
Aluminium hydroxide	$Al(OH)_3$		Suspension	20		+						+				
				40		+						+				
				60		+						+				
				80		+										
				100												
				120												
				140												
Aluminium nitrate	$Al(NO_3)_3$		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 (SYGEF)	EPDM	FPM	NBR	CR	CSM
Aluminium sulphate	$Al_2(SO_4)_3$		10%, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	O	+	+	+	+	+	+	+	+	+	+
				80		+			+	+		+			O
				100					+	+					
				120						+					
				140											
Aluminium sulphate			cold saturated, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	O
				80		+			+	+		+			O
				100						+					
				120						+					
				140											
Ammonia (SpRB)	NH_3	-33	gaseous, technically pure	20	+	-	-	+	+	+	+	+	+	+	+
				40	+			+	+	+		O			
				60	+			+	+	O					
				80						O					
				100						O					
				120											
				140											
Ammonium acetate	CH_3COONH_4		aqueous, all	20	+	+	O	+	+	+	+	+	+	+	+
				40	+	+		+	+	+	+	+	O	+	+
				60	O	+		+	+	+	+	+		O	
				80		+			+	+	O				
				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	O	+	+	+	+	+	+	+	+	+	+
				80		+			+	+	+	+			+
				100					+	+					
				120						+					
				140											
Ammonium chloride	NH_4Cl	115	aqueous, cold saturated	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Ammonium citrate				20	+					+						
				40	+					+						
				60	+					+						
				80						+						
				100						+						
				120												
				140												
Ammonium dicromate	$(NH_4)_2 Cr_2 O_7$		saturated	20		+										
				40		+										
				60		+										
				80		+										
				100												
				120												
				140												
Ammonium dihydrogenphosphate				20	+			+	+							
				40	+			+	+							
				60	+			+	+							
				80					+							
				100												
				120												
				140												
Ammonium fluoride	NH_4F			20	+	+		+	+	+						
				40	+			+	+	+						
				60	+			+	+	+						
				80					+	+						
				100						+						
				120												
				140												
Ammonium formiate				20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Ammonium hexafluorosuilicate				20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Ammonium hydrogen fluoride	NH_4HF_2		50%, aqueous	20	+	+	-	+	+	+		+	+			
				40	+	+		+	+	+						
				60	O	+		+	+	+						
				80												
				100												
				120												
				140												
Ammonium hydrogencarbonate				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 (SYGEF)		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_4OH		aqueous, cold saturated	20	+	-	+		+	-		+	-	+	+	+
				40	+		+		+			+		O	+	+
				60	O		O		+			O		O	+	O
				80											O	-
				100												
				120												
				140												
Ammonium nitrate	NH_4NO_3	112	aqueous, saturated	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	O	+	+		+	+	O		O
				80		+			O	+			+			
				100						+						
				120						+						
				140												
Ammonium oxalate	$H_4NOOC\text{-}COONH_4$			20						+		+				
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Ammonium persulphate	$(NH_4)_2S_2O_8$			20		+				+						
				40		+				+						
				60		+				+						
				80		+				+						
				100						+						
				120												
				140												
Ammonium phosphate	$(NH_4)_3PO_4$		saturated	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+			+	O	+	O
				80					+	+			+			
				100						+			+			
				120												
				140												
Ammonium sulphate	$(NH_4)_2SO_4$		aqueous, saturated	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	O	+	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Ammonium sulphide	$(NH_4)_2S$		aqueous, all	20	+	O	+	+	+	+		+	+	+	+	+
				40	+	O	+	+	+	+		+	O	+	+	+
				60	O	O	+	+	+	+		+	-	+	+	+
				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	$CH_3(CH_2)_4\text{-}COOCH_3$	141	technically pure	20	-	-	-	+	O	+		O	-	-	-	-
				40				+	O	O						
				60				+	-	O						
				80												
				100												
				120												
				140												
Amyl alcohol (SpRB)	$CH_3(CH_2)_3\text{-}CH_2\text{-}OH$	137	technically pure	20	+	+	-	+	+	+		+	O	+	+	O
				40	+	+		+	+	+		+		+	+	
				60	O	+		+	+	+		+		+	+	
				80					+	+						
				100						+						
				120						O						
				140												
Aniline	$C_6H_5NH_2$	182	technically pure	20	-	-	-	O	O	+		-	O	-	-	-
				40						O			O			
				60						-			O			
				80												
				100												
				120												
				140												
Aniline hydrochloride	C_6H_7N+HCl	245	aqueous, saturated	20	+	+	-	+	+	+		+	O	O	-	+
				40	O	+		+	+			+	-	-		+
				60				O	O			+				+
				80												O
				100												
				120												
				140												
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	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Antimony trichloride (SpRB)	$SbCl_3$		90%, aqueous	20	+	+	-	+	+	+		+	+	-	+	+
				40	+			+	+	+						
				60				+	+	+						
				80												
				100												
				120												
				140												
Aqua regia (SpRB)	HNO_3+HCl			20	+	+	-	-	-	O		-	O	-	-	O
				40	O											
				60												
				80												
				100												
				120												
				140												
Arsenic acid	H_3AsO_4		80%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+		+	+	+	+	+
				80		+			+	+		+	+	O	+	+
				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	+	+	+	+	+			+		+	+	O
				60	O	+	+	+	+			+		+	+	
				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	PP-H	PVDF (SYGEF)		EPDM	FPM	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_6H_5-CHO	180	saturated, aqueous	20	-	-	-	+	+	+		+	+	O	-	-
				40				+		O		+	+			
				60				+		-		+	+			
				80												
				100												
				120												
				140												
Benzene	C_6H_6	80	technically pure	20	-	-	-	O	O	+		-	+	O	-	-
				40				O	-	O						
				60						-						
				80												
				100												
				120												
				140												
Benzenesulfonic acid	$C_6H_5SO_3H$		technically pure	20						+			+			
				40						+			+			
				60						+						
				80						+						
				100						+						
				120												
				140												
Benzoic acid	C_6H_5-COOH	Fp.*, 122	aqueous, all	20	+	+	+	+	+	+		+	+	-	-	-
				40	+	+	+	+	+	+		+	+			
				60	O	+		+	+	+			+			
				80		O			+	+			+			
				100					+	+			O			
				120						+						
				140												
Benzoyl chloride	$C_6H_5CHCl_2$		technically pure	20						+						
				40						+						
				60						+						
				80						O						
				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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Benzyl alcohol (SpRB)	$C_6H_5-CH_2-OH$	206	technically pure	20	O	-	-	+	+	+		-	+	-	+	O
				40				+	+	+					+	
				60				O	O	O					+	
				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	+	+				O						
				80												
				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						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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Bromine, vapours	Br_2		high	20	-	-	-	-	-	+		-	+	-	-	-
				40						+						
				60						+						
				80						+						
				100						O						
				120												
				140												
Bromine water	$Br.H_2O$		saturated, aqueous	20	+	o	-	-	-	+		-	+	-	-	-
				40						+						
				60						+						
				80						+						
				100												
				120												
				140												
Butadiene (Q/E)	$H_2C=CH-CH=CH_2$	-4	technically pure	20	+	+	-	+	+	+		-	O	-	+	+
				40					+	+					+	O
				60					+	+					O	-
				80						+						
				100						+						
				120												
				140												
Butane	C_4H_{10}	0	technically pure	20	+	+	+	+	+	+		-	+	+	+	+
				40												
				60												
				80												
				100												
				120												
				140												
Butanediol (SpRB)	$HO-(CH_2)_4-OH$	230	aqueous, 10%	20	+	+	-	+	+			+	+	+	O	+
				40	O	+		+	+			+	+	+	-	+
				60				+	+			+	+	+		+
				80												
				100												
				120												
				140												
Butanol (SpRB)	C_4H_9OH	117	technically pure	20	+	+	-	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	O	+	+	+
				60	O	+		+	O	+		+	-	+	O	+
				80		O			-	+						
				100						O						
				120												
				140												
Butyl acetate	$CH_3COOCH_2CH_2CH_2CH_3$	126	technically pure	20	-	-	-	+	O	+		+	O	-	O	O
				40						O		-	-		-	-
				60						-						
				80												
				100												
				120												
				140												
Butyl phenol, p-tertiary	$(CH_3)_3C-C_6H_4-OH$	237	technically pure	20	O	O	-	O	+	+		-	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Butylene glycol (SpRB)	$HO\text{-}CH_2\text{-}CH{=}CH\text{-}CH_2\text{-}OH$	235	technically pure	20	+	+	+	+	+	+		+	+	-	+	O
				40	+	+	+	+	+	+		+	+		+	-
				60	O	+	+	+	+	+		+	O		+	
				80						+						
				100												
				120												
				140												
Butylene liquid	C_4H_8	51	technically pure	20	+			-	-	+		O	+	+	+	O
				40												
				60												
				80												
				100												
				120												
				140												
Butyric acid (SpRB)	$CH_3\text{-}CH_2\text{-}CH_2\text{-}COOH$	163	technically pure	20	+	+	-	+	+	+		O	O	-	O	O
				40				+		+						
				60				O		+						
				80						+						
				100						O						
				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	$(CH_3COO)_2Ca$		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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Calcium bisulphite	$Ca(HSO_3)_2$		cold saturated, aqueous	20	+	+	+			+		+	+	-	O	+
				40		+	+			+			+			
				60		+				+			+			
				80		+				+			+			
				100						+			+			
				120						+						
				140												
Calcium carbonate	$CaCO_3$			20	+	+		+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+						
				120												
				140												
Calcium chlorate	$Ca(ClO_3)_2$			20	+	+		+	+	+						
				40	+	+		+	+	+						
				60	+	+		+	+	+						
				80		+										
				100												
				120												
				140												
Calcium chloride	$CaCl_2$	125	saturated, aqueous, all	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+		+	+	+		+	+	+	+	+
				80		+			+	+		+	+	O	O	+
				100					+	+		O	+			+
				120						+						
				140												
Calcium fluoride	CaF_2			20	+			+	+				+			
				40	+			+	+				+			
				60	+			+	+				+			
				80					+							
				100												
				120												
				140												
Calcium hydrogencarbonate				20						+		+	+			
				40						+		+	+			
				60						+		+	+			
				80						+		+	+			
				100						+			+			
				120												
				140												
Calcium hydrogensulfide	$Ca(SH)_2$			20		+				+		+				
				40		+				+		+				
				60		+				+		+				
				80		+				+						
				100						+						
				120												
				140												
Calcium hydrosulfite	$Ca(HSO_3)_2$		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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Calcium hydroxide	$Ca(OH)_2$	100	saturated, aqueous	20	+	+	+	+	+	O		+	+	+	+	+
				40	+	+	+	+	+	-		+	+	+	+	+
				60	+	+	+	+	+			+	+	O	+	+
				80		+			+			+	+			+
				100									+			+
				120												
				140												
Calcium nitrate	$Ca(NO_3)_2$	115	50%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60		+		+	+	+		+	+			+
				80		+				+			+			
				100						+						
				120												
				140												
Calcium phosphate	$Ca(H_2PO_4)_2$ $CaHPO_4$ $Ca_3(PO_4)_2$			20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Calcium sulfide	Ca_5			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												
Calciumbromide	$CaBr_2$			20	+	+		+	+			+	+			
				40	+	+		+	+			+	+			
				60	+	+		+	+			+	+*			
				80		+			+							
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Calciumlactate	$(CH_3COO)_2Ca$		saturated	20				+	+	+		+				
				40				+	+	+		+				
				60				+	+	+		+				
				80					+	+						
				100						+						
				120												
				140												
Caprolactam	$C_6H_{11}NO$			20		-										
				40												
				60												
				80												
				100												
				120												
				140												
Caprolactone	$C_6H_{10}O_2$			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												
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															
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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Cäsium chloride	ClCs			20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Cäsiumhydroxide	CsOH			20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Caustic potash solution (potassium hydroxide)	KOH	131	50%, aqueous	20	+	+	+	+	+	-		+	-	O	-	+
				40	+	+	+	+	+			+		-		O
				60	O	+	+	+	+			+				O
				80		+			+			O				-
				100					+							
				120												
				140												
Caustic soda solution	NaOH		50%, aqueous	20	+	+	+	+	+	O		+	-	O	-	+
				40	+	+		+	+			+		-		O
				60		+		+	+			+				-
				80					+							
				100												
				120												
				140												
Cerium (III) -chloride	$CeCl_3$			20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Chloral hydrate	$CCl_3\text{-}CH(OH)_2$	98	technically pure	20	-		-	+	O	-		O	O	-	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Chlorosulphonic acid	$ClSO_3H$	158	technically pure	20	O	-	-	-	-	O		-	-	-	-	-
				40						-						
				60												
				80												
				100												
				120												
				140												
Chrome alum (chromium potassium sulphate)	$KCr(SO_4)2$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+		+	+			+	+	+	+	+
				80								+	+			
				100									+			
				120												
				140												
Chromic acid (SpRB)	CrO_3+H_2O		up to 50%, aqueous	20	O	+	-	O	O	+		O	+	-	-	O
				40	O	O		-	-	+		O	+			O
				60	-	O				+		O	+			O
				80		-				+						
				100						O						
				120						O						
				140												
Chromic acid (SpRB)			all, aqueous	20	O	O	-	O	O	+			+	-	-	O
				40						+			+			O
				60						+			O			O
				80						O						
				100						O						
				120												
				140												
Chromic acid + sulphuric acid + water (SpRB)	CrO_3 H_2SO_4 H_2O		50 g 15 g 35 g	20	+	+	-	-	-	+		O	+	-	-	O
				40	+	+				+		O	+			O
				60	O	+				+			+			
				80		O				O						
				100												
				120												
				140												
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	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Chlorine	Cl_2		moist, 97%, gaseous	20	-	-	-	-	-	-		-	+	-	-	○
				40												
				60												
				80												
				100												
				120												
				140												
Chlorine	Cl_2		anhydrous, technically pure	20	-	-	-	○	-	+		○	+	-	-	○
				40				○		+						
				60				-		+						
				80						+						
				100						○						
				120												
				140												
Chlorine	Cl_2		liquid, technically pure	20	-	-	-	-	-	+		-	○	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Chlorine water (SpRB)	Cl_2 H_2O		saturated	20	+	+	○	○	○	○		○	○	-	○	-
				40	+	+		○								
				60	○	○										
				80		-										
				100												
				120												
				140												
Chloroacetic acid, mono (SpRB)	$ClCH_2COOH$		50%, aqueous	20	+	-	-	+	+	+		○	-	-	-	○
				40	+			+	+	○						
				60				+	+	-						
				80												
				100												
				120												
				140												
Chloroacetic acid, mono (SpRB)	$ClCH_2COOH$	188	technically pure	20	+	-	-	+	+	-		○	-	-	-	○
				40	+			+	+							
				60	○			+	+							
				80												
				100												
				120												
				140												
Chlorobenzene	C_6H_5Cl	132	technically pure	20	-	-	-	○	+	+		-	-	-	-	○
				40						+						
				60						○						
				80						-						
				100												
				120												
				140												
Chloroethanol	$ClCH_2$-CH_2OH	129	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Chromium (III) -nitrate	$Cr(NO_3)_3$			20	+					+						
				40	+					+						
				60	+					+						
				80						+						
				100						+						
				120												
				140												
Chromium (III) -sulfate	$Cr_2(SO_4)_3$			20	+					+						
				40	+					+						
				60	+					+						
				80						+						
				100						+						
				120												
				140												
Cider				20	+	+	+	+	+	+		+	+	+	+	+
				40			+			+						
				60						+						
				80												
				100												
				120												
				140												
Citric acid		Fp. *153	10%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+		+	+	O	+	+
				80					+	+						
				100					+	+						
				120												
				140												
Citric acid				20	+			+	+							
				40	+			+	+							
				60				+	+							
				80					+							
				100												
				120												
				140												
Citric acid up to 10 %				20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Coal gas, benzene free				20	+	+	+	+	+	+			+	+	O	+
				40												
				60												
				80												
				100												
				120												
				140												
Coconut fat alcohol (SpRB)			technically pure	20	+	-	-	+	+	+			+	+	+	+
				40	+			O	+	+			+	+	O	O
				60	O				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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Compressedair, containing oil (SpRB)				20	-	-	-	+	O	+		-	+	+	+	+
				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	+	+	+	+	+			+	O	+	O
				80		+			+	+			+			
				100						+						
				120												
				140												
Corn oil (SpRB)			technically pure	20	O	O	O	+	+	+			+	+	O	+
				40		O		+	+	+			+	+	-	+
				60				O	O	+			+	+		O
				80						+						
				100												
				120												
				140												
Cresol	$HO\text{-}C_6H_4\text{-}CH_3$		cold saturated, aqueous	20	O	-	-	+	+	+			+	O	-	O
				40				+	+	+			+	O		
				60						+						
				80						O						
				100												
				120												
				140												
Crotonic aldehyde	$CH_3\text{-}CH{=}CH\text{-}CHO$	102	technically pure	20	-	-	-	+	+	+		+	+	+	+	+
				40						O						
				60						-						
				80												
				100												
				120												
				140												
Cyclohexane (Q/E)	C_6H_{12}	81	technically pure	20	-	-	-	+	+	+		-	+	+	-	-
				40				+		+						
				60				+		+						
				80						+						
				100												
				120												
				140												
Cyclohexanol (SpRB)	$C_6H_{12}O$	161	technically pure	20	+	+	-	+	+	+		-	+	O	+	+
				40	+	+		+	+	+						
				60	+	+		+	O	O						
				80		O				O						
				100						-						
				120												
				140												
Cyclohexanone	$C_6H_{10}O$	155	technically pure	20	-	-	-	+	+	+		O	-	-	-	-
				40				O	O	O						
				60				O	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 (SYGEF)	EPDM	FPM	NBR	CR	CSM
Densodrine W				20	+	+	O			+		+	+	+	
				40	+	+									
				60	+	+									
				80											
				100											
				120											
				140											
Detergents (SpRB)	see washing powder		for usual washing lathers												
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	$C_4H_9OC_4H_9$	142	technically pure	20	-	-	-	O	O		-	+	+	-	O
				40								+	O		O
				60				-	-			O	-		O
				80											
				100											
				120											
				140											
Dibutyl phthalate	$C_6H_4(COOC_4H_9)_2$	340	technically pure	20	-	-	-	+	+	+	O	O	-	-	-
				40				O	O	+					
				60				O	O	O					
				80											
				100											
				120											
				140											
Dibutyl sebacate	$C_8H_{16}(COOC_4H_9)_2$	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	+	-	-	+	+	+	+	O	-	O	+
				40	+			+	+	+	+	-		-	O
				60	O			O	O	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Dichloroacetic acid (SpRB)	$Cl_2CHCOOH$		50%, aqueous	20	+	-	-	+	+	+		+	O	-	+	+
				40	+			+	+	+		+	O		O	+
				60	O			+	+	+		+	-		-	O
				80						O						
				100						-						
				120												
				140												
Dichloroacetic acid methyl ester	$Cl_2CHCOOCH_3$	143	technically pure	20	-	-	-	+	+	O		+	-	-	-	+
				40				+	+			+				+
				60				+	+			O				O
				80												
				100												
				120												
				140												
Dichloroethan	Ethylene chloride															
Dichloroethylene	ClCH=CHCl	60	technically pure	20	-	-	-	-	O	+		-	O	-	-	-
				40						+						
				60												
				80												
				100												
				120												
				140												
Dichloromethane				20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Diesel oil (SpRB, Q/E)				20	+	+	O	+	O	+		-	+	+	O	O
				40	+	+				+			+	+		-
				60				O		+						
				80						+						
				100						+						
				120						+						
				140												
Diethyl ether				20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Diethylamine	$(C_2H_5)_2NH$	56	technically pure	20	O	-	-	+	+	+		O	-	-	-	-
				40						O						
				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	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Diglycolic acid (SpRB)	HOOC-CH$_2$-O-CH$_2$-COOH	Fp*., 148	30%, aqueous	20	+	+	+	+	+	+		+	O	+	+	O
				40	+	+		+	+							
				60	O	+		+	+							
				80												
				100												
				120												
				140												
Di-isobutyl ketone	$[(CH_3)2CHCH_2]_2CO$	124	technically pure	20	-	-	-	+	+	+		O	-	-	-	-
				40						+						
				60				-	-	O						
				80												
				100												
				120												
				140												
Dimethyl formamide	$(CH_3)_2CHNO$	153	technically pure	20	-	-	-	+	+	-		O	-	O	+	+
				40				+	+							
				60				O	+							
				80												
				100												
				120												
				140												
Dimethylamine	$(CH_3)_2NH$	7	technically pure	20	O	-	-	+	+	O		O	-	-	-	-
				40						-						
				60				O								
				80												
				100												
				120												
				140												
Dimethylphthalate (DMP)	$C_6H_4(CH_3)_2$			20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Dinonylphthalate (DNP)			technically pure	20	-	-	-	O	+			O	+	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Dioctylephthalate (SpRB) (DOP)			technically pure	20	-	-	-	O	+			O	+	-	-	-
				40												
				60					-							
				80												
				100												
				120												
				140												
Dioxane	$C_4H_8O_2$	101	technically pure	20	-	-	-	+	O	-			-	O	-	-
				40				+	O							
				60				+	O							
				80					-							
				100												
				120												
				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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Ethanolamine	see Annino ethanol															
Ethyl acetate	CH_3COOCH_2-CH_3	77	technically pure	20	-	-	-	+	+	○		+	-	-	-	-
				40				○	○							
				60				○	○							
				80												
				100												
				120												
				140												
Ethyl alcohol + acetic acid (fermentation mixture)			technically pure	20	+	○	-	+	+	+		○	○	○	+	+
				40	+			+		+		○	○	○	+	+
				60	○			+		+			○		+	+
				80						○						
				100												
				120												
				140												
Ethyl alcohol (Ethnoc) (SpRB)	CH_3-CH_2-OH	78	technically pure, 96%	20	+	○	-	+	+	+		+	○	○	+	+
				40	+			+	+	○		+	○			
				60	○			+	+	-		+	○			
				80					+							
				100												
				120												
				140												
Ethyl benzene	C_6H_5-CH_2CH_3	136	technically pure	20	-	-	-	○	○	○		-	+	-	-	-
				40												
				60					-							
				80												
				100												
				120												
				140												
Ethyl chloride	CH_3-CH_2Cl	12	technically pure	20	-	-	-	○	○	○		-	○	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Ethyl ether	CH_3CH_2-O-CH_2CH_3	35	technically pure	20	-	-	-	+	○	+		-	-	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Ethylenchloride (1,2-Dichloroethane)				20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Ethylene chloride	$ClCH_2$-CH_2Cl	83	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Ethylene diamine	$H_2N\text{-}CH_2\text{-}CH_2\text{-}NH_2$	117	technically pure	20	O	-	-	+	+	O		+	O	+	+	O
				40				+	+	O			O	O	O	O
				60				+	+	-			-	-	-	-
				80												
				100												
				120												
				140												
Ethylene glycol (SpRB)	$HO\text{-}CH_2\text{-}CH_2\text{-}OH$	198	technically pure	20	+	O	-	+	+	+		+	+	+	+	+
				40	+			+	+	+		+	+	+	+	+
				60	+			+	+	+		+	+	O	O	+
				80					+	+		+	O			O
				100					+	+						
				120						+						
				140												
Ethylene glycol	CH_2OHCH_2OH	198	technically pure	20	+		-	+	+	+		+	+	+	+	+
				40	+			+	+	+		+	+	+	+	+
				60	+			+	+	+		+	+	O	O	+
				80					+	+			O			O
				100						+						
				120												
				140												
Ethylene oxide	$CH_2\text{-}CH_2$	10	technically pure, moist	20	-	-	-	-	O	+		O	-	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Ethylenediaminetetra-acetic acid (EDTA)				20				+	+	+		+				
				40												
				60												
				80												
				100												
				120												
				140												
Fatty acids $>C_6$ (SpRB)	R-COOH		technically pure	20	+	+	-	+	+	+		+	+	O	O	-
				40	+	+		+	+	+						
				60	+	+		O	+	+						
				80						+						
				100												
				120												
				140												
Fatty alcohol sulphonates (SpRB)			aqueous	20	+	+		+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	O	O		+	O	+		+	+	+	+	+
				80						+						
				100						+						
				120												
				140												
Fertilizers			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 (SYGEF)	EPDM	FPM	NBR	CR	CSM
Fluorine	F_2		technically pure	20	-	-	-	-	-	-	-	-	-	-	-
				40											
				60											
				80											
				100											
				120											
				140											
Fluorosilicic acid (Q/E)	H_2SiF_6		32%, aqueous	20	+	+	+	+	+	+	+	O	O	O	+
				40	+	+	+	+		+			-	-	O
				60	+	+	+	+		+					-
				80						+					
				100						+					
				120											
				140											
Formaldehyde (SpRB)	HCHO		40%, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60			+	+		+	+	+	O	O	O
				80						+					
				100											
				120											
				140											
Formamide	$HCONH_2$	210	technically pure	20	-	-	-	+	+		+	O	+	+	
				40				+	+						
				60				+	+						
				80											
				100											
				120											
				140											
Formic acid (SpRB)	HCOOH		up to 50%, aqueous	20	+	-	O	+	+	+	+	+	-	+	+
				40	+			+	+	+	+	+		+	+
				60	O			+	O	+	O	O		O	+
				80						+		-			O
				100						+					
				120											
				140											
Formic acid (SpRB)	HCOOH	101	technically pure	20	+	-	-	+	+	+	+	+	-	+	+
				40	O			+	O	+	+			O	+
				60	-			+	-	+	+			-	+
				80						+	O				O
				100						+					
				120											
				140											
Formic acid (SpRB)			25%	20	+	+		+	+	+	+				
				40	+	+		+	+	+	+				
				60	+	+		+	+	+	+				
				80					+	+					
				100											
				120											
				140											
Freon 113	see trifluoro, trichlorethane	48													
Frigen 12 (D/P)	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Fruit juices (SpRB)				20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	+
				80		+			+	+		+	+	+	+	+
				100						+		+	+	+		+
				120						+			+			
				140												
Fruit pulp				20	+	+	+	+	+			+	+	+	+	+
				40			+	+	+							
				60				+	+							
				80												
				100												
				120												
				140												
Fuel oil				20	+	+		O	O	+		-	+	+	+	-
				40	O	+		-	-	+			+	+	+	
				60						+			+	+	O	
				80						+						
				100						+						
				120												
				140												
Furfuryl alcohol (SpRB)	$C_5H_6O_2$	171	technically pure	20	-	-	-	+	+	+		O	-	-	O	O
				40				+		+						
				60				+	O	O						
				80						-						
				100												
				120												
				140												
Gasoline (SpRB)	C_5H_{12} to $C_{12}H_{26}$	80-130	free of lead and aromatic compounds	20	+	+	-	+	O	+		-	+	+	-	O
				40	+	+		+		+			+	+		-
				60	+	+		O	-	+			+	+		
				80						+						
				100						+						
				120						+						
				140												
Gelatin			all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60		+	+	+	+	+						
				80						+						
				100												
				120												
				140												
Glucose	$C_6H_{12}O_6$	Fp*., 148	all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+		+	+	+	+	+
				80		+			+	+		+	+	+	+	+
				100						+			+			
				120												
				140												
Glycerol	HO-CH_2-CH(OH)-CH_2OH	290	technically pure	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		O	+	+	+	+
				60	+	+		+	+	+		O	O	+	+	+
				80		+			+	+			-	O	+	+
				100					+	+					O	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Glycocoll (SpRB)	$NH_2\text{-}CH_2\text{-}COOH$	Fp.* 233	10%, aqueous	20	+	+	+	+	+	+			+	+	+	+
				40	+	+	+	+	+	+			+	O	+	O
				60		+				+						
				80						+						
				100												
				120												
				140												
Glycol	see Ethylene glycol															
Glycolic acid	$HO\text{-}CH_2\text{-}COOH$	Fp.*, 80	37%, aqueous	20	+	-	+	+	+	+			+	+	+	+
				40			+	+		+						
				60				+		+						
				80						+						
				100						+						
				120												
				140												
Heptane (SpRB)	C_7H_{16}	98	technically pure	20	+	O	-	+	+	+		-	+	+	+	+
				40						+			+	+	+	O
				60				O	O	+			+	+	+	-
				80						+						
				100						+						
				120												
				140												
Hexane (SpRB)	C_6H_{14}	69	technically pure	20	+	O	-	+	+	+		-	+	+	+	+
				40						+			+	+	+	O
				60				O	O	+			+	+	+	-
				80						+						
				100						+						
				120												
				140												
Hydrazine hydrate (SpRB)	$H_2N\text{-}NH_2 . H_2O$	113	aqueous	20	+	-	-	+	+	-		+	O	-	-	+
				40				+	+							
				60				+	+							
				80												
				100												
				120												
				140												
Hydrobromic acid (SpRB)	HBr	124	aqueous, 50%	20	+	+	+	+	+	+		+	+	O	+	+
				40	+	+	+	+	+	+		+	+	-	+	+
				60	+	+		+	+	+		O	+		O	+
				80		O				+		-	O		-	O
				100						+			-			-
				120												
				140												
Hydrochloric acid (Q/E, D/P)	HCl		up to 38%	20	+	+	-	+	O	+		+	+	-	O	+
				40	+	+		+		+			+			
				60	+	+				+						
				80						+						
				100						+						
				120												
				140												
Hydrochloric acid (Q/E, D/P)	HCl		5%, aqueous	20	+		+	+	+	+		+	+	O	O	+
				40	+		+	+	+	+		+	+	-	-	O
				60	O			+	+	+		+	+			-
				80					O	+			+			
				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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Hydrochloric acid (Q/E, D/P)	HCl		10%, aqueous	20	+	+	+	+	+	+		+	+	O	O	+
				40	+	+	+	+	+	+		+	+	-	-	O
				60	O	+		+	O	+		+	+			-
				80		+			O	+			+			
				100						+						
				120						+						
				140												
Hydrochloric acid (Q/E, D/P)	HCl		up to 30%, aqueous	20	+	+	O	+	+	+		+	+	-	-	+
				40	+	+	-	+	O	+		+	+			O
				60	O	+		+	O	+		O	O			-
				80		+			-	+						
				100						+						
				120												
				140												
Hydrochloric acid (Q/E, D/P)	HCl		36%, aqueous	20	+	+	-	+	+	+		O	+	-	-	O
				40	+	+		+	O	+		O	O			-
				60	O	O		+	-	+		-	-			
				80		O				+						
				100						+						
				120												
				140												
Hydrocyanic acid	HCN	26	technically pure	20	+	+	-	+	+	+		+	+	O	O	+
				40	+	+		+	+	+		O	O	-	-	O
				60	O	+		+	+	+						
				80						+						
				100												
				120												
				140												
Hydrofluoric acid	HF			20	+	-	-	+	+	+		-	+	-	-	+
				40	O			+	+	+			+			+
				60	O			O	+	+			O			O
				80						+						
				100						+						
				120												
				140												
Hydrogen	H_2	-253	technically pure	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	+
				80		+				+		+	+	+	+	+
				100					-	+		+	+	+		
				120												
				140												
Hydrogen chloride (Q/E)	HCl	-85	technically pure, gaseous	20	+	+	-	+	+	+		+	+	O	O	O
				40	+	+		+	+	+		+	+	-	-	O
				60	O	+		+	+	+		+	+			-
				80		O				+						
				100						+						
				120												
				140												
Hydrogen perocide			70%	20	+	+	-	+	+	O		O	+			
				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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Hydrogen peroxide (SpRB)	H_2O_2		50%, aqueous	20	+	+	-	+	+	O		O	+			
				40												
				60												
				80												
				100												
				120												
				140												
Hydrogen peroxide (SpRB)	H_2O_2		10%, aqueous	20	+	+	-	+	+	O		O	+	O	-	+
				40	+			+	+	O		O	O	-		+
				60	O			+	+	-		-	-			O
				80												-
				100												
				120												
				140												
Hydrogen peroxide (SpRB)	H_2O_2	139	90%, aqueous	20	+		-	+	-	O			O	-	-	O
				40												
				60				-								
				80												
				100												
				120												
				140												
Hydrogen peroxide (SpRB)	H_2O_2	105	30%, aqueous	20	+	+	-	+	+	O		O	+	-	-	+
				40												O
				60												-
				80												
				100												
				120												
				140												
Hydrogen sulphide	H_2S		technically pure	20	+	+	+	+	+	+		+	+	+	O	+
				40	+	+	+	+	+	+		-	+	O	-	O
				60	+	+		O	+	+			O	-		O
				80						+			-			-
				100						+						
				120						+						
				140												
Hydrogen sulphide	H_2S		saturated, aqueous	20	+	+	+	+	+	+		+	+	-	+	+
				40	+	+	+	+	+	+		-	+	-	-	+
				60	O	+		+	+	+			+			O
				80						+			O			-
				100						+						
				120						+						
				140												
Hydroquinone	$C_6H_4(OH)_2$		saturated	20	+	+		+	+			+				
				40	+	+		+	+							
				60				+	+							
				80					+							
				100												
				120												
				140												
Hydrosulphite	see Sodium dithione															
Hydroxylamine sulfate				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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Hydroxylamine sulphate	$(NH_3OH)_2SO_4$		all, aqueous	20	+	+	-	+	+			+	+	+	O	+
				40	+	+		+	+				+	O		+
				60				+	+							
				80												
				100												
				120												
				140												
Iodine-potassium iodide solution (lugol's solution)				20	+	-	-			+			+			
				40												
				60												
				80												
				100												
				120												
				140												
Iodium	I_2	185	100%	20	-	-	-			+			+			
				40												
				60												
				80												
				100												
				120												
				140												
Iron (II) -chloride			saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+			+			
				100						+			+			
				120												
				140												
Iron (II) -chloride	$FeCl_2$		saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Iron (II) -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	PP-H	PVDF (SYGEF)		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 (II) -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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Iron salts			all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+		+	+	+		+	+	+	+	+
				80		+			+	+		+	+			+
				100						+			+			
				120						+						
				140												
Isooctane (SpRB)	$(CH_3)_3$-C-CH_2-CH-$(CH_3)_2$	99	technically pure	20	+		-	+	+	+			+	+	+	O
				40						+						
				60				O	O	+						
				80						+						
				100						+						
				120												
				140												
Isophorone (SpRB)	$C_9H_{14}O$		technically pure	20						-						
				40												
				60												
				80												
				100												
				120												
				140												
Isopropyl alcohol (SpRB)	$(CH_3)_2$-CH-OH	82	technically pure	20				+	+	+		+				
				40						+						
				60						+						
				80						O						
				100												
				120												
				140												
Isopropyl ether	$(CH_3)_2$-CH-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	+	+	+	+	+	+		+	+	+	+	+
				40	O	+	+	+	+	+		+	+	+	+	+
				60	O	+		+	+	+		+	+	+	+	+
				80					+	+		+	+			
				100					+	+						
				120						+						
				140												
Lactic acid (SpRB)	$CH_3CHOHCOOH$		10%, aqueous	20	+	+	+	+	+	+		O	+	-	-	O
				40	O	+	O	+	+	+		O	O			O
				60	-	+	-	+	+	O		O	O			O
				80		+			+	O		-	O			
				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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Lanolin (SpRB)			technically pure	20	+	o	+	+	+	+			+	+	+	O
				40	O		+	+	+	+			+	+	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												
Leadcarbonate				20	+	+		+	+	+		+				
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Leadnitrate	$Pb(NO_3)2$			20		+										
				40		+										
				60		+										
				80		+										
				100												
				120												
				140												
Leadnitrate				20	+					+						
				40	+					+						
				60	+					+						
				80						+						
				100						+						
				120												
				140												
Leadtetrafluoroborate				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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Linseed oil (SpRB)			technically pure	20	+	+	+	+	+	+			+	+	O	+
				40	+	+	-	+	+	+			+	+	-	O
				60	O			+	+	+			+	+		-
				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	-	+	O	+		-	+	+	+	+
				40	+			+		+			+	+	O	O
				60	+			O		+			+	O	-	-
				80						+			O			
				100						+			-			
				120						+						
				140												
Magnesium salts	$MgCl_2$, $MgCO_3$, Mg(No3)$_2$, $Mg(OH)_2$, $MgSO_4$		all, aqueous,saturated	20	+	+	+	+	+	+			+	+	+	+
				40	+	+	+	+	+	+			+	+	+	+
				60	O	+		+	+	+		+	+	+	+	+
				80		+			+	+		+	+			+
				100					+	+			+			
				120						+						
				140												
Magnesiumhydrogencarbonate				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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Maleic acid (SpRB)	$(CH\text{-}COOH)_2$	Fp. *131	cold saturated, aqueous	20	+	+	+	+	+	+			+	-	-	-
				40	+	+		+	+	+			+			
				60	O			+	+	+			+			
				80						+			-			
				100						+						
				120						+						
				140												
Media water or similar media				20	+	+	+	+	+	+						
				40	+	+	+	+	+	+						
				60	+	+	+	+	+	+						
				80		+			+	+						
				100					+	+						
				120						+						
				140						+						
Mercury	Hg	357	pure	20	+	+	+	+	+	+		+	+	+	+	+
				40	+			+	+	+		+	+	+	+	+
				60	+			+	+	+		+	+	+	+	+
				80						+			+			
				100						+						
				120						+						
				140												
Mercury (II) -chloride	$HgCl_2$			20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80		+			+	+						
				100						+						
				120												
				140												
Mercury (II) -cyanide	Hg(CN)2			20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80		+				+						
				100						+						
				120												
				140												
Mercury (II) -cyanide	$Hg(NO_3)_2$			20	+	+		+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80		+			+	+			+			
				100						+						
				120												
				140												
Mercury (II) -sulfate				20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80		+			+	+			+			
				100						+						
				120												
				140												
Mercury salts	$HgNO_3$, $Hg\ Cl_2$, $Hg(CN)_2$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	O	O	O
				40	+	+		+	+	+		+	+	O	O	O
				60	O	+		+	+	+			+	-	-	-
				80						+						
				100						+						
				120						+						
				140												
Methane	see natural gas	-161	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Methanol (SpRB)	CH_3OH	65	all	20	+	-	-	+	+	+		+	O	+	+	+
				40	+			+	+	O		+	O	+	+	+
				60	O			+	+	-		+	O	+	O	+
				80												
				100												
				120												
				140												
Methyl acetate	CH_3COOCH_3	56	technically pure	20	-	-	-	+	+	+			-	-	-	-
				40					+	O						
				60					O							
				80												
				100												
				120												
				140												
Methyl amine	CH_3NH_2	-6	32%, aqueous	20	O	-	-	+	+	O			+	-	+	+
				40												
				60												
				80												
				100												
				120												
				140												
Methyl bromide	CH_3Br	4	technically pure	20	-	-	-	O	-	+			O	-	-	O
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Methyl chloride	CH_3Cl	-24	technically pure	20	-	-	-	O	-	+			-	-	-	-
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Methyl ethyl ketone	$CH_3COC_2H_5$	80	technically pure	20	-	-	-	+	+	-			-	-	-	-
				40				O	O							
				60				-	O							
				80												
				100												
				120												
				140												
Methylene chloride	CH_2Cl_2	40	technically pure	20	-	-	-	O	O	+			O	-	-	-
				40						O						
				60						O						
				80												
				100												
				120												
				140												
Methylisobutylketone	$C_6H_{12}O$			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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Methylmethacrylate	$C_5H_8O_2$			20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Methylphenylketone (Acetophenon)	C_8H_8O			20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Milk (SpRB)				20	+	+	+	+	+	+			+	+	+	+
				40	+	+	+	+	+	+						
				60	+	+	+	+	+	+						
				80		+			+	+						
				100					+	+						
				120						+						
				140												
Mineral oils, free of aromatics				20	+	+	-	+	+	+			+	+	O	O
				40	+			+	+	+			+	+	-	-
				60	+			O	O	+			+	+		
				80						+						
				100						+						
				120						+						
				140												
Mineral water				20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	+
				80		+			+	+		+	+	+		+
				100					+	+		+	+			+
				120						+			+			
				140												
Mixed acids - nitric - hydrofluoric - sulphuric	15% HNO_3 15% HF 18% H_2SO_4		3 parts 1 part 2 parts	20	O	O	-	O	-	+			+	-	-	+
				40						+			O			O
				60						+						
				80												
				100												
				120												
				140												
Mixed acids - sulphuric - nitric - water	H_2SO_4 HNO_3 H_2O		48% 49% 43%	20	+	+	-	-	-	+			-	-	-	-
				40	O											
				60	-											
				80												
				100												
				120												
				140												
Mixed acids - sulphuric - nitric - water	H_2SO_4 HNO_3 H_2O		50% 50% 40%	20	O	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Mixed acids	H_2SO_4		10%	20	O	O	-	-	-	O			-	-	-	-
- sulphuric	HNO_3		87%	40												
- nitric	H_2O		43%	60												
- water				80												
				100												
				120												
				140												
Mixed acids	H_2SO_4		50%	20	+	+	-	-	-	+			+	-	-	O
- sulphuric	HNO_3		33%	40	O											
- nitric	H_2O		17%	60												
- water				80												
				100												
				120												
				140												
Mixed acids	H_2SO_4		10%	20	+	+	-	O	-	+			+	-	O	+
- sulphuric	HNO_3		20%	40	+					+			+			O
- nitric	H_2O		70%	60						+			+			
- water				80						+						
				100												
				120												
				140												
Mixed acids	H_2SO_4		50%	20	+		-	-	-	+			+	-	O	O
- sulphuric	HNO_3		31%	40												
- nitric	H_2O		19%	60												
- water				80												
				100												
				120												
				140												
Mixed acids	H_2SO_4		30%	20	+	+	-	+	+	+			+	-	+	+
- sulphuric	H_3PO_4		60%	40	+	+		O	O	+			+		O	O
- phosphoric	H_2O		10%	60		+				+			+			
- phosphoric				80						+						
				100												
				120												
				140												
Molasses				20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+		+	+	+	+	+
				80		+				+		+	+	+	O	+
				100												
				120												
				140												
Molasses wort				20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	+
				80		+				+						
				100												
				120												
				140												
Monochloroacetic acid ethyl ester	$ClCH_2COOC_2H_5$	144	technically pure	20	-	-	-	+	+	O			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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Morpholin	C_4H_9NO	129	technically pure	20	-	-	-	+	+	+			+	-	O	O
				40				+	+	+						
				60				+	+	O						
				80												
				100												
				120												
				140												
Mowilith D			usual commercial	20	+	+		+	+	+			+	+	+	+
				40												
				60												
				80												
				100												
				120												
				140												
Naphthalene		218	technically pure	20	-	-	-	+	+	+		-	+	+	-	O
				40						+			+	+		-
				60				O		O			+	+		
				80												
				100												
				120												
				140												
Natriumhydrogensulfite	$NaHSO_3$			20	+	+		+	+	+		+	+			
				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80		+			+	+						
				100						+						
				120												
				140												
Natriumsulfate				20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Natriumtetraborate				20	+	+	+	+	+	+		+	+			
(Borax)				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80		+			+							
				100												
				120												
				140												
Nickel salts	$(CH_3COO)_2Ni$, $NiCl_2$, $Ni(NO_3)_2$,		cold saturated,	20	+	+	+	+	+	+		+	+	+	+	+
	$Ni\ SO_4$		aqueous	40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+			+	+	+	+
				80						+			+			
				100						+			+			
				120						+						
				140												
Nitrating acid	H_2SO_4		65% 20%	20						+						
	HNO_3		15%	40												
	H_2O			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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Nitric acid (SpRB)	HNO_3			20	+	+	-	+	O	+		+	+			
				40	+	+				+			+			
				60	+	+				+			+			
				80						+						
				100						+						
				120												
				140												
Nitric acid (SpRB)	HNO_3			20	+	+	-	+	+	+		+	+			
				40	+	+		+	O	+			+			
				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		65%, 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															
Nitrilotriacetic acid	$N(CH_2\text{-}COOH)_3$			20				+	+			+				
				40												
				60												
				80												
				100												
				120												
				140												
Nitrobenzene	$C_6H_5\text{-}NO_2$	209	technically pure	20	-	-	-	+	+	+		-	O	-	-	-
				40				O	+	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Nitrotoluene (o-, m-, p-)		222-238	technically pure	20	-	-	-	+	+	+		-	O	O	-	-
				40				O	O	+			-	-		
				60						+						
				80						+						
				100						O						
				120												
				140												
Nitrous acid	HNO_2			20	+	+	-	+	-	+		+	+			
				40	+	+				+						
				60						+						
				80												
				100												
				120												
				140												
Nitrous gases	see Nitric oxide		diluted, moist, anhydrous													
N-Methylpyrrolidon				20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
N,N-Dimethylaniline	$C_6H_5N(CH_3)_2$		technically pure	20	-	-	-	+	+			+				
				40												
				60												
				80												
				100												
				120												
				140												
n-Pentylacetate				20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Oleic acid (SpRB)	$C_{17}H_{33}COOH$		technically pure	20	+	O	-	+	+	+		-	+	O	-	-
				40	+			+	+	+			O	-		
				60	+			O	O	+			-			
				80						+						
				100						+						
				120						+						
				140												
Oleum (SpRB)	$H_2SO_4+SO_3$		10% SO_3	20	-	-	-	-	-	-		-	-	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Oleum vapours (SpRB)			traces	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Olive oil (SpRB)				20	+	-	-	+	+	+		-	+	+	+	+
				40	+			+	+	+			+	+	+	+
				60	+			O	+	+			+	+	+	O
				80					+	+			+			-
				100												
				120												
				140												
Oxalic acid (SpRB)	$(COOH)_2$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	O	O	O
				40	+	+	+	+	+	+			+	-	-	O
				60	+	+		+	+	+			O			-
				80		O				+			-			
				100						+						
				120												
				140												
Oxygen	O_2		technically pure	20	+	+	+	+	+	+		+	+	+	+	+
				40	+		+	+	+	+		+	+		+	+
				60	+		+	O	O	+		+	+		+	+
				80						+			+		+	+
				100						O			+			+
				120						O			+			
				140												
Ozone (SpRB)	O_3		up to 2%, in air	20	+	+	-	O	O	O		O	+	-	O	+
				40				-	-							
				60												
				80												
				100												
				120												
				140												
Ozone (SpRB)	O_3		cold saturated, aqueous	20	+	+	-	O	O	O		-	+	-	O	+
				40	+			-	-				O		-	+
				60									-			O
				80												
				100												
				120												
				140												
Palm oil, palm nut oil (SpRB)				20	+	O	+	+	+	+		-	+	+	+	O
				40	-			+	+	+			+	+	O	-
				60				O	O	+			+	O	-	
				80						+						
				100						+						
				120												
				140												
Palmitic acid (SpRB)	$C_{15}H_{31}COOH$	390	technically pure	20	+	-	+	O	O	+		O	+	O	+	O
				40						+			O	-	-	-
				60					-	+			-			
				80						+						
				100						+						
				120						+						
				140												
Paraffin emulsions			usual commercial, aqueous	20	+	+	O	+	+	+		-	+	+	+	+
				40	+	+		+	+	+			+	+	O	-
				60				O	O	+			+	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Paraffin oil				20	+	+	O	+	+	+		-	+	+	+	O
				40	+			+	+	+			+	O	O	-
				60	O			+	O	+			+	O	-	
				80						+			O			
				100						+						
				120						+						
				140												
p-Dibromo benzene	$C_6H_5Br_2$		technically pure	20	-	-	-	O	O	+		-	+	-	-	-
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Perchlorethylene (tetrachlorethylene)	$Cl_2C{=}CCl_2$	121	technically pure	20	-	-		O	O	+			+	O	-	-
				40						+			+	-		
				60						+			+			
				80						O						
				100						-						
				120												
				140												
Perchlorid acid (SpRB)	$HClO_4$		10%, aqueous	20	+	+	O	+	+	+		+	+	-	-	+
				40	+	+		+	+	+		O	+			+
				60	O	+		+	+	+			+			O
				80						+			O			-
				100						+						
				120												
				140												
Perchlorid acid (SpRB)			70%, aqueous	20	O	O	-	+	O	+		-	+	-	-	+
				40				O	-	+			+			+
				60				-		+			+			O
				80						+			O			
				100						+						
				120												
				140												
Petroleum			technically pure	20	+	-	-	+	+	+		-	+	+	O	-
				40				+	O	+			+	+	-	
				60				O	O	+			O	+		
				80						+						
				100						+						
				120						+						
				140												
Petroleum ether (SpRB)		40-70	technically pure	20	+	-	-	+	+	+		-	+	+	-	-
				40	+			O	O	+			+	O		
				60	+			O	O	+			O	-		
				80						+						
				100						+						
				120												
				140												
Phenol (SpRB)	C_6H_5-OH	182	up to 10%, aqueous	20	+	+	-	+	+	+			+	-	-	-
				40	O	+		+	+	+			+			
				60				O	+	+		+	+			
				80						+		O	O			
				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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Phenol (SpRB)			up to 5%	20	+	+	-	+	+	+		+	+	-	-	
				40		+		+	+	+		O	+			
				60				+	+	+			+			
				80						+			O			
				100						O						
				120												
				140												
Phenol (SpRB)	C_6H_5-OH		up to 90%, aqueous	20	O	-	-	+	+	+		-	+	-	-	-
				40				+	+	+			O		O	
				60				O	+	O			-			
				80												
				100												
				120												
				140												
Phenylhydrazine	C_6H_5-NH-NH_2	243	technically pure	20	-	-	-	O	O	O		-	+	-	-	-
				40						-			+			
				60									O			
				80												
				100												
				120												
				140												
Phenylhydrazine hydrochloride	C_6H_5-NH-NH_2.HCl		aqueous	20	O	O	-		+	+			+	O	O	+
				40					O	+			+	-	-	+
				60					O	+		O	O			O
				80									-			-
				100												
				120												
				140												
Phosgene (SpRB)	$COCl_2$	8	liquid, technically pure	20	-	-	-	-	-	-		-	+	O	+	+
				40												
				60												
				80												
				100												
				120												
				140												
Phosgene (SpRB)			gaseous, technically pure	20	+	-	-	O	O	+		+	+	+	+	+
				40	O					+			+	+	O	O
				60	O								O	+	-	
				80												
				100												
				120												
				140												
Phosphate disodique	see d'isodiumphosphate		saturated													
Phosphoric acid	H_3PO_4		up to 30%, aqueous	20	+	+	+	+	+	+		+	+	O	+	+
				40	+	+	+	+	+	+		+	+	O	+	+
				60	O	+	O	+	+	+		O	+	-	+	+
				80		+			+	+			+		O	O
				100						+			+			
				120						+						
				140												
Phosphoric acid			50%, aqueous	20	+	+	+	+	+	+		+	+	O	+	+
				40	+	+	+	+	+	+		O	+	-	+	+
				60	+	+	O	+	+	+			+		O	+
				80		+			+	+			+			+
				100						+			O			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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Phosphoric acid			85%, aqueous	20	+	+	+	+	+	+		+	+	-	+	+
				40	+	+	+	+	+	+		+	+		+	O
				60	+	+	O	O	+	+		O	+		O	-
				80		+			+	+			+			
				100						+			O			
				120						+						
				140												
Phosphoric acid	H_3PO_4			20	+	+	-	+	+	+		O	+	-	-	-
				40	+	+		+	+	+			+			
				60		+				+			O			
				80						+						
				100												
				120												
				140												
Phosphoric acid	H_3PO_4			20	+	+	-	+	+	+			+			
				40	+	+		+	+	+			+			
				60	+	+			+	+			+			
				80		+			+	+			+			
				100						+			O			
				120												
				140												
Phosphoric acid tributyl ester	$(H_9C_4O)_3P=O$			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	-	-	-	+	O	-			+	-	-	+
				40												
				60				O	O							
				80												
				100												
				120												
				140												
Photographic developer (SpRB)			usual commercial	20	+	+	+	+	+	+		+	+	O	+	+
				40	+	+	+	+	+	+		+	+	O	+	+
				60	O	+	O	O		+						
				80		O										
				100												
				120												
				140												
Photographic emulsions (SpRB)				20	+	+	+	+	+	+		+	+	O	+	+
				40	+	+	+	+	+	+		+	+		+	+
				60		O				+						
				80												
				100												
				120												
				140												
Photographic fixer (SpRB)			usual commercial	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Phthalic acid (SpRB)	$C_6H_5(COOH)_2$	Fp.*, 208	saturated, aqueous	20	+	-	-	+	+	+		+	-	-	+	+
				40	O			+	+	+		O			+	+
				60	-			+	+	+					O	
				80						+						
				100						+						
				120												
				140												
Phthalic acid dioctayl ester	$C_{24}H_{38}O_4$			20	-	-	-	+	+	-		+	-	-		
				40												
				60												
				80												
				100												
				120												
				140												
Picric acid (SpRB)	$C_6H_3N_3O_7$	FP. 122	1%, aqueous	20	+	-	-	+	+	+		+	+	O	O	+
				40						+		+	+	-	-	O
				60						+		+	+			-
				80						+		+	+			
				100						+		+	+			
				120												
				140												
Potash	see potassium carbonate		cold saturated, aqueous													
Potash lye	KOH		50%	20	+	+		+	+	-		+				
				40	+	+		+	+			+				
				60	+	+		+	+			+				
				80												
				100												
				120												
				140												
Potassium (SpRB)	$KMnO_4$		cold saturated, aqueous	20	+	+		+	+	+		+	+	O	O	+
				40	+	+		+	+	+			+	-	-	+
				60	O			O		+			+			+
				80						+			+			
				100						+						
				120												
				140												
Potassium acetate (SpRB)	CH_3COOK		saturated	20	+	+	+	+	+	+		+	-			
				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80		+			+	+		+				
				100						+						
				120												
				140												
Potassium bichromate (SpRB)	$K_2Cr_2O_7$	107	saturated, aqueous	20	+	+	+	+	+	+		+	+	+	O	+
				40	+	+	+	+	+	+			+	O	-	+
				60	O	+	+	+	+	+			+			+
				80					+	+						
				100					+	+						
				120						+						
				140												
Potassium borate	K_3BO_3		10%, aqueous	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Potassium bromate	$KBrO_3$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	O	+	+		+	+	+	+	+
				80		+			+	+			+	+	O	+
				100					+	+				+	O	+
				120						+						
				140												
Potassium bromide	KBr		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+		+	+	+	+	+
				80		+				+			+	O	+	+
				100						+			+	O	O	+
				120						+						
				140												
Potassium carbonate (potash)				20	+	+	+	+	+	O		+				
				40	+	+		+	+			+				
				60	+	+		+	+			+				
				80		+			+							
				100												
				120												
				140												
Potassium chlorate (SpRB)	$KClO_3$		cold saturated, aqueous	20	+	+	+	+	+	O		+	+	+	+	+
				40	+	+	+	+	+	-		+	+	O	O	+
				60	+	+	+	+	+				+			+
				80		+							+			O
				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	+	+	+		+	+			+	O	+	+
				60	+	+	+		+	+			+	-	O	O
				80						+						
				100						+						
				120												
				140												
Potassium cyanide	KCN		cold saturated, aqueous	20	+	+	+	+	+	+			+	+	+	+
				40	+	+	+	+	+	+			O	+	+	+
				60	+	+	+	+	+	O		+	-	+	O	+
				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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Potassium fluoride	KF		saturated	20	+	+		+	+	+			+			
				40	+	+		+	+	+						
				60	+	+		+	+	+						
				80		+			+	+						
				100						+						
				120												
				140												
Potassium Hexacyanoferrate -(II)	$K_4[Fe(CN)_6]._3H_2O$			20	+	+		+	+	+		+	+			
				40	+	+		+	+	+						
				60	+	+		+	+	+						
				80		+			+	+						
				100						+						
				120												
				140												
Potassium hydrogen carbonate	$KHCO_3$		saturated	20	+	+		+	+	+		+	+			
				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80		+			+							
				100												
				120												
				140												
Potassium hydrogen sulphate	$KHSO_4$		saturated	20	+	+		+	+			+				
				40	+	+		+	+			+				
				60	+	+		+	+			+				
				80		+			+			+				
				100												
				120												
				140												
Potassium iodide	KJ		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+			+	O	O	+
				60	+	+	+	+	+	+			+	-	-	+
				80		+				+			+			
				100						+						
				120												
				140												
Potassium nitrate	KNO_3		50%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+			+	+	+	+
				60	+	+	+	+	+	+			+	+	+	+
				80		+				+						
				100						+						
				120												
				140												
Potassium perchlorate (SpRB)	$KClO_4$		cold saturated, aqueous	20	+	+		+		+		+	+	+	+	+
				40	+	+				+			+	O	O	+
				60	O	+				+			+			+
				80		+				+			+			O
				100												
				120												
				140												
Potassium persulphate (SpRB)	$K_2S_2O_8$		all, aqueous	20	+	+	+	+	+	+		+	+	-	+	+
				40	+	+	+	+	+	+		+	+		+	+
				60	O	+	+	+	+	+			+		+	+
				80						+			+		O	O
				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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Potassium sulphate	K_2SO_4		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	○	+	+	+	+	+			+	+	+	+
				80		+				+			+			
				100						+			+			
				120												
				140												
Potassium sulphide	K_2S		saturated	20	+	+		+	+	○		+				
				40	+	+		+	+	○		+				
				60	+	+		+	+	○		+				
				80		+			+			+				
				100												
				120												
				140												
Potassium sulphite	K_2SO_3		saturated	20	+	+		+	+			+				
				40	+	+		+	+							
				60	+	+		+	+							
				80		+										
				100												
				120												
				140												
Potassium-aluminiumsulfate (alum)			50%	20	+	+		+	+	+		+				
				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80		+			+	+		+				
				100						+						
				120												
				140												
Pottasium hexacyanoferrate -(III)	$K_3[Fe(CN)_6]$.			20	+	+		+	+	+		+	+			
				40	+	+		+	+	+						
				60	+	+		+	+	+						
				80		+			+	+						
				100						+						
				120												
				140												
Pottasium tartrat				20	+			+	+	+		+				
				40	+			+	+	+		+				
				60				+	+	+		+				
				80					+	+						
				100						+						
				120												
				140												
Pottasiumhydrogensulfite				20	+					+		+				
				40	+					+		+				
				60						+						
				80						+						
				100						+						
				120												
				140												
Pottasiumhypochlorite	KOCl			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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Pottasiumperoxodisulfate	$K_2S_2O_8$		saturated	20	+	+										
				40	+	+										
				60	+	+										
				80		+										
				100												
				120												
				140												
Pottasiumphosphate	KH_2PO_4 und $K_2H\ PO_4$		all, aqueous	20	+	+	O	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	O	O	+
				60	O	+		+	+	+			+	-	-	+
				80		+			+	+			+			O
				100									+			
				120												
				140												
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	+	+	-	+	+	+		-	+	+	+	O
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Propanol, n- and iso- (SpRB)	C_3H_7OH	97 bzw. 82	technically pure	20	+	-	-	+	+	+		+	+	+	+	+
				40	O			+	+	+		+	+	O	+	O
				60	O			+	+	+			+	-	+	O
				80						O						
				100												
				120												
				140												
Propargyl alcohol (SpRB)	CHčC-CH_2-OH	114	7%, aqueous	20	+	-	-	+	+	+		+	+	+	+	+
				40	+			+	+	O		+	+	+	+	+
				60	+			+	+	O			+	+	O	O
				80												
				100												
				120												
				140												
Propionic acid (SpRB)	CH_3CH_2COOH	141	50%, aqueous	20	+	O	-	+	+	+		+	+	-	O	O
				40	+			+	+	+		+	+		-	-
				60	O			+	+	+			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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Propionic acid (SpRB)		141	technically pure	20	+	O	-	+	+	+		+	+	-	-	-
				40	O			O	O	+		O	+			
				60				O	O	+			+			
				80									O			
				100												
				120												
				140												
Propylene glycol (SpRB)	$C_3H_8O_2$	188	technically pure	20	+	-	O	+	+	+		+	+	+	+	+
				40	+			+	+	+		+	+	O	+	+
				60	+			+	+	+			O	-		+
				80												
				100												
				120												
				140												
Propylene oxide	C_3H_6O	35	technically pure	20	O		-	+	+	+		O	-	-	-	-
				40						O						
				60												
				80												
				100												
				120												
				140												
Pyridine	C_5H_5N	115	technically pure	20	-	-	-	+	O	+		O	-	-	-	-
				40				O	O	-						
				60				O	O							
				80												
				100												
				120												
				140												
Pyrogallol	$C_6H_3(OH)_3$		100%	20						+			+			
				40						+						
				60												
				80												
				100												
				120												
				140												
Ramsit fabric waterproofing agents			usual commercial	20	+			+	+	+		+	+	+	+	+
				40	+					+						
				60	+					+						
				80												
				100												
				120												
				140												
Salicylic acid	$C_6H_4(OH)COOH$		saturated	20	+	+	O	+	+	+		+	+	+	+	+
				40	+			+	+	+		+				
				60				+	+	+		+				
				80						+						
				100												
				120												
				140												
Sea water	see Brine															
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	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Silicone oil				20	+	+	+	+	+	+		+	+	+	+	+
				40	O	+		+	+	+		+	+	+	+	+
				60	-			+	+	+		+	+	+	O	
				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 (SpRB)			all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+		+	+	+		+	+	+	+	+
				80						+						
				100						+						
				120												
				140												
Soda	see Sodium carbonate															
Sodium acetate	CH_3COONa		all, aqueous	20	+	+	+	+	+	+		+	-	+	+	O
				40	+	+		+	+	+		+		+	+	
				60	+	+		+	+	+		+				
				80		+			+	+						
				100					+	O						
				120												
				140												
Sodium aluminium sulfate				20	+			+	+							
				40	+			+	+							
				60	+			+	+							
				80					+							
				100												
				120												
				140												
Sodium arsenite	Na_3AsO_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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Sodium benzoate	C_6H_5-COONa		cold saturated, aqueous	20	+	+	-	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		O	+	+	+	+
				60	O	+		+	+	+			+			O
				80		+				+			O			
				100						O						
				120												
				140												
Sodium bicarbonate	$NaHCO_3$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	+
				80					+	+		+	+			
				100						+						
				120												
				140												
Sodium bisulphate	$NaHSO_4$		10%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		O	+	O	+	+
				60	O	+	+	+	+	+			+	-	O	
				80						+			+			
				100						+			+			
				120						+						
				140												
Sodium bisulphite	$NaHSO_3$		all, aqueous	20	+	+		+	+	+		+	O	O	+	+
				40	O	+		+	+	+		O	-	-	+	+
				60	-	+		+	+	+		-			O	+
				80						+					-	O
				100						+						
				120												
				140												
Sodium borate	Na_3BO_3		saturated	20	+	+		+	+			+	+			
				40	+	+		+	+			+	+			
				60	+	+		+	+			+	+			
				80		+			+							
				100												
				120												
				140												
Sodium bromate	$NaBrO_3$		all, aqueous	20	+	+		+	+	+		+	+	+	+	+
				40	O	+		O	O	+			+	O	+	+
				60						+			+	-	O	+
				80						+						
				100						+						
				120												
				140												
Sodium bromide	NaBr		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+			+	O	+	+
				60	O	+	+	+	+	+			+		O	O
				80		+			+	+			+			
				100						+						
				120						+						
				140												
Sodium carbonate	see soda		cold saturated, aqueous													
Sodium chlorate (SpRB)	$NaClO_3$		all, aqueous	20	+	+	+	+	+	O		+	+	+	+	+
				40	+	+	+	+	+			+	+	O	+	+
				60	O	+	+	+	+			+	+	-	O	+
				80		+						O	+		-	O
				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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Sodium chlorite (SpRB)	$NaClO_2$		diluted, aqueous	20	O	+		+	+	+		+	+	-	O	+
				40		+		O	O	O		+	+		-	+
				60		+				O		+	+			+
				80		+										
				100												
				120												
				140												
Sodium chromate (SpRB)	Na_2CrO_4		diluted, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+		+	+		+	+	O	+	+
				60	O		+			+		+	+	-	O	O
				80						+						
				100						+						
				120												
				140												
Sodium disulphite	$Na_2S_2O_5$		all, aqueous	20	+	+		+	+	+		+	+	O	+	+
				40	+	+				+		+	+	-	+	+
				60	O	+				+		+	+		+	O
				80						+						
				100						+						
				120												
				140												
Sodium dithionite	see hyposulphite		up to 10%, aqueous													
Sodium fluoride	NaF		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+			+		+	+	+	+	+
				60	+	+	+			+		+	+	O	+	+
Sodium hydroxide (see Caustic soda)				80						+						
				100						+						
				120												
				140												
Sodium hypochlorite (SpRB)	NaOCl		12,5% active chlorine, aqueous	20	+			O	O	O		+	+	-	-	+
				40	+			-	-							
				60	O											
Sodium iodide	NaI		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+			+			+	+	+	+
				60	O	+	+			+			+	O	+	O
				80		+				+						
				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	+	+	+	+	+	+			+	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Sodium oxalate	$Na_2C_2O_4$		cold saturated, aqueous	20	+	+	+	+	+	+			+	+	+	+
				40	+	+				+						
				60	O	+				O						
				80												
				100												
				120												
				140												
Sodium perborate	$NaBO_3\ 4H_2O$		saturated	20	+	+		+	+	+		+	+			
				40	+	+				+						
				60	+	+				+						
				80		+										
				100												
				120												
				140												
Sodium perchlorate	$NaClO_4$		saturated	20	+	+		+	+			+	+			
				40	+	+										
				60	+	+										
				80		+										
				100												
				120												
				140												
Sodium persulphate (SpRB)	$Na_2S_2O_8$		cold saturated, aqueous	20	+			+	+	+		+	+	-	+	+
				40	+			+	+	+		+	+		+	+
				60	O			+	+	+			+		+	+
				80									+		O	O
				100									+			
				120												
				140												
Sodium phosphate	Na_3PO_4		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	O	+		+	+	+		+	+	+	+	+
				80		+			+	O						
				100					+	-						
				120												
				140												
Sodium silicate	Na_2SiO_3		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+		+	+	O		+	+	+	+	+
				80					+	-						
				100												
				120												
				140												
Sodium Sulfide	Natriumsulfid															
Sodium sulphate	Na_2SO_4, $NaHSO_4$		cold saturated, aqueous	20	+	+	+	+	+	+		O	+	+	+	+
				40	+	+	+	+	+	+		O	+	+	+	+
				60	O	+	+	+	+	+		O	+	+	+	+
				80					+	+			+			
				100						+						
				120						+						
				140												
Sodium sulphide	Na_2S		cold saturated, aqueous	20	+	+	+	+	+	O		+	+	+	-	+
				40	+	+	+	+	+	O		+		+		+
				60	O	+	+	+	+	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 (SYGEF)	EPDM	FPM	NBR	CR	CSM
Sodium sulphite	Na_2SO_3		cold saturated, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+		+	+	+	+	+	O	+	+
				60	O	+		+	+	+	+	+	-	O	+
				80		+			+	+					
				100						+					
				120											
				140											
Sodium thiosulphate	$Na_2S_2O_3$		cold saturated, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40									O	+	+
				60									-	O	O
				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_2Cs2O_7			20	O	+		+	+		+	+			
				40		+		+			+	+			
				60		+						+			
				80		+									
				100											
				120											
				140											
Sodiumhydrogencarbonate	$NaHCO_3$			20	+	+	+	+	+	+	+	+			
				40	+	+		+	+	+	+				
				60	+	+		+	+	+	+				
				80		+			+						
				100											
				120											
				140											
Sodiumhydrogensulfate	$NaHSO_4$			20	+	+	+	+	+	+	+	+			
				40	+	+		+	+	+	+	+			
				60	+	+		+	+	+	+	+			
				80		+			+	+					
				100						+					
				120											
				140											
Spindle oil				20	O	O	-	O	+	+	-	+	+	O	-
				40					O	+		O	+	-	O
				60				O	-	+		-	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Spinning bath acids containing carbon disulphide (SpRB)			100 mg CS_2/l	20	+			+	+	+			+	-	-	○
				40	+					+						
				60												
				80												
				100												
				120												
				140												
Spinning bath acids containing carbon disulphide (SpRB)			200 mg CS_2/l	20	○			+	+	+		-	+	-	-	-
				40						+						
				60												
				80												
				100												
				120												
				140												
Spinning bath acids containing carbon disulphide (SpRB)			700 mg CS_2/l	20	-			+	+	+		-	+	-	-	-
				40						+						
				60												
				80												
				100												
				120												
				140												
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	$(C_6H_{10}O_5)n$		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80		+				+						
				100						+						
				120												
				140												
Starch syrup			usual commercial	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80		+			+	+		+	+	+	+	+
				100						+		+	+	+	+	+
				120												
				140												
Stearic acid (SpRB)	$C_{17}H_{35}COOH$	Fp. 69	technically pure	20	+	○	+	+	+	+		+	+	+	+	○
				40	+		+			+		+	+	+	+	○
				60	+			○	○	+		○	○	○	○	-
				80						+						
				100						+						
				120						+						
				140												
Styrol				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 (SYGEF)		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	○	+		+	+	+		+	+	+	+	+
				80					+	+		+	+			+
				100					+	+						
				120						+						
				140												
Sulfur	S	Fp.*, 119	technically pure	20	○	○	-	+	+	+		+	+	-	+	+
				40	-			+	+	+			+			+
				60				+	+	+			+			+
				80					+	+			+			+
				100						+						
				120						+						
				140												
Sulfur dioxide	SO$_2$	-10	technically pure, anhydrous	20	+	+	-	+	+	○		+	+	-	-	○
				40	+	+		+	+	○		○	○			-
				60	+	+		+	+	-		-				
				80												
				100												
				120												
				140												
Sulfur dioxide	SO$_2$		technically pure, moist	20	-	-	-	-	-	-		-	○	-	-	○
				40												
				60												
				80												
				100												
				120												
				140												
Sulfur dioxide	SO$_2$		all, moist	20	+	+	-	+	+	+		+	+	-	-	○
				40	+	+		+	+	○		○	○			-
				60	○			+	+	-		-	-			
				80												
				100												
				120												
				140												
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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Sulfuric acid [see note 2.3.1 on jointing]	H_2SO_4	120	up to 40%, aqueous	20	+	+	+	+	+	+		+	+	O	+	+
				40	+	+	O	+	+	+		+	+	-	O	+
				60	O	+		+	+	+		+	+			O
				80		+				+		O	O			O
				100						+		-	-			-
				120						+						
				140												
Sulfuric acid [see note 2.3.1 on jointing] [SpRB]	H_2SO_4	140	up to 60%, aqueous	20	+	+	-	+	+	+		+	+	-	-	+
				40	+	+		+	O	+		+	+			O
				60	+	+		+	-	+		O	+			O
				80		+				+		-	O			-
				100						+						
				120						+						
				140												
Sulfuric acid [see note 2.3.1 on jointing] [SpRB]	H_2SO_4	195	up to 80%, aqueous	20	+	+	-	+	+	+		O	+	-	-	+
				40	+	+		+	+	+		O	+			O
				60	+	+		O	O	+		-	O			-
				80		+				+			-			
				100						+						
				120						O						
				140												
Sulfuric acid [see note 2.3.1 on jointing] [SpRB]	H_2SO_4	250	90%, aqueous	20	+	+	-	O	O	+		-	+	-	-	-
				40	+	+				+			+			
				60		+				+						
				80						+						
				100						O						
				120						O						
				140												
Sulfuric acid [see note 2.3.1 on jointing] [SpRB]	H_2SO_4		96%, aqueous	20	+	+	-	-	-	+		-	+	-	-	-
				40	+	+				+			+			
				60	O	+				-						
				80												
				100												
				120												
				140												
Sulfuric acid [see note 2.3.1 on jointing] [SpRB]	H_2SO_4		97%	20	+	+	-	-	-	O		-	+	-	-	-
				40		+										
				60												
				80												
				100												
				120												
				140												
Sulfuric acid [see note 2.3.1 on jointing] [SpRB]	H_2SO_4	340	98%	20	+	+	-	-	-	-		-	O	-	-	-
				40	O	+										
				60		O										
				80												
				100												
				120												
				140												
Sulfurous acid	H_2SO_3		saturated, aqueous	20	+	+	O	+	+	+		+	+	-	-	O
				40	+	+	+	+	+	+		-	+			O
				60	O			+	+	+			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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Sulfuryl chloride	SO_2Cl_2	69	technically pure	20	-	-	-	-	-	O			+	-	O	+
				40												
				60												
				80												
				100												
				120												
				140												
Surfactants (SpRB)			up to 5%, aqueous	20	O	-	-	+	+	+		+	+	+	+	+
				40	O				O	O						
				60	O				O	O						
				80						O						
				100												
				120												
				140												
Surfactants (ESC)				20	O	O	O	O	O	O		O	O	O	O	
				40												
				60												
				80												
				100												
				120												
				140												
Tallow (SpRB)			technically pure	20	+	-	-	+	+	+		+	+	+	+	+
				40	+			+	+	+		+	+	+	+	+
				60	+			+	+	+		+	+	+	+	+
				80						+						
				100						+						
				120												
				140												
Tannic acid (SpRB)			all, aqueous	20	+	+	+	+	+				+	+	+	+
				40		+	+	+	+							
				60		+		+	+							
				80												
				100												
				120												
				140												
Tanning extracts form plants (SpRB)			usual commercial	20	+	+	+	+	+	+		+	+	+	+	+
				40		+	+									
				60												
				80												
				100												
				120												
				140												
Tartaric acid				20						+						
				40						+						
				60												
				80												
				100												
				120												
				140												
Tartaric acid	$HO_2C\text{-}CH(OH)\text{-}CH(OH)\text{-}CO_2H$		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+		+	+	+	+		+	+	+	+	+
				60	O			+	+	+		+	+	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Tartaric acid up to 10%				20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Tetrachlorethylene				20	-	-	-	-	-	+		-	+			
				40												
				60												
				80												
				100												
				120												
				140												
Tetrachloroethane	$Cl_2CH\text{-}CHCl_2$	146	technically pure	20	-	-	-	O	O	+		-	O	-	-	-
				40						+						
				60						O						
				80												
				100												
				120												
				140												
Tetrachloroethylene	see Perchloroethylene	121														
Tetraetylene lead (SpRB)	$(C_2H_5)_4Pb$		technically pure	20	+	+	-	+	+	+		O	+	+	O	+
				40						+						
				60						+						
				80						+						
				100						+						
				120						+						
				140												
Tetrahydrofurane	C_4H_8O	66	technically pure	20	-	-	-	O	O	-		O	-	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Tetrahydronaphthalene	Teralin	207	technically pure													
Thionyl chloride	$SOCl_2$	79	technically pure	20	-	-	-	-	-	-		O	+	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Tin-(II)-chloride	$SnCl_2$			20				+	+							
				40				+	+							
				60				+	+							
				80					+							
				100												
				120												
				140												
Toluene	$C_6H_5\text{-}CH_3$	111	technically pure	20	-	-	-	○	○	+		-	+	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Triacetin (Glycerintriacetat)	$C_9H_{14}O_6$			20	-	-	-	+	+	+		+				
				40						+						
				60												
				80												
				100												
				120												
				140												
Tributylphosphate	$(C_4H_9)_3PO_4$	289	technically pure	20	-	-	-	+	+	+		+	-	-	-	-
				40				+	+							
				60				+	+							
				80												
				100												
				120												
				140												
Trichloroacetic acid	$Cl_3C\text{-}COOH$	196	technically pure	20	○	-	-	+	+	○		○	-	-	-	-
				40				○	+							
				60				-	○							
				80												
				100												
				120												
				140												
Trichloroacetic acid	$Cl_3\text{-}C\text{-}COOH$		50%, aqueous	20	+	-	-	+	+	+		○	-	-	-	-
				40	○			+	+	+						
				60				+	○	○						
				80						-						
				100												
				120												
				140												
Trichloroethane	Methylchloroform	74	technically pure													
Trichloroethylene	$Cl_2C{=}CHCl$	87	technically pure	20	-	-	-	-	○	+		-	+	-	-	-
				40						+						
				60						+						
				80						○						
				100												
				120												
				140												
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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Tricresyl phosphate (SpRB)	$H_3C-C_6H_5-O)_3PO_4$		technically pure	20	-	-	-	+	+			+	-	O	-	-
				40				+						-		
				60				+	O							
				80												
				100												
				120												
				140												
Triethanolamine (SpRB)	$N(CH_2-CH_2-OH)_3$	Fp. *21	technically pure	20	O	-	-	+	+	+		O	-	O	-	-
				40						+						
				60												
				80												
				100												
				120												
				140												
Triethylamine (SpRB)	$N(CH_2-CH_3)3$	89	technically pure	20	-	-	-	+	+	O		-	-	-	-	-
				40						-						
				60												
				80												
				100												
				120												
				140												
Trifluoro acetic acid (SpRB)	$F_3C-COOH$		up to 50%	20	-	-	-	+	+	+		O	-	-	-	-
				40						O						
				60												
				80												
				100												
				120												
				140												
Trioctyl phosphate (SpRB)	$(C_8H_{17})_3 PO_4$		technically pure	20	-	-	-	+	+	O		+	-	O	-	-
				40				+	O							
				60												
				80												
				100												
				120												
				140												
Turpentine oil (SpRB)			technically pure	20	+	-	-	O	-	+		-	+	O	-	-
				40	O			O					+			
				60									+			
				80												
				100												
				120												
				140												
Urea (SpRB)	$H_2N-CO-NH_2$	Fp.*, 133	up to 30%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+		+	+	+		+	+	+	+	+
				80		O				+						
				100						O						
				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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Vaseline			technically pure	20	O	O	-	+	O	+		-	+	+	-	-
				40	-					+			+	+		
				60				-	-	+			+	+		
				80						+			+	+		
				100						+			+	+		
				120						+			+			
				140												
Vegetable oils				20	O	-	-	+	+	+		-	+	+	O	O
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Vegetable oils and fats (SpRB)				20	+	O	-	+	+	+		-	+	+	O	O
				40	O			O	+	+			+	+	O	O
				60					O	+			+	+	-	-
				80						+						
				100						+						
				120												
				140												
Vinegar	see wine vinegar															
Vinyl acetate	$CH_2{=}CHOOCCH_3$	73	technically pure	20	-	-	-	+	+	+		+	-	-	-	-
				40				+		-						
				60					O							
				80												
				100												
				120												
				140												
Vinyl chloride	$CH_2{=}CHCl$	-14	technically pure	20	-	-	-	-	-	+		-	+	-	-	
				40						+						
				60												
				80												
				100												
				120												
				140												
Viscose spinning solution				20	+	-	-	+	+	+			+	-	O	+
				40	+			+	+	+		+	+		O	+
				60	+			+	+	+		+	+		-	+
				80												
				100												
				120												
				140												
Waste gases containing - Alkaline				20	+	+		+	+	+		+	+	+	+	+
				40	+	+		+	+	O		+	+	+	+	+
				60	+	+		+	+	-		+	+	+	+	O
				80		+			+			+	O			-
				100									-			
				120												
				140												
Waste gases containing - Carbon oxides			all	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Waste gases containing - Hydrochloric acid			all	20	+	+		+	+	+		+	+	O	+	+
				40	+	+		+	+	+		+	+	-	+	+
				60	+	+		+	O	+		+	+		+	+
				80		+				+		O	+			+
				100						+			+			
				120						+						
				140												
Waste gases containing - Hydrogen fluoride (SpRB)			traces	20	+	+		+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	O	+	+
				60	+	+		+	+	+		O	+	-	O	+
				80		+				+			+			
				100						+						
				120												
				140												
Waste gases containing - Nitrous gases			traces	20	+	+		+	+	+		+	+	O	+	+
				40	+	+		+	+	+		+	+	-	+	+
				60	+	+		+	O	+		+	+		O	+
				80		+				+		O	+			O
				100						+			O			
				120												
				140												
Waste gases containing - Sulphur dioxide			traces	20	+	+		+	+	+		+	+	O	+	+
				40	+	+		+	+	+		+	+	-	+	+
				60	+	+		+	+	+		+	+		+	+
				80		+			+	+		+	+			+
				100						+			+			
				120						+						
				140												
Waste gases containing - Sulphur trioxide (SpRB)			traces	20	+	+		+	+	+		+	+	O	+	+
				40	+	+		+	+	+		+	+	-	+	+
				60	+	+		+	O	+		+	+		+	+
				80		+				+		O	+			
				100						+						
				120												
				140												
Waste gases containing - Sulphuric acid			all	20	+	+		+	+	+		+	+	O	+	+
				40	+	+		+	+	+		+	+	-	+	+
				60	+	+		+	+	+		+	+		+	+
				80		+			O	+		O	+			+
				100						+			+			
				120						+						
				140												
Water	H_2O	100		20	+	+	+	+	+	+			+	+	+	+
- distilled				40	+	+	+	+	+	+		+	+	+	+	+
- deionised				60	+	+	+	+	+	+		O	+	+	+	+
				80		+			+	+		-	+	+		+
				100					+	+			+	+		
				120						+			+			
				140												
Water, condensed				20	+	+	+	+	+	+			+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+		O	+	+	+	+
				80		+			+	+			+	O		+
				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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Water, drinking, chlorinated				20	+	+	+	+	+	+			+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		O	+	+	+	+
				80					+	+			+	O		+
				100					+	+			+			
				120						+						
				140												
Water, waste water without organic solvent and surfactants				20	+	+	+	+	+	+			+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60		+	+	+	+	+		O	+	+	+	+
				80		+			+	+			+	+		+
				100						+				O		
				120						+						
				140												
Wax alcohol (SpRB)	$C_{31}H_{63}OH$		technically pure	20	+	O	-	O	O	+		+	+	+	+	-
				40	+			-	-	+		+	+	+	+	
				60	+					+		+	+	+	+	
				80												
				100												
				120												
				140												
Wine vinegar (SpRB)			usual commercial	20	+	o	O	+	+	+		+	O	-	O	+
				40	+			+	+	+			-		-	O
				60	+			+	+	+						-
				80					+	+						
				100						+						
				120												
				140												
Wines, red and white			usual commercial	20	+	O	+	+	+	+		+	+	+	+	+
				40			+	+	+	+						
				60				+	+	+						
				80						+						
				100						+						
				120												
				140												
Xylene	$C_6H_4(CH_3)_2$	138? 144	technically pure	20	-	-	-	-	-	+		-	+	-	-	-
				40						+			O			
				60						O			-			
				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	+	+	+	+	+	+		+	+	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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
Zinccarbonate				20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+						
				120												
				140												
Zincchloride			saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+			+			
				100						+						
				120												
				140												
Zincnitrate	$Zn(NO_3)_2$		saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+			+			
				100						+						
				120												
				140												
Zincoxide			Suspension	20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Zincphosphate			saturated	20	+	+	O	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+			+			
				100						+						
				120												
				140												
Zincstearate			Suspension	20	-	-	-	+	+	+		+	O			
				40				+	+	+		+				
				60				+	+	+		+				
				80					+	+						
				100						+						
				120												
				140												
Zincsulfate	$ZnSO_4$			20	+	+		+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
1-Chloropentan	$C_5H_{11}Cl$			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 (SYGEF)		EPDM	FPM	NBR	CR	CSM
1,1,2-Trifluoro, 1,2,2-Trichloroethane (Freon 113) (SpRB)	$FCl_2C\text{-}CClF_2$	47	technically pure	20	+		-			+			+	+	+	+
				40	+											
				60												
				80												
				100												
				120												
				140												

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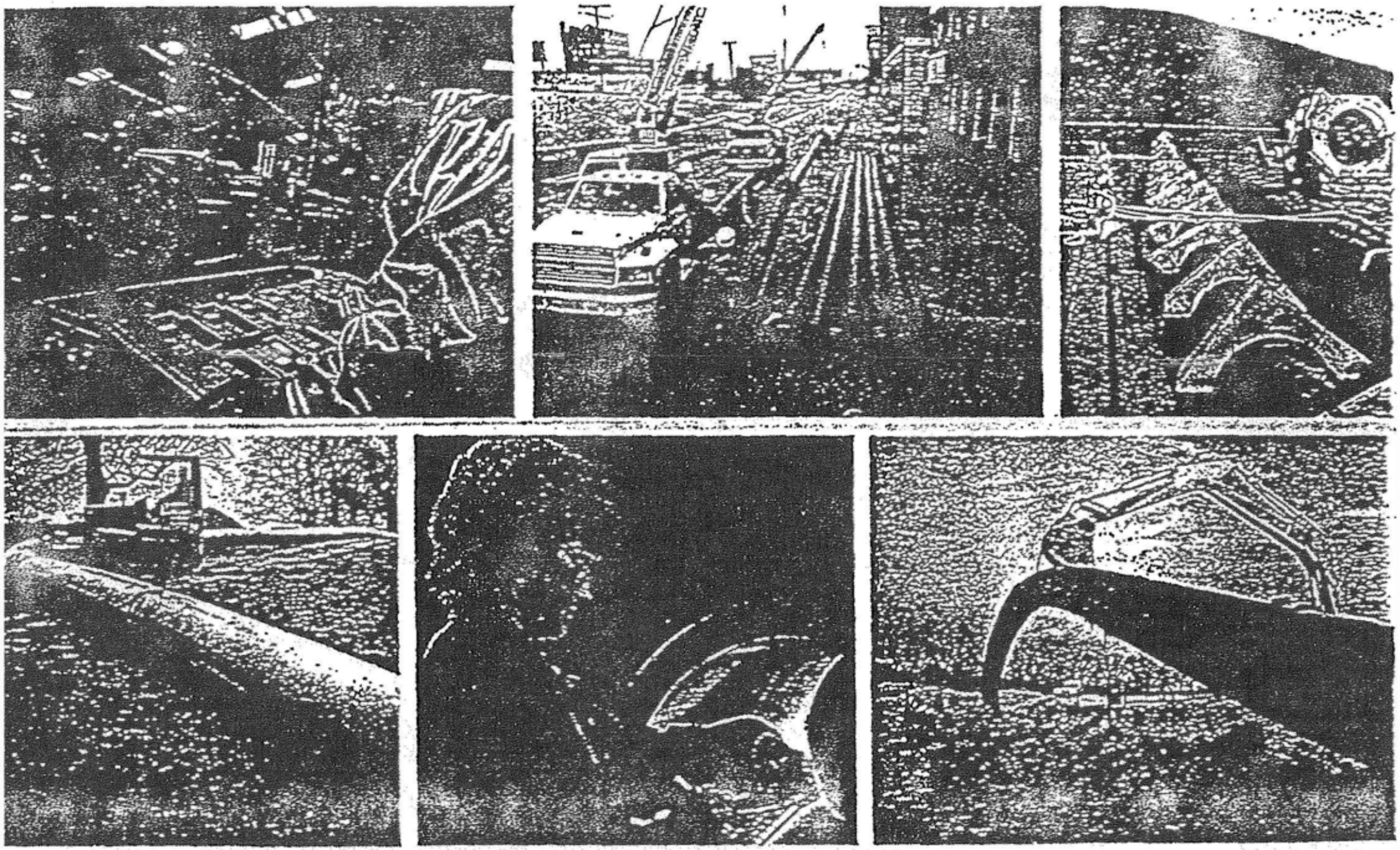
DRISCOPIPE

Engineering Characteristics



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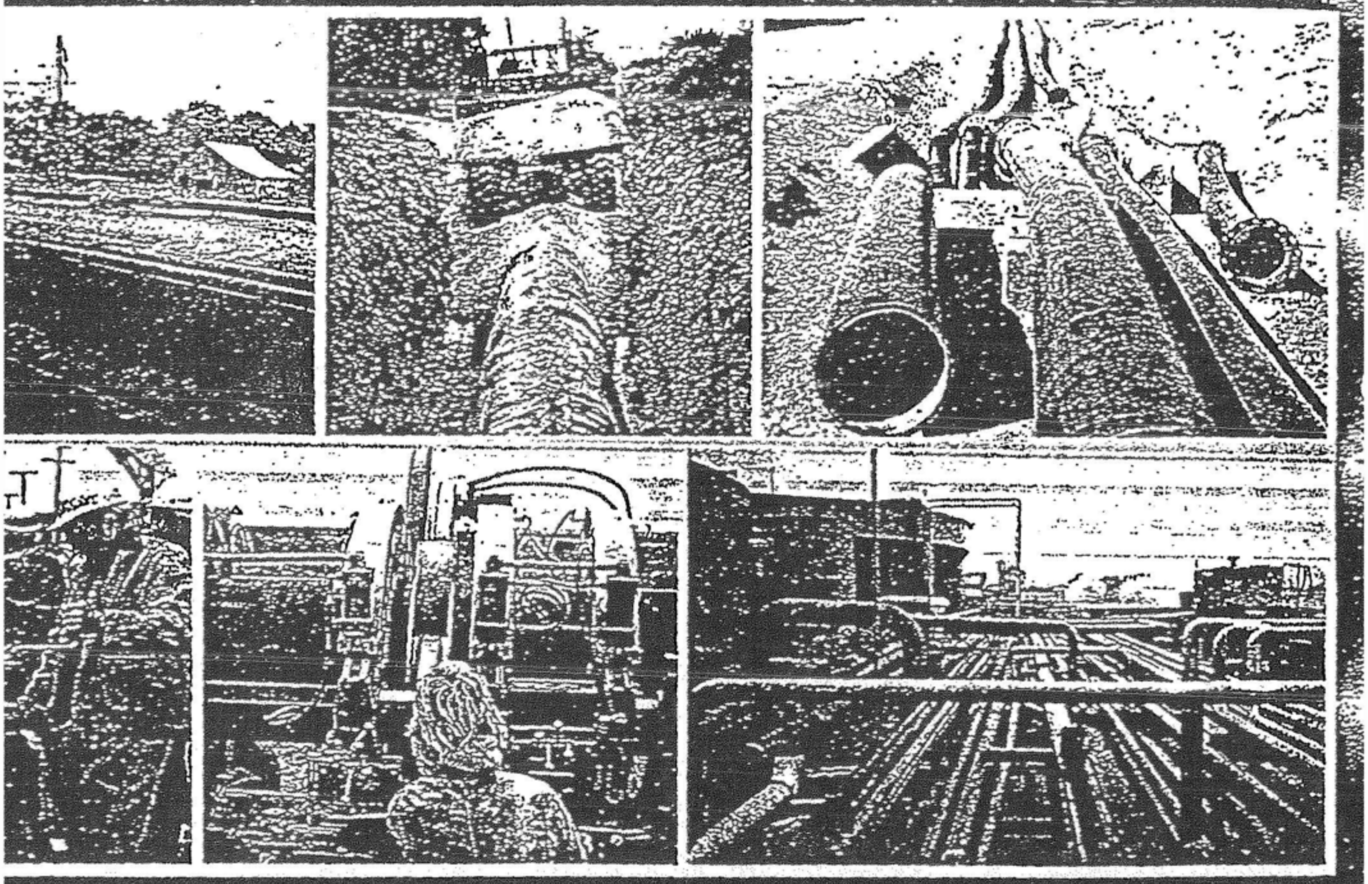
Contents

Photographs shown are typical Driscopipe 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.

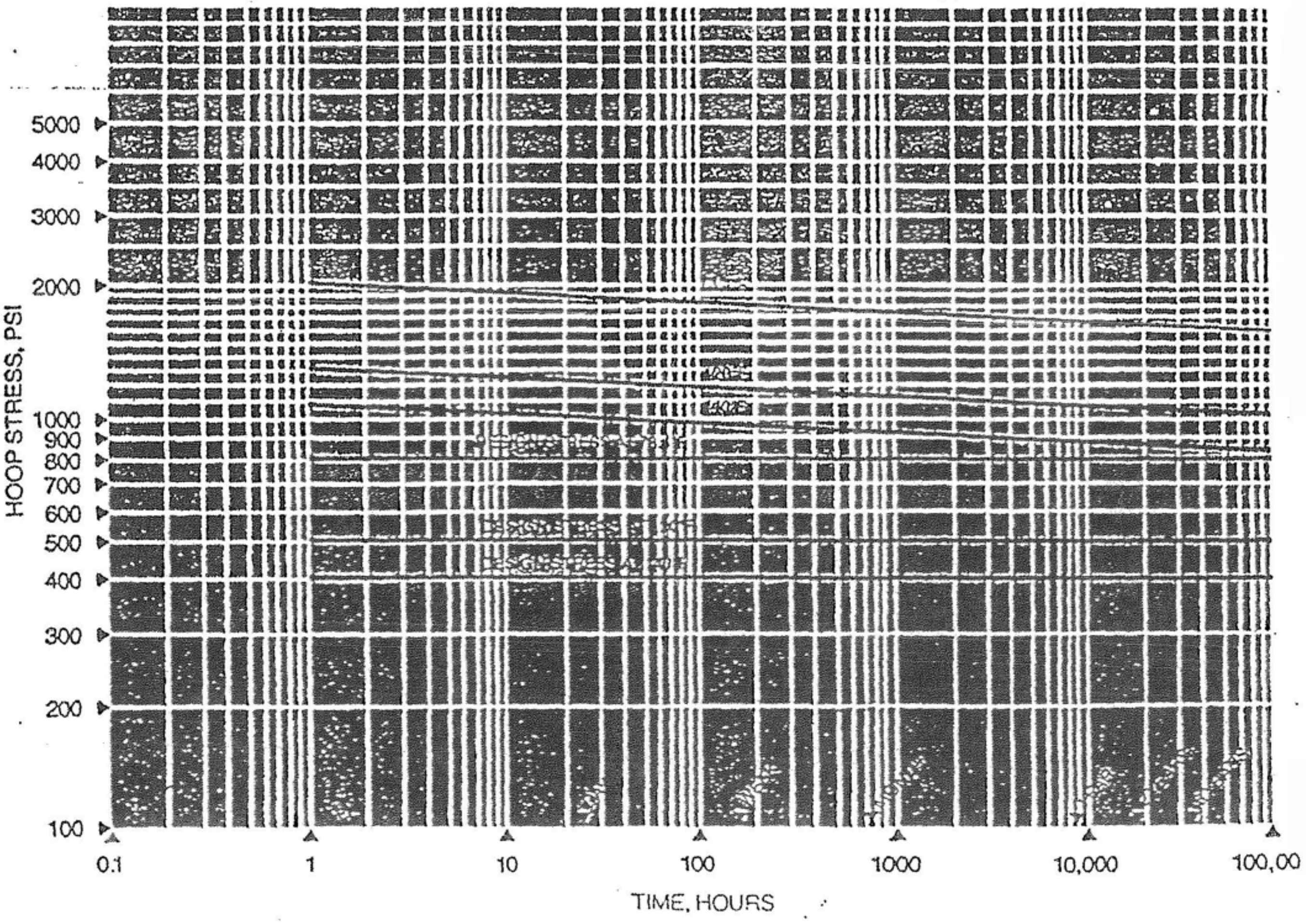
Long term hoop stresses for design purposes are normally selected at a level which is much lower than the long term strength of the materials. This ensures that the pipe is operating in a hoop stress range where creep (relaxation) of the materials is nil and assures service life in excess of 50 years. 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 st 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 cedures among laboratories ... variation among s 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

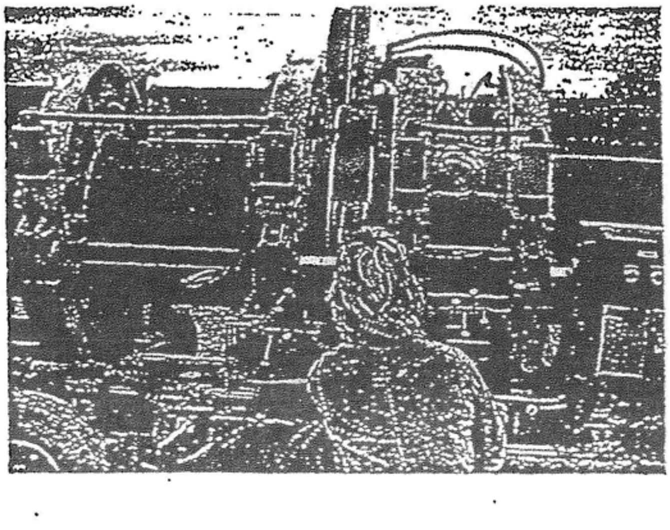
t = Minimum Wall Thickness, Inches

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, boundry drag, relative roughness, sand grain roughness and friction loss at various velocities.

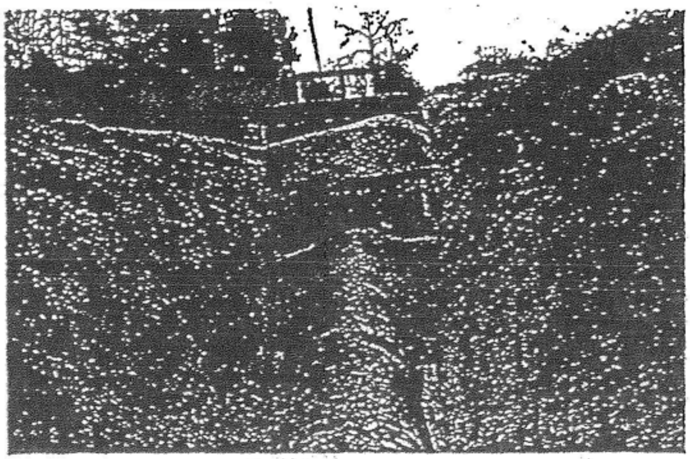
Lightweight – Flexible

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°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.

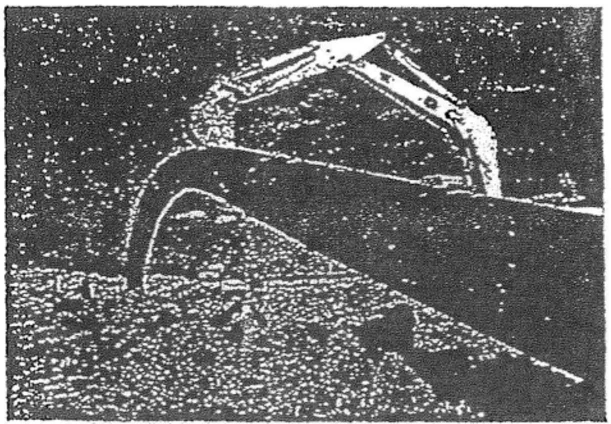
Even though "toughness" has become generally recognized by the industry as a highly desirable characteristic ... there is no standard test which can be used to directly compare the "toughness" among polyethylenes ... as well as among the different plastic materials which are considered suitable for piping.

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

he most recent ASTM specification written to identify olyethylene 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 ASTM D 1693	Test Duration Hours	Percent of Failures Allowed	Test Temp. °C
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.

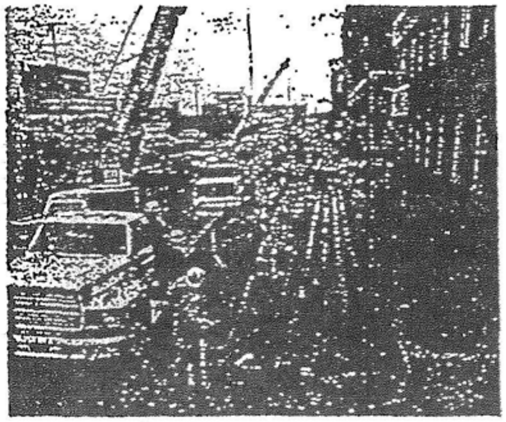
This method of testing for ESCR was first written in 1959 and was developed primarily to evaluate polyethylene as a jacketing material for power and communications cable. Although the method requires he use of laboratory compression molded specimens rather than pipe, it became the generally accepted 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.

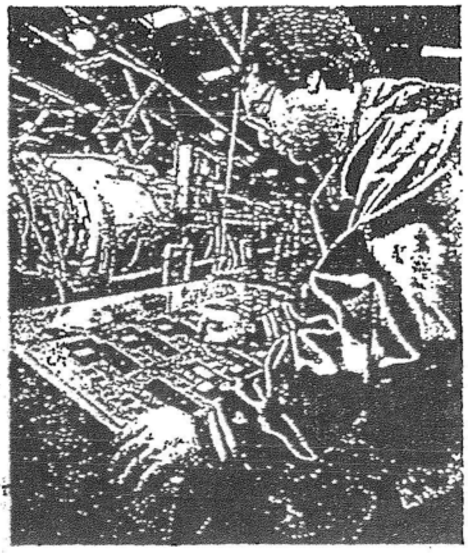
Information relative to the resistance of Driscopipe to a wide range of chemicals is shown in the following tables. This information is based on results of immersion tests (usually 3 months) at various temperatures. Changes in tensile strength and elongation are evaluated at a rapid strain rate to emphasize 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 DRISCOPIPE

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 (21°C)	140°F (60°C)
Acetic Acid 1-10%	S	S
Acetic Acid 10-60%	S	M
Acetic Acid 80-100%	S	M
Acetone	M	U
Acrylic Emulsions	S	S
Aluminum Chloride-Dilute	S	S
Aluminum Chloride Conc.	S	S
Aluminum Fluoride Conc.	S	S
Aluminum Sulfate Conc.	S	S
ums (All Types) Conc.	S	S
Ammonia 100% Dry Gas	S	S
Ammonium Carbonate	S	S
Ammonium Chloride Sat'd	S	S
Ammonium Fluoride 20%	S	S
Ammonium Hydroxide 0.88 S.G.	S	S
Ammonium Metaphosphate Sat'd	S	S
Ammonium Nitrate Sat'd	S	S
Ammonium Persulfate Sat'd	S	S
Ammonium Sulfate Sat'd	S	S
Ammonium Sulfide Sat'd	S	S
Ammonium Thiocyanate Sat'd	S	S
Amyl Acetate	M	U
Amyl Alcohol 100%	S	S
Amyl Chloride 100%	N	U
Aniline 100%	S	N
Antimony Chloride	S	S
Aqua Regia	U	U
Barium Carbonate Sat'd	S	S
Barium Chloride	S	S
Barium Hydroxide	S	S
Barium Sulfate Sat'd	S	S
Barium Sulfide Sat'd	S	S
Beer	S	S
Benzene	M	U
Benzene Sulfonic Acid	S	S
Bismuth Carbonate Sat'd	S	S
Bleach Lye 10%	S	S
Black Liquor	S	S
Borax Cold Sat'd	S	S
Boric Acid Dilute	S	S

Reagent	70°F (21°C)	140°F (60°C)
Boric Acid Conc.	S	S
Bromic Acid 10%	S	S
Bromine Liquid 100%	M	U
Butanediol 10%	S	S
Butanediol 60%	S	S
Butanediol 100%	S	S
Butyl Alcohol 100%	S	S
Calcium Bisulfide	S	S
Calcium Carbonate Sat'd	S	S
Calcium Chlorate Sat'd	S	S
Calcium Chloride Sat'd	S	S
Calcium Hydroxide	S	S
Calcium Hypochlorite BL'GH Sol.	S	S
Calcium Nitrate 50%	S	S
Calcium Sulfate	S	S
Camphor Oil	N	U
Carbon Dioxide 100% Dry	S	S
Carbon Dioxide 100% Wet	S	S
Carbon Dioxide Cold Sat'd	S	S
Carbon Disulfide	N	U
Carbon Monoxide	S	S
Carbon Tetrachloride	M	U
Carbonic Acid	S	S
Castor Oil Conc.	S	S
Chlorine Dry Gas 100%	S	M
Chlorine Moist Gas	M	U
Chlorine Liquid	M	U
Chlorobenzene	M	U
Chloroform	M	U
Chlorosulfonic Acid 100%	M	U
Chrome Alum Sat'd	S	S
Chromic Acid 20%	S	S
Chromic Acid Up to 50%	S	S
Chromic Acid and Sulfuric Acid	S	M
Cider	S	S
Citric Acid Sat'd	S	S
Coconut Oil Alcohols	S	S
Cola Concentrates	S	S
Copper Chloride Sat'd	S	S
Copper Cyanide Sat'd	S	S
Copper Fluoride 2%	S	S
Copper Nitrate Sat'd	S	S
Copper Sulfate Dilute	S	S
Copper Sulfate Sat'd	S	S
Cottonseed Oil	S	S
Crude Oil*	S	M
Cuprous Chloride Sat'd	S	S
Cyclohexanol	S	S
Cyclohexanone	M	U
Detergents Synthetic	S	S
Developers, Photographic	S	S
Dextrin Sat'd	S	S
Dextrose Sat'd	S	S
Dibutylphthalate	S	M
Disodium Phosphate	S	S

Reagent	70°F (21°C)	140°F (60°C)
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 Sat'd	S	S
Ferric Nitrate Sat'd	S	S
Ferrous Chloride Sat'd	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 Sat'd	S	S
Fruit Pulp	S	S
Fuel Oil	S	U
Furfural 100%	M	U
Furfuryl Alcohol	M	U
Gallic Acid Sat'd	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 Sat'd Aq.	S	S
Hexanol, Tert.	S	S
Hydrobromic Acid 50%	S	S
Hydrocyanic Acid Sat'd	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

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*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 on page 10

continued from page 9

CHEMICAL RESISTANCE OF DRISCOPIPE

Reagent	70°F (21°C)	140°F (60°C)
Hydrogen Peroxide 30%	S	S
Hydrogen Peroxide 90%	S	M
Hydrogen Phosphide 100%	S	S
Hydroquinone	S	S
Hydrogen Sulfide	S	S
Hypochlorus Acid Conc.	S	S
Inks	S	S
Iodine (Alc. Sol.) Conc.	S	U
Lactic Acid 10%	S	S
Lactic Acid 90%	S	S
Latex	S	S
Lead Acetate Sat'd	S	S
Lube Oil*	S	M
Magnesium Carbonate Sat'd	S	S
Magnesium Chloride Sat'd	S	S
Magnesium Hydroxide Sat'd	S	S
Magnesium Nitrate Sat'd	S	S
Magnesium Sulfate Sat'd	S	S
Mercuric Chloride Sat'd	S	S
Mercuric Cyanide Sat'd	S	S
Mercurous Nitrate Sat'd	S	S
Mercury	S	S
Methyl Alcohol 100%	S	S
Methyl Bromide	M	U
Methyl Chloride	M	U
Methyl Ethyl Ketone 100%	M	U
Methylsulfuric Acid	S	S
Methylene Chloride 100%	M	U
Milk	S	S
Mineral Oils	S	U
Molasses Comm.	S	S
Nickel Chloride Sat'd	S	S
Nickel Nitrate Conc.	S	S
Nickel Sulfate Sat'd	S	S
Nicotine Dilute	S	S
Nicotinic Acid	S	S
Nitric Acid 0-30%	S	S
Nitric Acid 30-50%	S	M
Nitric Acid 70%	S	M
Nitric Acid 95-98%	U	U
Nitrobenzene 100%	U	U
Octyl Cresol	S	U
Oils and Fats*	S	M
Oleic Acid Conc.	S	U
Oleum Conc.	U	U
Orange Extract	S	S
Oxalic Acid Dilute	S	S
Oxalic Acid Sat'd	S	S
Ozone 100%	S	U
Perchloric Acid 10%	S	S
Petroleum Ether	U	U
Phenol 90%	U	U
Phosphoric Acid Up to 30%	S	S
Phosphoric Acid Over 30%	S	S
Phosphoric Acid 90%	S	S
Phosphorous (Yellow) 100%	S	N
Phosphorus Pentoxide 100%	S	N
Photographic Solutions	S	S
Pickling Baths		
Sulfuric Acid	S	S
Hydrochloric Acid	S	S
Sulfuric-Nitric	S	U
Plating Solutions		
Brass	S	S
Cadmium	S	S
Chromium	N	N
Copper	S	S
Gold	S	S
Indium	S	S
Lead	S	S
Nickel	S	S
Rhodium	S	S
Silver	S	S
Tin	S	S
Zinc	S	S
Potassium Bicarbonate Sat'd	S	S
Potassium Borate 1%	S	S
Potassium Bromate 10%	S	S
Potassium Bromide Sat'd	S	S
Potassium Carbonate	S	S
Potassium Chlorate Sat'd	S	S
Potassium Chloride Sat'd	S	S
Potassium Chromate 40%	S	S
Potassium Cyanide Sat'd	S	S
Potassium Dichromate 40%	S	S
Potassium Ferri/ Ferro Cyanide Sat'd	S	S
Potassium Fluoride	S	S
Potassium Hydroxide 20%	S	S
Potassium Hydroxide Conc.	S	S
Potassium Nitrate Sat'd	S	S
Potassium Perborate Sat'd	S	S
Potassium Perchlorate 10%	S	S
Potassium Sulfate Conc.	S	S
Potassium Sulfide Conc.	S	S
Potassium Sulfite Conc.	S	S
Potassium Persulfate Sat'd	S	S
Propargyl Alcohol	S	S
Propyl Alcohol	S	S
Propylene Dichloride 100%	U	U
Propylene Glycol	S	S
Rayon Coagulating Bath	S	S
Sea Water	S	S
Selenic Acid	S	S
Shortening	S	S
Silicic Acid	S	S
Silver Nitrate Sol.	S	S
Soap Solution Any Conc'n	S	S
Sodium Acetate Sat'd	S	S
Sodium Benzoate 35%	S	S
Sodium Bicarbonate Sat'd	S	S
Sodium Bisulfate Sat'd	S	S
Sodium Bisulfite Sat'd	S	S
Sodium Borate	S	S
Sodium Bromide Dilute Sol.	S	S
Sodium Carbonate Con.	S	S
Sodium Carbonate	S	S
Sodium Chlorate Sat'd.	S	S
Sodium Chloride Sat'd	S	S
Sodium Cyanide	S	S
Sodium Dichromate Sat'd	S	S
Sodium Ferricyanide	S	S
Sodium Ferrocyanide Sat'd	S	S
Sodium Fluoride Sat'd	S	S
Sodium Hydroxide Conc.	S	S
Sodium Hypochlorite	S	S
Sodium Nitrate	S	S
Sodium Sulfate	S	S
Sodium Sulfide 25%	S	S
Sodium Sulfide Sat'd Sol.	S	S
Sodium Sulfite Sat'd	S	S
Stannous Chloride Sat'd	S	S
Stannic Chloride Sat'd	S	S
Starch Solution Sat'd	S	S
Stearic Acid 100%	S	S
Sulfuric Acid 0-50%	S	S
Sulfuric Acid 70%	S	M
Sulfuric Acid 80%	S	U
Sulfuric Acid 96%	M	U
Sulfuric Acid 98%	M	U
Sulfuric Acid, Fuming	U	U
Sulfurous Acid	S	S
Tallow*	S	M
Tannic Acid 10%	S	S
Tanning Extracts Comm.	S	S
Tartaric Acid Sat'd	N	N
Tetrahydrofurane	N	U
Titanium Tetrachloride Sat'd	N	U
Toluene	M	U
Transformer Oil	S	M
Trisodium Phosphate Sat'd	S	S
Trichloroethylene	U	U
Urea Up to 30%	S	S
Urine	S	S
Vinegar Comm.	S	S
Vanilla Extract	S	S
Wetting Agents	S	S
Whiskey	S	N
Wines	S	S
Xylene	M	U
Yeast	S	S
Zinc Chloride Sat'd	S	S
Zinc Sulfate Sat'd	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

nce 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°F. The recommended operating temperature is limited only on the higher temperature side to a range of 140-180°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 400-500°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.

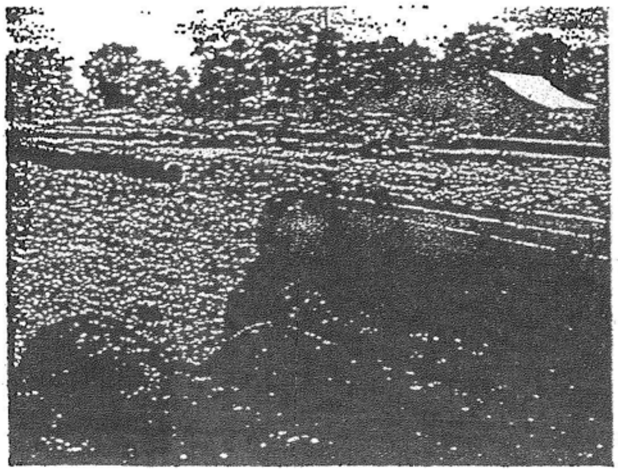
Knowledge of the long term strength of Driscopipe at the various temperatures allows selective design of a system. Accurate interpolations can be made for other temperatures between those which are known when data at three or more temperature levels is available.

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, °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.

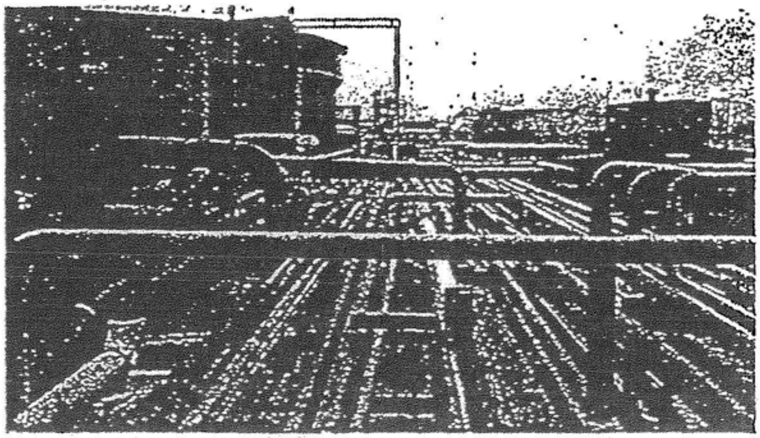
Temperature °F	Modulus of Elasticity, psi
−20°	300,000
0°	260,000
32°	200,000
75°	130,000
100°	105,000
140°	60,000

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.



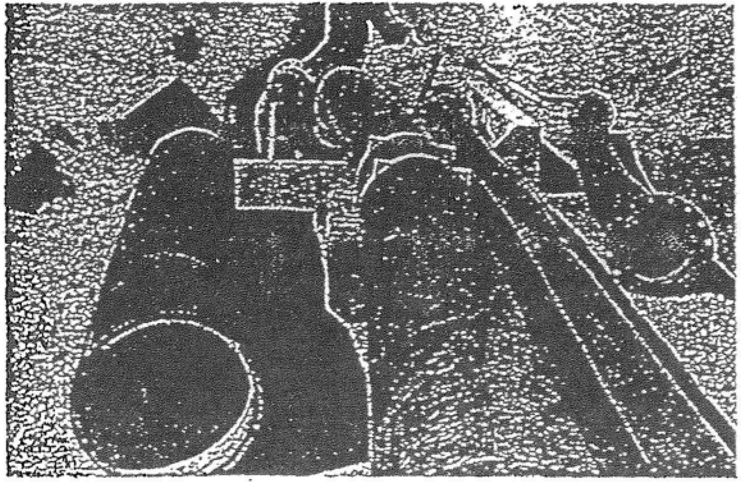
Tests have been conducted wherein the temperature re than 100 feet of unrestrained pipe was anged 130°F in a period of a few minutes. The total force created by contraction was measured and proved to be about (½) one-half the theoretical calculated value. Thermoplastic materials are unique in their ability 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 perature 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, isoproponol 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.

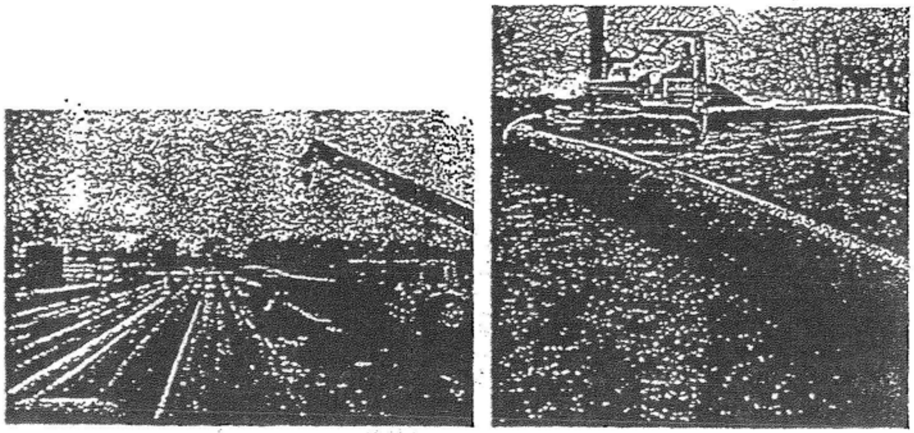
Driscopipe is also protected against degradation caused by ultraviolet rays when exposed to direct sunlight. The material contains 2½% of finely divided carbon black which also accounts for the black color of Driscopipe. Carbon black is the most effective single additive capable of enhancing the weathering 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.

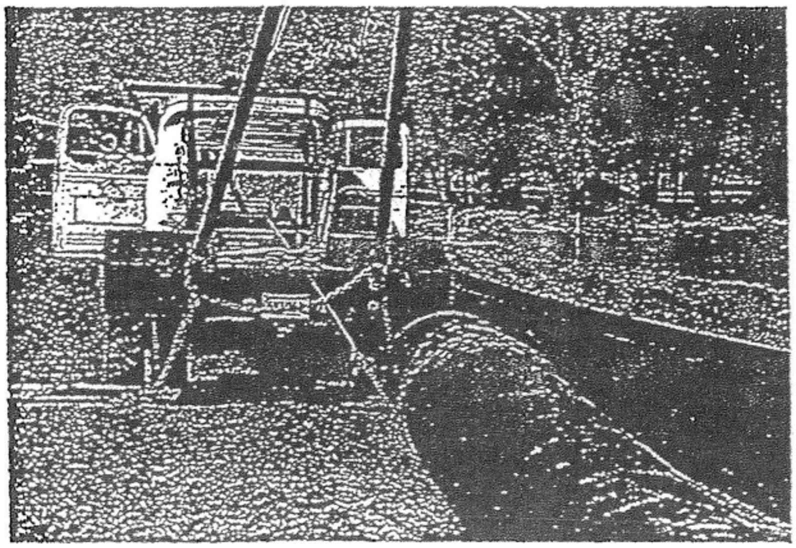
These permeation rates are considered very low. They result in negligible loss of product and create no hazard. For example, polyethylene piping systems are the predominant material used to construct new gas distribution systems and to renew old deteriorated systems. The permeation rate will vary in 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 ¼ of one cubic foot. At 120 psi, it would be ½ 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.

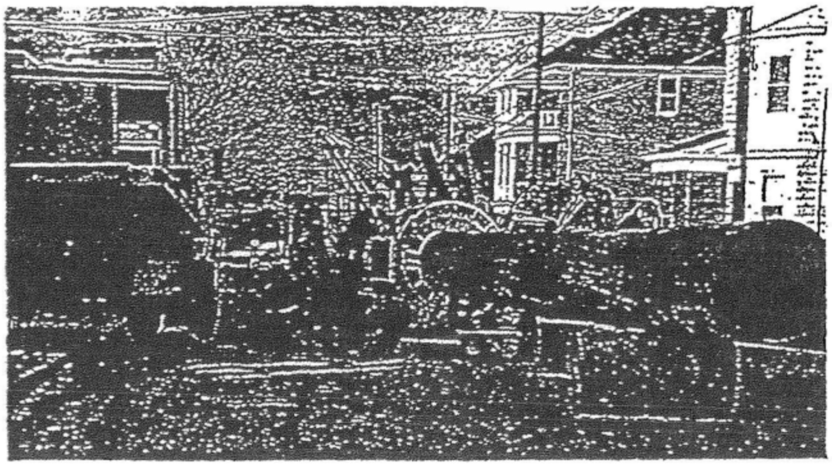
The heat fusion joining system has been so successful that it is the "standard" joining system for polyethylene. There are many reasons ... here are some.

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.

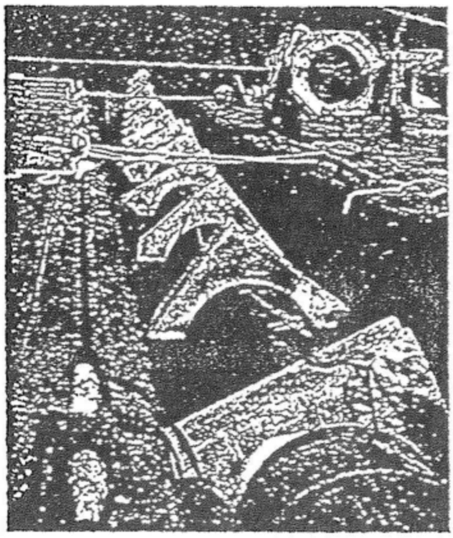


One heat fusion operator, with equipment, typically [illegible] the whole operation himself, sometimes using a second person as a helper. Pipe tolerances, ovality and curvature are no problem and "melt" is easily controlled by the visual procedure.

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 [illegible] 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.

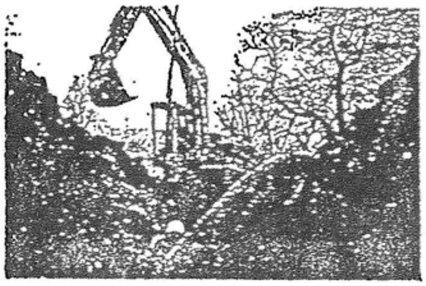
Fatigue Resistance

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 avialable 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 derating 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!



DRISCOPIPE

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A Subsidiary of Phillips 66 Company

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P.O. Box 83-3866
2929 North Central Expressway
Suite 100
Richardson, Texas 75083

Phone:
U.S. Domestic Toll Free (800) 527-0662

TWX:	**Fax:**
910-867-4818	214-783-2689

PLASTICS WITH POWER TO WIN.® PHILLIPS 66 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 flouride, 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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Medium	73°F	140°F
Beeswax	X	**/ to —
Benzene	/	/
Benezenesulphonic acid	X	X
Benzoic acid	*X	X
Benzyl alcohol	X	X to /
Borax, all concentrations	X	X
Boric acid	*X	X
Brine, saturated	X	X
Bromine	—	—
Bromine vapor	—	
Butanetriol	X	X
Butanol	X	X
Butoxyl	*X	/
Butyl acetate	X	/
Butyl glycol	X	X
Butyric acid	X	/
Calcium chloride	*X	X
Calcium hypochlorite	*X	X
Camphor	X	/
Carbon dioxide	X	X
Carbon disulphide	/	
Carbon tetrachloride	**/ to —	—
Caustic potash	X	X
Caustic soda	X	X
Chlorine, liquid	—	—
Chlorine bleaching solution (12% active chlorine)	/	—
Chlorine gas, dry	/	—
Chlorine gas, moist	/	—
Clorine water (disinfection of mains)	X	
Chloroacetic acid (mono)	X	X
Chlorobenzene	/	—
Chloroethanol	X	XD
Chloroform	**/ to —	—
Chlorosulphonic acid	—	—
Chromic acid (80%)	X	—D
Citric acid	X	X
Coconut oil	X	/
Copper salts	*X	X
Corn oil	X	/
Creosote	X	XD
Creosol	X	XD
Cyclohexane	X	X
Cyclohexanol	X	X
Cyclohexanone	X	X
Decahydronaphthalene	X	/
Desiccator grease	X	/
Detergents, synthetic	X	X
Dextrin, aqueous (18% saturated)	X	X
Dibutyl ether	X to /	—
Dibutyl phthalate	X	/
Dichloroacetic acid (100%)	X	/D
Dichloroacetic acid (50%)	X	X
Dicliloroacetic acid methyl ester	X	X
Dichlorbenzene	/	—
Diclolorethane	/	/
Dicloroethylene	—	—
Diesel oil	X	/
Diethyl ether	X to /	/
Diisobutyl ketone	X	/ to —
Dimethyl formamide (100%)	X	X to /
Dioxane	X	X
Emulsifiers	X	X
Esters, aliphatic	X	X to /
Ether	X to /	/
Ethyl acetate	/	—
Ethyl alcohol	X	X
Ethyl glycol	X	X
Ethyl hexanol	X	X
Ethylene chloride (dichlorothene)	/	/
Ethylene diamine	X	X
Fatty acids $(>C^6)$	X	/
Feric chloride*	X	X
Fluorine	—	—
Fluorocarbons	/	—
Fluorosilic acid, aqueous (up to 32%)	X	X
Formaldehyde (40%)	X	X
Formamide	X	X
Formic acid	X	
Fruit juices	X	X
Fruit pulp	X	X
Furfuryl alcohol	X	XD
Gelatine	X	X
Glucose	*X	X
Glycerol	X	X
Glycerol chlorohydrin	X	X
Glycol (conc.)	X	X

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Glycolic acid (50%)	X	X
Glycolic acid (70%)	X	X
Halothane	/	/
Hydrazine hydrate	X	X
Hydrobromic acid (50%)	X	X
Hydrochloric acid (all concentrations)	X	X
Hydrocyanic acid	X	X
Hydrofluoric acid (40%)	X	/
Hydrofluoric acid (70%)	X	/
Hydrogen	X	X
Hydrogen chloride gas, moist and dry	X	X
Hydrogen peroxide (30%)	X	X
Hydrogen peroxide (100%)	X	
Hydrogen sulfide	X	X
Iodine, tincture of, DAB 7 (German Pharmacopoeia)	X	/D
Isooctane	X	/
Isopropanol	X	X
Isopropyl ether	X to /	—
Jam	X	X
Keotones	X	X to /
Lactic acid	X	X
Lead acetate	*X	X
Linseed oil	X	X
Magnesium chloride	*X	X
Magnesium sulphate	*X	X
Maleic acid	X	X
Malic acid	X	X
Menthol	X	/
Mercuric chloride (sublimate)	X	X
Mercury	X	X
Methanol	X	X
Methyl butanol	X	X
Methyl ethyl ketone	X	/ to —
Methyl glycol	X	X
Methylene chloride	/	/
Mineral oils	X	X to /
Molasses	X	X
Monochloroacetic acid	X	X
Monochloroacetic ethyl ester	X	X
Monochloroacetic methyl ester	X	X
Morpholine	X	X
Naptha	X	/
Naphthalene	X	/
Nickel salts	*X	X
Nitric acid (25%)	X	X
Nitric acid (50%)	/	—
Nitrobenzene	X	/
o-Nitrotoluene	X	/
Octyl cresol	/	—
Oils, ethereal	/	/
Oils, vegetable & animal	X	X to /
Oleic acid (conc.)	X	/
Oxalic acid (50%)	X	X
Ozone	/	—
Ozone, aqueous solution (Drinking water purification)	X	
Paraffin oil	X	X
Perchloric acid (20%)	X	X
Perchloric acid (50%)	X	/
Perchloric acid (70%)	X	—D
Petrol	X	X to /
Petroleum	X	/
Petroleum ether	X	/
Petroleum jelly	**X to /	/
Phenol	X	XD
Phosphates	*X	X
Phosphoric acid (25%)	X	X
Phosphoric acid (50%)	X	X
Phosphoric acid (95%)	X	/D
Phosphorus oxychloride	X	/D
Phosphorus pentoxide	X	X
Phosphorus trichloride	X	/
Photographic developers, commecial	X	X
Phthalic acid (50%)	X	X
Polyglycols	X	X
Potassium bichromate (40%)	X	X
Potassium borate, aqueous (1%)	X	X
Potassium bromate, aqueous (up to 10%)	X	X
Potassium bromide	*X	X
Potassium chloride	*X	X
Potassium chromate, aqueous (40%)	X	
Potassium cyanide	*X	X
Potassium hydroxide (30% solution)	X	X
Potassium nitrate	*X	X
Potassium permanganate	X	XD
Propanol	X	X
Propionic acid (50%)	X	X
Propionic acid (100%)	X	/

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Medium	73°F	140°F
Propylene glycol	X	X
Pseudocumene	/	/
Pyridine	X	/
Seawater	X	X
Silicic acid	X	X
Silicone oil	X	X
Silver nitrate	X	X
Soduim benzoate	X	X
Sodium bisulphite, weak aqueous solutions	X	X
Sodium carbonate	*X	X
Sodium chloride	*X	X
Sodium chlorite (50%)	X	/
Sodium hydroxide (30% solution)	X	X
Sodium hypochlorite (12% active chlorine)	/	—
Sodium nitrate	*X	X
Sodium silicate	*X	X
Sodium sulfide	*X	X
Sodium thiosulphate	X	X
Spermaceti	X	/
Spindle oil	X to /	/
Starch	X	X
Steric acid	X	/
Succinc acid (50%)	X	X
Sugar syrup	X	X
Sulfates	*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 /	
Tetetrahydronapthalene	X	/
Thionyl chloride	—	—
Thiophene	/	/
Toluene	/	—
Transformer oil	X	/
Tributyl phosphate	X	X
Trichloroacetic acid (50%)	X	X
Trichloroacetic acid (100%)	X	/ to —
Trichloroethylene	**X to /	—
Triethanolamine	X	X
Turpentine, oil of	x to /	/
Tween 20 and 90 (Atlas Chemicals)	X	X
Urea	*X	X
Vinegar (commecial conc.)	X	X
Viscose spinning solutions	X	X
Waste gases containing		
carbon dioxide	X	X
carbon monoxide	X	X
hydrocloric acid (all conc.)	X	X
hydrogen fluoride (traces)	X	X
nitrous vitriol (traces)	X	X
sulfur dioxide (low conc.)	X	X
sulphuric acid, moist (all conc.)	X	X
Water gas	X	X
Xylene	—	—
Yeast, aqueous preparations	X	X
Zinc chloride	*X	X

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