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A STUDY OF CEMENT - PIPE BONDING

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ABSTRACT

The emphasis placed on bonding with the introduction of Acoustic Cement Bond Logs has led to a study of many of the variables influencing this property, as well as methods for improving bond at the casing-cement interface. Special cementing problems concerning gas storage wells and tubing-less completion wells have also indicated the need for better pipe-cement bonding. This presentation stresses some of the problems involved and possible solutions.

The application of a resin-sand coating at specific points on the casing will give a greater adhesion at cement-pipe interface. Resistance of the cement-pipe bond to fluid intrusion and loading is greatly increased. Laboratory and field results as well as acoustic logs emphasize the improvement in bonding when a roughness factor is introduced. Comparative bonding data both with and without mill varnish on the pipe are also evaluated.

INTRODUCTION

The two types of bonds to be considered in this presentation are shear and hydraulic bond between cement and pipe. Shear bond is defined as the bond that mechanically supports pipe in the hole, and is determined by measuring the force required to initiate pipe movement in a cement sheath. This force when divided by the cement-casing contact surface area yields the shear bond in psi. Hydraulic bond blocks migration of fluids in a cemented area and is determined by applying pressure at the pipe-cement interface until leakage occurs. The hydraulic pressure when leakage appears at either end of the specimen is defined as the bond failure pressure in psig. Gas bond tests were determined in the same manner as

hydraulic bond tests using compressed air or nitrogen as the pressuring medium. Figure 1 illustrates the sample configuration generally used for determining these bond strengths in the laboratory. Dimensionally the specimens can be of any size without significant effect.¹

Hydraulic bonding is of primary importance, particularly in isolating zones in a producing or injection well, as most cementing jobs provide adequate mechanical support (shear bond) to hold the pipe in place. This does not infer that shear bond should be overlooked in determining WOC time prior to subsequent drilling or completion work.^{2,3}

In determining the bonding ability of cement to pipe it is necessary to consider the effect of various casing conditions and completion techniques if optimum bond is to be obtained and maintained. Some of the primary considerations in planning a more successful cement job from the casing bonding standpoint are:

1. Pipe surface finish.
2. Drilling fluid.
3. Thermal and stimulation stresses.
4. Casing equipment.

PIPE SURFACE FINISH

Hydraulic and gas bond were directly affected by the pipe surface finish against which the cement was placed. Types of casing investigated were steel and plastic as used in field applications. Hydraulic bonds were determined on steel pipe with the following surface finishes: New Mill varnish, Mill scale (Chemical removal of varnish), Sandblasted, Used (Rusty) and Resin-sand coated. Two types of plastic pipe used were filament wound and centrifugally cast with both smooth and rough external surfaces. Table 1 shows the

hydraulic, gas, and shear bond strength measurements of cement to steel and plastic pipe with varying external surface finishes. As may be seen, the rougher the external pipe finish, (Figure 2) the higher the hydraulic bond using either liquids or gas.

These bond strengths indicate the importance of preparing pipe surfaces prior to placement of cement in the well. As an example, mill varnish exhibits the lowest bond strengths compared with other types of finishes, with time dependency after setting being noted in new mill varnish pipe below 140°F. Table 2 illustrates the reduction in bonding of cement to pipe that occurs at about two days with this type of surface finish.

Acoustic cement bond logs were run on a test well to verify results obtained in physical bond measurement, and correlation was obtained in that acoustic logs indicated a corresponding reduction in bond from two to five days after cementing. It is evident that this low physical bond strength period would be a critical time for running acoustic logs or completion practices on new mill varnish pipe, especially where the temperature is below 140°F. This phenomenon of time dependency has not been evidenced on other types of pipe surfaces or at higher temperatures. At higher temperatures, the rate of cement expansion overcomes the time dependency effect of mill varnishes. At lower temperatures a longer time is required for the cement to expand sufficiently to overcome those effects. A comparison between various pipe finishes according to an acoustic bond log is shown in Figure 3. This log was run three and seven days after cementing. Subsequent logs showed the new and used pipe sections to be completely acoustically bonded. The joint of used pipe at 560 feet, showing higher amplitude, had sections of mill varnish still intact.

As would be expected, plastic pipe with smooth exterior surfaces exhibits similar hydraulic bond values to mill varnish casing. This type of casing with its lower collapse pressure flexes more readily than steel pipe; thus lower bond failure pressure was experienced with rough surface plastic pipe than with the corresponding steel pipe.

Application of a resin-sand coating to the pipe exterior resulted in considerable improvement in bond. This type of surface finish as compared to sandblasted pipe, illustrated in Figure 2, increases the shear bond strength about 20 times and the hydraulic bond approximately 2 times (Table 1). Even more pronounced improvement was noted for resistance to gas flow at the bonded interface. The resin-sand coat provides a rougher surface finish to which the cement can adhere, therefore, failure occurs within the cement sheath (Figure 4) after jet perforating rather than at the bond interface. The hydraulic bond failure pressure using water on this type of pipe finish is about 5 to 1 compared to new mill varnish pipe. Gas failure pressure is approximately 40 to 1 comparing resin-sand coated pipe to new mill varnish pipe.

DRILLING FLUIDS

Variations in hydraulic bond strengths were observed whenever pipe surfaces were wet with fluids other than water. Drilling fluids used in these tests included water base, oil base and inverted oil emulsion muds. Pipe surfaces coated with mud cause reduction of the cement-pipe bond, with oil wet surfaces exhibiting the lowest bond on equivalent pipe finishes. Under these conditions rougher surfaces again provide higher bonds than smooth surfaces. The bond of cement to an oil wet surface is approximately $\frac{1}{2}$ that of a water-wet or dry surface (Table 3). This should be an important consideration in any well completion program. Therefore, the practice of running a chemical wash ahead of primary cementing jobs to remove the circulatable mud and return the casing to a water-wet surface condition is desirable.⁴ The use of friction reducing additives in a cement slurry results in better mud removal thus providing a more satisfactory bonding condition.⁵

THERMAL AND STIMULATION STRESSES

The direction in which pressure is applied and the length of time pressure is held on the bonded interface are other important factors in hydraulic bonding. Two major applications of pressure should be considered: (1) Completion and stimulation pressure where maximum pressure is inside the casing; (2) Production pressures where formation pressures are maximum and tubing pressures are minimum.

Bearden and Lane² have pointed out that closed-in pressure after completion of a primary cement job is very detrimental to a cement-pipe bond. Additional work has been done on both hydraulic and shear bonding which verifies previous data.¹ Figure 5 shows the diameter expansion of unsupported pipe with reference to internal pressure.

The heat of hydration of a setting cement can produce a similar effect to internal pressuring of the casing and cause expansion of the pipe. Ability to dissipate this heat depends upon the thermal conductivity and heat capacity of the displacing fluid. The build-up of heat inside the casing will normally begin when the cement takes its initial set, with maximum increase in temperature occurring at a later stage. After the cement has set, the temperature will slowly return to that of the formation, causing the casing to contract. This expansion and contraction of the pipe places an additional stress on the casing and cement which could result in a decrease in bond strength. Additional damage to the bond might occur should the casing be closed-in at the time the temperature is rising inside the casing.

Temperature variations will occur throughout a cement column in a well due to the various types of formations encountered. Bond strengths normally develop more readily across porous formations than through impermeable formations such as shales due to possible cement dehydration. Faster bond strength development will also occur across higher temperature formations than opposite cooler zones. The use of proper cement additives and different types of cement can

minimize this variation.^{6,7}

During stimulation through a perforation, high internal casing pressures may cause horizontal and vertical fracturing of the cement sheath. Vertical fracturing of the cement sheath normally occurs after hydraulic bond failure is initiated when the cement sheath is forced into tension by expansion of the pipe and pressure of the fluid between the pipe and cement.

Hydraulic bond failure extension is a time function dependent upon cement properties, pressure applied, and viscosity of the pressuring medium. The rate at which bond failure progresses has been measured in both laboratory and well tests. Laboratory investigation entailed measurements on ten foot lengths of hydraulic bond test specimens. Test well work consisted of cementing casing in a normal manner, with communication being established between two sets of perforations by use of a straddle packer. These investigations showed the bond failure rate with water varied between 1.125 feet per minute and 1.250 feet per minute. Laboratory tests indicate that even with stronger back-ups to simulate denser formations, the rate is approximately the same.

Normally, gas pressuring causes faster bond failure progression (linear rate) than water, oil or mud. For instance, gas pressuring tests indicate that bond failure progression is in excess of 20 feet per minute. Pressure requirements with gas, on similar type surfaces, are considerably lower than for water, being approximately 1/20 as great.

Inward pipe deflection has been calculated and then measured at 0.000015 inches at the time hydraulic bond failure occurred on used pipe. This will vary with the type of surface finish and pressuring medium. The above value was measured using water, while more viscous fluids should result in higher deflection, and gases would give lower readings.

Vertical bond failure will normally occur 30° either side of the pressure application point when a uniform cement sheath is in place around the pipe. Unequal distribution of cement may cause bond failure to occur at the weakest plane which could account for communication in multiple string tubingless completions.

CASING EQUIPMENT

Tests have been conducted on various types of casing attachments, such as collars, centralizers and wall cleaners, to evaluate their effect on hydraulic and shear bonding. Results indicate that casing intrusions into the cement column have little influence on hydraulic or gas bond failure pressure, but the rate of failure progression is apparently decreased. There is the possibility that in some instances casing attachments can be responsible for a change in direction of the hydraulic bond failure path. Attachments might direct bond failure from casing-cement interface to the formation-cement interface, which may fail at lower pressures as pointed out in previous work.¹ However, a large increase in shear bonding strength is obtained because of the necessity to shear a portion

of the cement itself rather than the pipe-cement interface.

SUMMARY

1. Hydraulic and shear bond increases with surface roughness.
2. Viscosity of the pressuring fluid will increase bond failure pressure as viscosity increases.
3. Oil wet pipe surfaces reduce hydraulic and shear bond strength of cement to pipe.
4. A change in casing internal pressure and temperature will cause a corresponding change in hydraulic and shear bond strength.
5. Mill varnish has a detrimental effect on cement bond strengths.
6. Hydraulic bond failure is a function primarily of pipe expansion or contraction.
7. Casing attachments increase shear bond strength but have no significant effect on hydraulic bond failure.

CONCLUSION

In planning primary cementing jobs more consideration should be given to:

1. Casing surface finishes.
2. Cementing placement techniques.
3. Timing of operations in the cemented casing.

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TABLE 1

BONDING PROPERTIES OF VARIOUS PIPE FINISHES

Cement — API Class A Cement
 Water — 5.2 Gallons Per Sack
 Curing Temperature — 80°F.
 Curing Time — 1 Day
 Casing Size — 2 Inch inside 4 Inch

TYPE OF FINISH	BOND STRENGTH		
	Shear PSI	Hydraulic PSIG	Gas PSIG
Steel			
New (Mill Varnish)	74	200-250	15
New (Varnish Chemically Removed)	104	300-400	70
New (Sandblasted)	123	500-700	150
Used (Rusty)	141	500-700	150
New (Sandblasted - Resin-Sand Coated)	2400	1100-1200	400+
Plastic			
Filament Wound (Smooth)	79	210	---
(Rough)	99	270	---
Centrifugally Cast (Smooth)	81	220	---
(Rough)	101	310	---

TABLE 2

BOND STRENGTH

Casing Condition — New Mill Varnish
 Cement — API Class A Cement
 Water — 5.2 Gallons Per Sack
 Curing Temperature — 80°F.

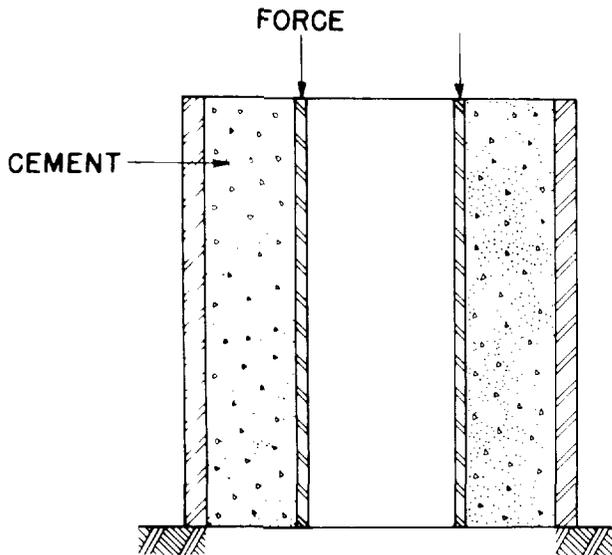
Time Days	Hydraulic (Water-PSIG)	Gas (Nitrogen-PSIG)	Shear PSI
1	200	15	74
2	170	10	63
3	210	30	72
4	250	40	74
5	270	55	76

TABLE 3

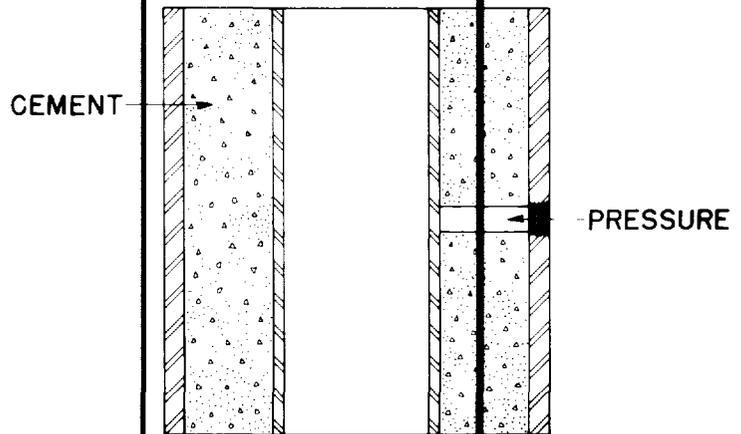
BONDING PROPERTIES ON SURFACE WETTING OF PIPE

Cement — API Class A Cement
 Water — 5.2 Gallons Per Sack
 Curing Temperature — 80°F.
 Curing Time — 1 Day
 Casing Size — 2 Inch inside 4 Inch
 Type Casing — Used

Type of Mud	Shear Bond PSI
None	141
Water Base	97
Inverted Oil Emulsion	66
Oil-Base	63



SHEAR BOND TEST



HYDRAULIC BOND TEST TO PIPE

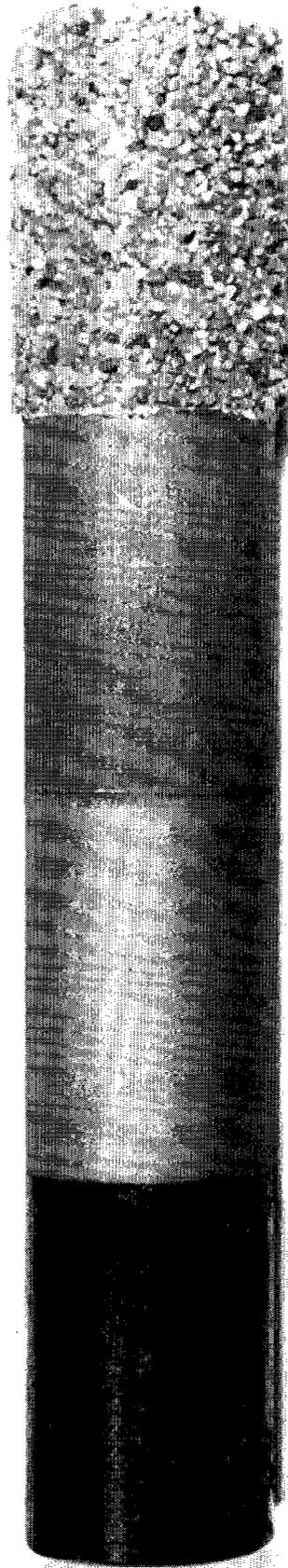
FIGURE 1

**RESIN-SAND
COATED**

RUSTY

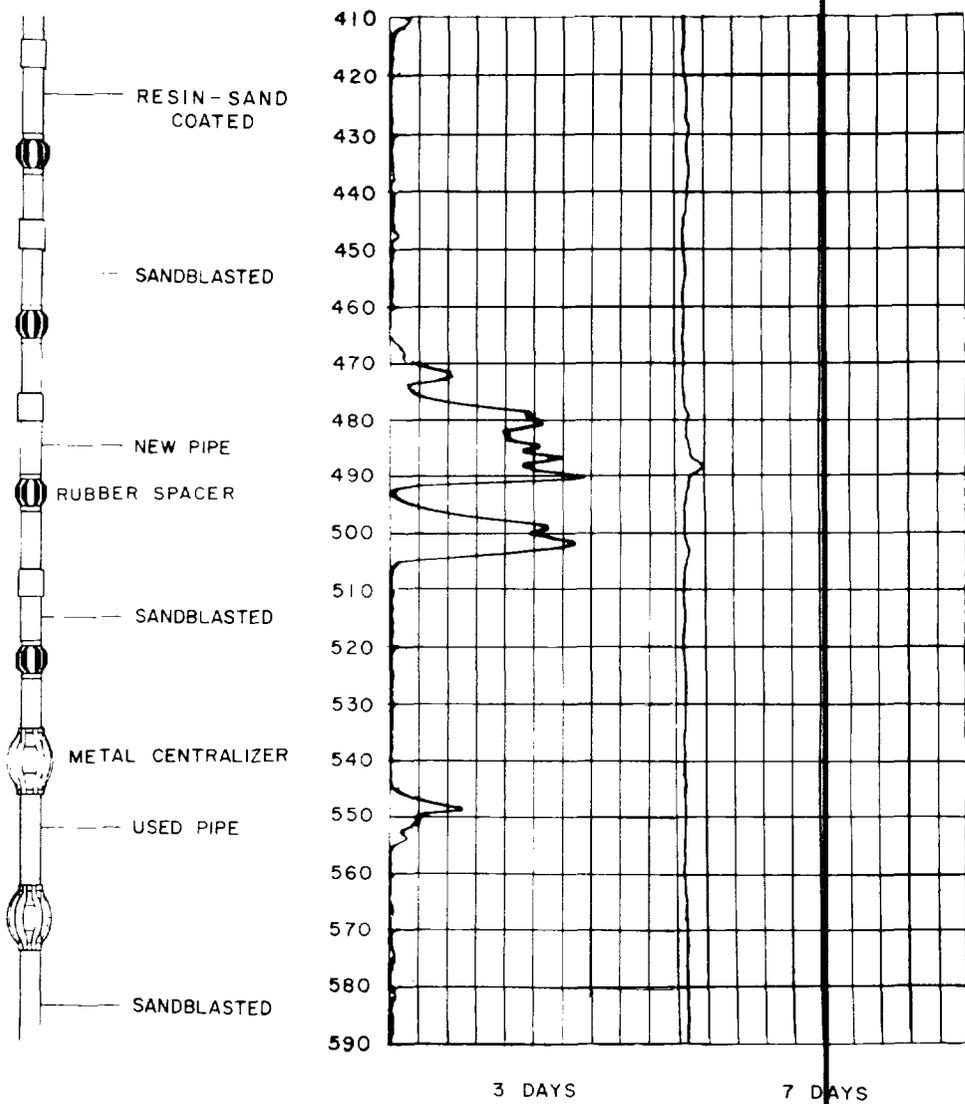
SAND BLASTED

MILL VARNISH



Shear Bond PSI	Hydraulic Bond PSIG	Gas Bond PSIG
2400	1100-1200	400+
141	500-700	150-250
123	500-700	150-250
79	200	10-20

FIGURE 2



ACOUSTIC BOND LOGS
FIGURE 3



FIGURE 4

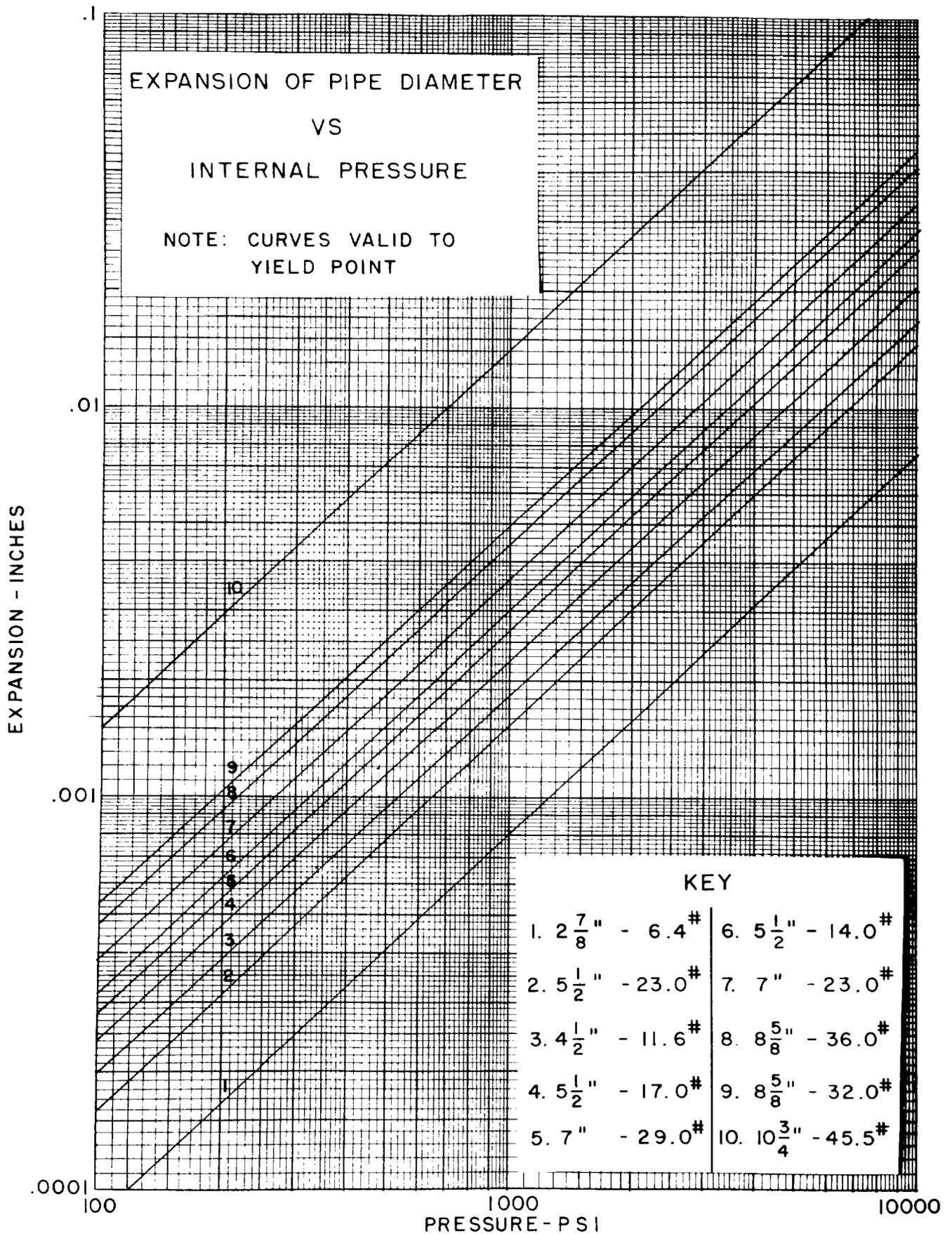


FIGURE 5

COMPLIMENTS
OF



HALLIBURTON COMPANY
DUNCAN, OKLAHOMA

BEFORE THE	
OIL CONSERVATION COMMISSION	
Santa Fe, New Mexico	
<i>Pan Am</i>	Exhibit No. <u>6</u>
Case No.	<u>3029</u>