Internal Cement Lining For Tubular Goods

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INTRODUCTION

Cement-lined steel or iron pipe is not a new approach to corrosion prevention. In 1836 the French Academy of Science reported the successful use of cement-lined pipe. They reported that, "Hydraulic cement, applied about 2.5 mm (0.1 inches) thick, is of all compositions, combining facility of application and cheapness, that which adheres the best to the casting, is the most indestructible, and prevents most effectually all oxidation (Corrosion) and consequent formation of tubercles". Of course, it is well documented that the great Roman aquaducts were constructed of hydraulic cement, forerunner of modern portland cement.

HISTORY

In 1843, 126 years ago, a United States patent was issued to Jonathan Ball covering a machine for cement-lining pipe. Probably the oldest installations of cement-lined pipe presently in use in the United States are in the New England area. These systems are principally small-diameter underground water service lines, and most of this pipe has been successfully protected from corrosive waters for more than sixty years. Much of this pipe has been removed during street widening and municipal improvement programs and has been found to be in excellent condition.

Following the Civil War, cement-lined pipe in large diameters found application in several eastern and southern cities. This pipe, known as Phipps Patent Pipe, was constructed of a riveted steel cylinder, approximately 1/16 in. thick, coated on the inside and outside with 0.5 inch to 0.75 inch cement. The external cement coating was protected by an outer steel armor which rusted away soon after installation. The outer steel coat was used to prevent damage during transportation and installation and served no useful purpose once the pipe was installed. Some of this pipe is known to have been in service in several southeastern cities since 1890 or earlier. The high cost of this pipe precluded its extensive use and the manufacturer ultimately failed.

The modern form of cement-lined pipe first appeared in commercial quantities during the early 1930's. Its acceptance resulted from its economy, durability and outstanding corrosion resistance. Actually, the demand for large quantities of relatively high-pressure pipe capable of transporting large volumes of extremely corrosive water evolved from the vast expansion of the oil industry in the United Scates and the development of water flooding and pressure maintenance programs together with increasing demands for conservation procedures in salt water disposal operations. During the past twenty years many millions of feet of cement-lined pipe and tubing have been used in the most aggressive natural waters known to the oil industry. The continued acceptance and ever increasing demand for down-hole applications attest to both the durability and corrosion-resistance of cement-lined steel tubular goods.

CHARACTERISTICS OF CEMENT LININGS

For many years the engineering profession has had access to much literature and data on cements and their applications; however, there is relatively little data available to the petroleum industry relative to the unique art of cement-lining steel pipe and the application of this product to corrosion prevention. Resultantly, cement linings have not always found the acceptance they deserve. It is well to summarize pertinent facts concerning cement-lined pipe:

1. The physical properties of cement mortars can be varied to meet diverse applications.
2. Cement mortars constitute effective corrosion inhibitors.
3. Cracks of minimum dimension do not destroy effective corrosion protection.
4. Fine cracks in cement linings will self-heal.

5. A good bond can exist between a steel cylinder and a cement lining.

Many admixtures are available in cement mortars which include synthetics. Today, high-temperature cements are available where needed. A very recent development for cement lining is an acid-resistant cement capable of withstanding repeated acid treatments within specified limitations.

Hydraulic cements have been used for many years to protect steel structures from corrosive attack in marine environments. The protective mechanism is well recognized and documented. In a cement-protected system, free lime in the presence of moisture maintains a pH level at the cement-steel interface above 12. Even the presence of oxygen will not destroy protection of the steel so long as the pH level remains at an inhibitive level. A simple and classic demonstration of this inhibitive mechanism may be performed by submerging iron nails in ordinary tap water. Where pieces of cement have been allowed to passivate the system, no corrosion appears. Where nothing is done to elevate pH, rapid corrosion of the nails is apparent.

During the installation of cement-lined pipe or tubing, tension cracks will occur. The passivation effects of elevated pH have been shown effective in cracks of at least 2 mils.

The self-healing characteristic of cement is well known. Portland cement continues to hydrate over very long periods. Free lime and pozzolans in this type of cement will continue to react with time, forming new cement. These reactions require the continued presence of water which is a condition fulfilled in all cement-lined oil-field applications.

Bonding of cement and steel is extremely effective in cement-lined pipe where high speed rotation results in a prestressed hoop. The mortar will insert itself in all the surface pits and

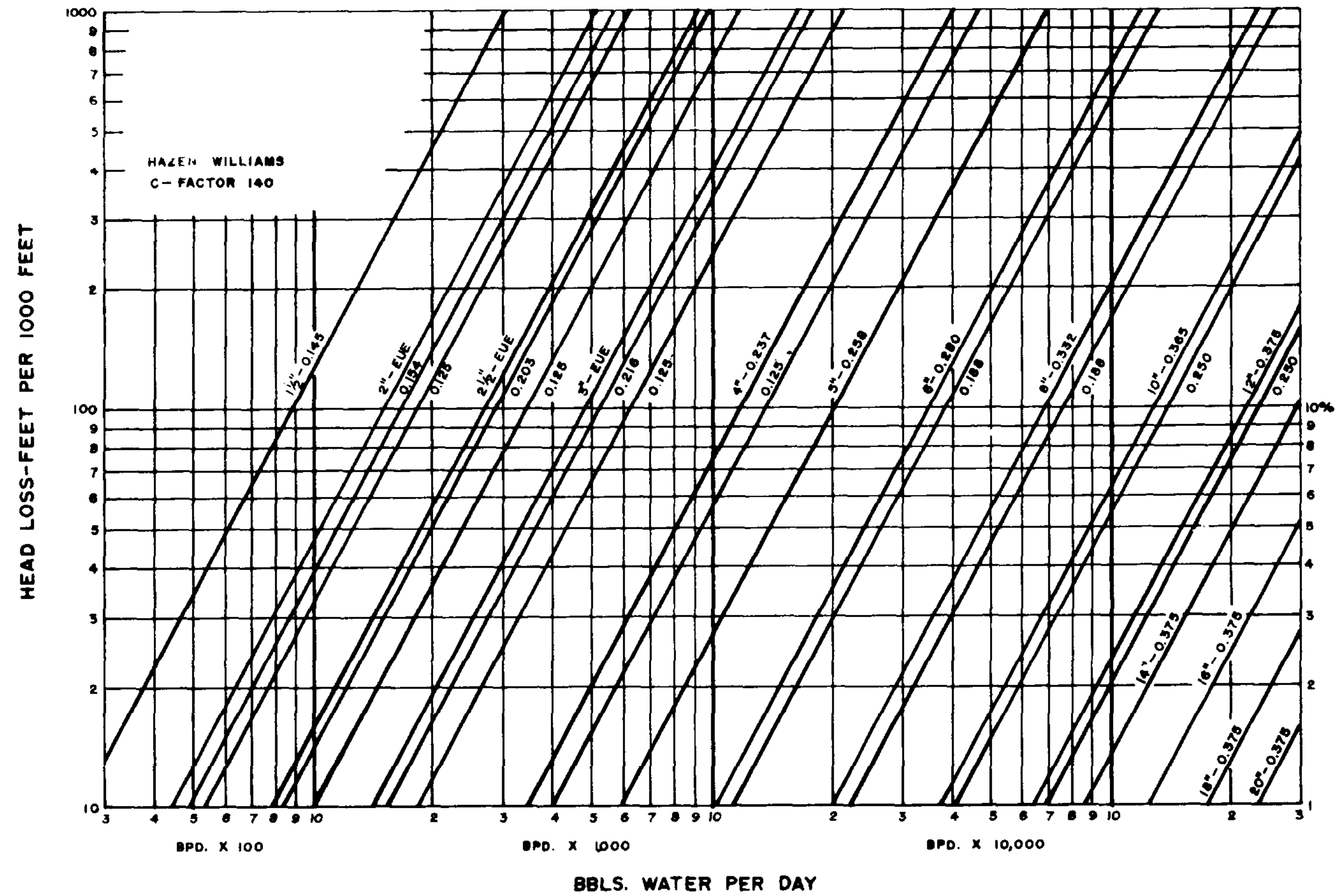

FIGURE 1

Friction Loss Chart for Cement-Lined Pipe crevices in the pipe and forms an excellent mechanical bond.

It is interesting to note that an additional advantage of cement-lining is the surprisingly low friction loss property. Laboratory work has indicated a Hazen and Williams "C" coefficient for cement-lined pipe of 148. Extensive field testing, including one 125,000 foot water-distribution system installed by a major oil company in the Permian Basin, confirms a recommended design coefficient of 140. The coefficient for cement-lined pipe is actually superior to that of welded pipe and therefore, compensates in part for the diameter reduction caused by the lining thickness. Figure 1 is a friction-loss chart for cement-lined pipe.

PIPE REQUIREMENTS

Certain minimum standards are required with respect to the physical structure of pipe to be cement-lined. Internal laminations, inadequate scarf removal or internal weld bead cannot be tolerated. Straightness specifications vary; however, camber in excess of 3/8 inch per joint is excessive. In the case of smaller diameter pipe, crooked joints may be straightened. In many cases, larger diameter pipe can be cut and salvaged. Used tubing presents the greatest amount of physical distortion. Tubing is frequently bent close to the ends as it is pulled from a well. Where a joint of tubing has been flattened with tongs, it must be rejected for lining; however, crooked pipe can usually be straightened unless it has been dropped in a well and corkscrewed. Because of the consistency of cement slurries, tubing which has already been severely pitted can still be lined.

SPECIFICATIONS FOR CEMENT LININGS

Cement-lining specifications for composition and application vary materially between applicators; however certain minimum standards are prerequisite. Table 1 presents acceptable lining thicknesses for various pipe sizes and wall thicknesses. Perhaps the most universally accepted cement composition is 60 per cent hi-early strength portland cement containing zero tricalcium aluminate and conforming to ASTM C-33 and 40 per cent artificial pozzolan or fly ash conforming to ASTM C-350. Alternate linings may contain sand, blast furnace slag, silica flour and portland cement with reduced sulfate resistance. Proportionate mortar mixes may vary with applicators' techniques and customers' requirements.

TABLE 1

Weights & Dimensions for Cement-Lined Pipes

LINE PIPE

Pipe Size O D	Steel Thickness Unlined	Weight Per Foot (Unlined)	Theoretical Lining Thickness*	Theoretical I D (Lined)*	Theoretical Lining Wt/Ft*	Theoretical Wt/Ft (Lined)*
1-9/10	0 145	2 720#	0 125	1 360	0 55#	3 27#
2-3/8	0 154	3 650	0 156	1 755	0 88	4 53
2-3/8	0 125	3 000	0 156	1 813	0 90	3 90
2-7/8	0 203	5 790	0 156	2 157	1 06	6 85
2-7/8	0 125	3 670	0 156	2 313	1 13	4 80
3-1/2	0 216	7 580	0 188	2 692	1 59	9 17
3-1/2	0 125	4 510	0 188	2 874	1 69	6 20
4-1/2	0 237	10 790	0 188	3 650	2 12	12 91
4-1/2	0 125	5 840	0 188	3 874	2 25	8 09
5-9/16	0 258	14 620	0 250	4 547	3 53	18 15
6-5/8	0 280	18 970	0 250	5 565	4 28	23 25
6-5/8	0 188	12 890	0 250	5 749	4 42	17 31
8-5/8	0 322	28 550	0 375	7 231	8 40	36 95
8-5/8	0 188	16 900	0 375	7 499	8 69	25 59
10-3/4	0 365	40 480	0 375	9 270	10 65	51 13
10-3/4	0 250	28 040	0 375	9 500	10 90	38 94
12-3/4	0 375	49 560	0 375	11 250	12 83	62 39
12-3/4	0 250	33 380	0 375	11 500	13 11	46 49
14	0 375	54 570	0 375	12.500	14 21	68 78
14	0 312	45 680	0 375	12 626	14 33	60 01
16	0 375	62 580	0 438	14 374	19 10	81 68
16	0 312	52 360	0 438	14 500	19 26	72 62
18	0 375	70 590	0 438	16 374	21 68	92 27
18	0 312	59 030	0 438	16 500	21 84	80 87
20	0 375	78 600	0 500	18 250	27 60	106 20
24	0 375	94 620	0 500	22 250	33 49	128 11

TUBING

2-3/8	0 190	4 700	0 156	1 682	85	5 55
2-7/8	0 217	6 500	0 156	2 128	1 05	7 55
3-1/2	0 254	9 300	0 188	2 617	1 55	10 85
4-1/2	0 271	12.750	0.219	3 520	2 41	15 16

*Allowed 1-9/10 – 4-1/2 ±1/32
*Tolerances 5-9/16 – 24 O D ±1/16

LINING TECHNIQUES

The 60-40 pozzolanic cement slurry is placed in the pipe either by pouring in a weighed amount of slurry or by the improved method of metering the slurry into position through a lance. Using the lance technique, a heavier weight slurry can be placed, which precludes undesirable segregation in large diameter pipe. Where the lance is used, precise adjustment in pumping rate and lance speed assure extremely accurate placement of the slurry. After introducing the slurry, the joint of pipe being lined is rotated at speeds in excess of 2500 surface feet per minute. The resulting coating is extremely smooth and dense having a permeability less than 0.01 millidarcies, porosity less than 8 per cent, density of 135 pounds per cubic foot, and compressive strength in excess of 5200 pounds per square inch.

Cement-lining slurries using sand as an admixture are much heavier and more difficult to distribute uniformly. In many cases the mortar is hand-placed on a angle iron which is inserted in the pipe and inverted to distribute the mortar.

The mortar mix is spun at speeds less than 800 surface feet per minute in order to reduce severe segregation of the sand and cement. Concentricity and uniformity of lining thickness are problems which have been encountered with this lining technique.

CLEANING AND PREPARATION

Although there is some difference of opinion concerning the preparation of pipe for cement-lining, it is commonly agreed that both new and used pipe and tubing must be clean of mill varnish, oil, grease, paraffin, thread lubricant, loose mill scale or any other foreign material. Some specifications call for a sandblasted surface with varying degrees of anchor pattern. Most specifications, however, do not require sandblasting unless necessary to remove foreign material such as carbonate or sulfate scale. The presence of tight rust in the steel tube is considered by many experts to improve bonding. A quotation from a paper by Unz says: "Cement mortar has the particular property of removing all rust and loose scale particles from the steel during curing. The particles are dissolved, owing to a superficial corrosion process, and form iron salts. These salts are diffused in the mortar and then reprecipitated. . . Owing to this absorption process, an excellent bond is obtained between concrete and reinforcement. The bond is particularly strong where some atmospheric rust has been present on the steel surface."

This unique property may be observed by appropriately preparing two pip samples, one with a tight rusty surface and one with a bright sandblasted surface. The samples are both lined and cured and then split open. The lining in the sandblasted sample will slip free from the pipe whereas the lining from the rusty sample will usually require removal by force. Observation of the contact surface of the cement from the rusty sample will also reveal precipitated iron salts imbedded in the cement.

In general, line pipe can be cleaned with air, some shotgun blasting or wire brushing. In the case of used pipe, threaded and coupled pipe, and both new and used tubing, heat and flame cleaning are usually necessary to remove hydrocarbon residues, scale and thread lubricant. Where severe scale depositions are found, sandblasting or drilling may be required to clean the pipe. The importance of adequate preparation for lining is so great that rigorous inspection of each joint prior to lining should be required by the applicator.

CURING

Cement-lined pipe may be cured in several ways. Water-curing is an excellent technique; however, it is impractical for large volumes of pipe and is restricted to curing fittings. Water-spray and air-curing are the simplest curing techniques and are used in field operations and some smaller plant installations. Air-curing is slow since a minimum of several days' cure is required and storage in cold weather presents a problem since NACE specifications require the curing temperature to be at least 50° F. The most efficient and practical curing approach is with steam. Here the curing time may be specified by the purchaser and may vary from 15 to 24 hours. Steam-curing temperatures should be approximately 130° F to 165° F. Heating and cooling should proceed at a rate not to exceed 1°F per minute. The cement liner should maintain recording temperature gauges for each steam kiln and where specified, temperature charts should be available to the purchaser. Obviously, the steam-curing technique eliminates the problem of moisture control which is vital to successful cement-lining. With steam-curing, there is no danger from cold weather, and accelerated curing produces a product ready for installation where required.

END FINISHING

The end finishing of cement-lined pipe is critical because any protective system is only as effective as its weakest point. All plain end and grooved pipe must be finished with the cement lining perfectly flush and perpendicular to the end of the pipe. A special admixture, used by some applicators, includes asbestos fibers to give extra body to the cement ends. In threaded and coupled pipe, cement is brought to the midpoint of the coupling and flush with the threaded end. Where recently-developed plastic inserts are cast into the threaded pipe coupling and threaded end, end finish will conform to the insert design.

After curing, all exposed cement ends must be carefully buffed and inspected for chips, cracks or deformities. Minor damage should be repaired with a special patching cement before the pipe has passed inspection. Where more severe damage exists, the ends should be chipped out and replaced. In this event, the pipe must be run through the steam cure again. In some cases a joint of pipe will be bent or out of round on the end, and in this event the pipe must be cut off or rejected. All threads, bevels, lands and grooves must be brushed clean of cement.

COMPLETION AND STORAGE

Following close final inspection, cement-lined pipe should be capped with impermeable plastic caps or bags. In order to prevent excessive drying and assure that the curing process continues, a small amount of water should be placed in each joint. When the pipe is to be stored for extended periods, additional water should be added occasionally. Most specifications call for weekly or biweekly addition of water. Many examples may be found of pipe which has remained in storage for years without water and is still in nearly perfect condition. In such cases where fine cracks or crazing can be observed, the pipe can be restored by adding water and rolling the pipe occasionally over a period of a week or so.

FITTINGS

Any cement-lined piping system will require some fittings and these are also cement-lined. Fittings are properly lined using an end mix admixture containing approximately three per cent asbestos fiber by weight. Where a fitting is relatively short and straight, such as nipples, reducers and flanges, the inner steel surface should be roughened with an electric arc welder to provide an anchor surface. Since most fittings are hand-lined, complexity presents no problem so long as the surface to be lined can be reached by a man's finger. Specially fabricated manifolding with multiple outlets can be effectively lined.

PIPE COUPLING

Plain end pipe beveled for welding is the most popular type of surface line. The welded joint has been popular with cement-lining users because it has proven to be the most economical and has historically demonstrated its resistance to corrosion.

With few exceptions, an asbestos gasket is used at the face of the welded joint. The gasket should be supplied by the applicator and should be machine-cut leaving no ragged edges. These gaskets are cut to match the cement-lining I.D. and to match the pipe I.D., less 1/16 inch. Gaskets are supplied in 1/32 and 1/16-inch thicknesses with larger diameter and heavier pipe wall thickness requiring the heavier gasket material. At one time, the use of a fast-setting synthetic hydraulic cement was widely used for welded joints; however, only a few companies still use this technique. Slip-on welded sleeves using a rubber liner or a synthetic mastic have received some acceptance. Grooved pipe couplings have also received a degree of acceptance. For cement-lining, the grooved coupling manufacturers have developed a coupling and rubber insert especially designed to seal the exposed metal ends.

Threaded and coupled line pipe joints are most commonly protected with a synthetic mastic material which is placed in the coupling by the applicator. As the threaded joint is screwed into the coupling, the exposed metal buries itself in the mastic, effecting an excellent seal against corrosive attack by oil-field fluids. The early mastics used in threaded joints were subject to attack by sulfides and hydrocarbons; however, neoprene and now a more recent synthetic mastic development have proven inert to all oil-field fluids. The latest mastic developed will not lose its mastic quality with time nor is it adversely affected by subfreezing or elevated temperatures. A patented steel reinforced Hycar ring has been available in place of mastic for several years and has developed some following. The most recent innovation in threaded and coupled cement-lined joints is a plastic insert set presently available in EUE tubing only. The plastic inserts are cast into the pin and coupling during the lining operation. These inserts assure maximum concentricity and drift diameter at the tubing joint. The two-part insert set has a male-female taper joint which permits a wide range of thread make-up which is essential to tubing. When joint mastic is applied to the exterior of the male tapered insert, the best joint seal yet available is assured.

CARE AND HANDLING

Although many specifications have been written concerning the handling of cement-lined pipe, practical handling procedures are fairly simple. In lifting and handling cement-lined pipe, no internal lifting hook or rolling device can be tolerated. Pipe may be lifted with outside end-hooks, calipers, slings or other similar devices. Whether pipe may be picked up at the mid-point or at the two ends depends on length, diameter and wall thickness. "Safety first" suggests a conservative approach and when end or center lift is used, pipe must not be lifted quickly or snapped. As will be discussed later, cement-linings are not damaged by bending so long as the steel is not permanently deformed.

Stacking cement-lined pipe presents no difficult problems if sufficient bearing surface is provided to prevent deformation of the pipe. Pipe must not be stacked so that excessive weight might distort lower tiers.

Only minimum handling precautions are necessary. The rules for stacking apply to loading pipe. Pole trailers should only be used where sufficient bolsters are spaced to preclude excessive sagging or flexing. Obviously this rule applies to overhand which should never exceed legal limits. A careful applicator will not permit substandard loading unless the purchaser insists.

When pipe is unloaded in the field, reasonable precautions must be observed. Obviously, pipe must not be dropped or bent during stringing operations. Caps or bags should remain on the pipe until time to weld. Ends should be examined prior to welding and any end damage repaired with special fast-setting hydraulic cement. Where gaskets are used, they may be glued or taped in place so that they cover only the exposed cement surface.

INSTALLATION

Conventional welding techniques for cement-lined pipe require that the pipe be tacked at the top while the last joint is suspended at approximately a five-degree angle. The joint is then lowered in place and lined up with conventional line-up clamps. This technique assures that the gasket is firmly pressed in place between the two joints. After tacking at the bottom, a stringer pass is made downhill around the pipe. Because of the amount of moisture present in the cement-lined pipe, it may be necessary to leave a small hole in the stringer pass to permit the escape of steam. This hole can then be completed at the beginning of the hot pass. In large diameter and heavy wall pipe one or more filler passes may be required before the cap or finish pass is made. All welds must be brushed clean. After welding, contraction of the weld area results in a highly-compressed gasket assuring a corrosion-resistant joint.

As cement-lined pipe is lowered into the ditch, considerable care should be taken to restrict the maximum bend radii to those shown in Table 2. The same table is useful in designing maximum allowable curvature for a piping system. Where these figures must be exceeded, fittings should be used.

TABLE 2

Recommended Minimum Bend Radius for Cement-Lined Pipe

Nominal Pipe Size (in)	Minimum Radius (ft)
2	150
3-4	200
6	300
8	400
10	500
12	600
14-16	800
18	1000
20	1200

In recent years, a considerable amount of welded cement-lined pipe has been installed in swampland and offshore. Basic handling precautions are unchanged. In swampland, pipe is made up in several hundred-foot lengths and dragged into place. In offshore installation, care must be exercised to keep the radius of curvature from the lay barge within limits. This is accomplished with approximate stinger and boom design.

DOWN-HOLE APPLICATIONS

Down-hole applications for cement-lined tubing and casing are extensive. Many millions of feet have been installed. In recent months, one operator has pulled several 10,000-foot water injection wells for remedial work. These wells had been subjected to extremely corrosive water in excess of six years. Inspection of the cement linings showed no cement or steel deterioration. After replacing the mastic and repairing several ends which had been damaged during removal of the tubing, the tubing was rerun. Typically, cement-lined tubing can be rerun after pulling for remedial well work and the protective mechanism will remain intact for many additional years.

Virtually no oil-field down-hole fluid system is harmful to cement-lined tubing. With the advent of acid-resistant cement linings, even low pH process and waste water disposal systems are cement-lined. As previously discussed, it is generally agreed that passivation is due to elevated pH effectively inhibiting corrosion in cracks up to 2 mils wide in cement linings. It has been shown by laboratory tests and engineering calculations that the differences in the elasticities of steel and cement result in tension cracks in long tubing strings. Using conservative safety factors it can be shown that N-80 cement-lined tubing can be set below 10,000 feet. Many field installations as well as laboratory tests have demonstrated the validity of calculated safe setting depths. Table 3 presents safe setting depths for various tubing sizes and classes.

Although cement-lined tubing has a reduced internal diameter, the excellent flow characteristics of cement linings tend to offset diameter reduction. The modern applicator exercises extreme care in obtaining a minimum internal diameter and drift diameter capable of accepting most wire line tools that might be used in an injection well. In nominal 2-inch tubing, the applicators should blow a 1-9/16 inch ball through the pipe and drift the first three feet of each end of each joint with a 1-9/16 inch bar. No problem should be encountered in running 1-1/2 inch wire line tools. With normal care, neither tools or wire lines will damage cement-lined pipe.

CARE AND INSTALLATION OF TUBING

Certain precautions are essential to the successful application of cement-lined tubing. All transportation and handling precautions specified for lined pipe apply to tubing. During running operations, thread protectors should always be used for tailing-in. As a tubing joint is lowered and stabbed, care must be taken to keep the blunt end of the descending joint from striking the top of the open coupling. Where plastic inserts and/or mastic joint compound have been installed by the applicator, no extra work is required of the rig crew; however, care should be taken to keep the leading edge of the pin end thread clean of thread lubricant. The joint compound adheres tenaciously to clean grease-free

TABLE 3

Maximum Setting Depth

Tubing Size O.D.	Tubing Wall (inches)	Weight-#/Ft. (cement-lined)	Steel Grade	Setting Depth (S.F. = 1.8)
2-3/8"	.190	5.55	H	5200'
			J	7100
			N	10400
2-7/8"	.217	7.55	H	5300'
			J	7300
			N	10600
3-1/2"	.254	10.85	H	5300'
			J	7300
			N	10600
4-1/2"	.271	12.75	H	5200'
			J	7200
			N	10500

steel and cement to effect an excellent corrosion barrier; however, no bond is possible between the mastic and any lubricated surface.

At no time should slips be set before tubing has come to a complete stop. Always use wrap-around tongs and backups to avoid crushing the tubing. Tubing should never be torqued beyond recommended API values. In unseating a retrievable packer, sudden jerks and excessive tension should be avoided; however, the author has witnessed extraordinary tension and release conditions with absolutely no damage to the cement lining. Cement-lined tubing may be safely racked in double or triple stands during well servicing if thread protectors are used.

CASE HISTORIES

Case histories of cement-lined installations are too numerous to enumerate. Cement-lined line pipe and tubing have been used in every corrosive oil-field water known to United States oil production and water injection operations. All major oil companies and many independents have extensive surface installations, and most have thousands, if not millions, of feet of tubing in service. The deepest known tubing setting depth is 10,500 feet. The oldest installation of modern vintage is not known; however, there is much documented data on successful installations still in service after 20 years.

SUMMARY

Cement-lining pipe is a historically successful approach to internal corrosion protection for tubular goods. Cement linings are resistant to oil-field fluids and will remain serviceable for many years. Cement linings are not subject to excessive damage when handled with reasonable precautions. Cement-lined pipe is available in the oil field at a relatively low price, is applicable to nearly any type of pipe and joint, and can be applied to new or used tubular goods.

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