TUBING AND CASING REPAIR WITH PLASTIC LINERS

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ABSTRACT

The goal of the work in lining tubing is to be able to place a liner or velocity string, without necessity of a conventional rig, into a well with minimum time disruption to production

This paper discusses the application techniques and history of in-place repair of downhole casing and tubing. Over 230 wells have been lined with plastic and several plastic velocity/siphon strings have been installed. Technology development is necessary to extend the plastic lining techniques to deeper and hotter wells. Plastic well lining is discussed and successes and limitations are esplored.

SUMMARY

The plastic lining process has about 5 years applications history. primarily lining casing with high-density polyethylene (HDPE) to depths of up to 5000 ft and temperatures less than 150°F. Significant improvements have been noted in economic well performance after liner application in two major areas: injection wells and gas producers. Within limits of temperature, pressure and solvent activity. the plastic liners, both tight fit and loose fit. offer some significant advantages to steel liners in several cases of well repair.

A new technology push with the lining process is currently under way with intent to line tubing. regardless of produced fluid type, to achieve 5 major objectives:

1. Place a continuous corrosion barrier that is significantly more corrosion and erosion resistant than steel.
2. Adjust the tubing diameter to achieve improved lift where the production velocity in gas wells has fallen below the critical velocity to lift liquids.
3. Reduce friction of the flowing system to allow more pressure drawdown at the sand face.
4. Many of the plastics used in lining appear to resist fouling by scales, paraffins and asphaltenes. An assessment is needed of these capabilities.
5. There is potential, in tight-tit liners, *to* seal leaks in tubulars where the pressure is higher inside the tubing than outside.

The results of tests thus far have:

1. Successfully placed a 2-7/8" liner into a well to a depth of over 4000 at a total deviation of 23°, through a subsurface safety valve and multiple profiles and gas lift mandrels.
2. Successfully removed the plastic from gas lift mandrels to allow the change-out of gas lift valves and operation of the gas lift system after plastic lining.
3. Identified several plastics and composite materials that could be used as tight-tit liners and velocity strings to depths of about 10.000 ft and stable working temperatures to 250°F.
4. Determined methods of placing both velocity strings and tight fit liners. of virtually *any* size, to depths of 10.000 ft or more.
5. Have designed prototypes of hanger systems for surface and downhole hanging of velocity strings. Tests are being scheduled.
6. Have solved technical questions of fusion bond strength in Rilsan and other materials.
7. Have set up field trials of both the plastic liner and plastic velocity string, using the 2-7/8" unit developed for offshore application.

PROCESS DESCRIPTION

In-place lining uses spooled plastic tubing, selected for the engineering aspects of the job. in a length that will reach a design point in the tubulars. The plastic liner is run through a roller reduction unit that doubles as an injector. Weights hanging below the reduced diameter liner keep the pipe reduced (analogous to the thinning produced when a rubber band is stretched) until the weights set down on the bottom of the well or a plug placed at a desired bottom depth for the liner.

With the tension released, the plastic liner "remembers" its original size and expands tightly against the pipe wall, sealing the flow path. The seal produced between plastic and steel will easily pass a mechanical integrity test and has sealed 1/2" holes at 1800 psi internal pressure differential. The weights are retrieved through the liner and the well is returned to operation afier the plug is pulled. Well killing may be required, but wellhead disassembly may not be required if the repair is in the tubing. Time to set a liner is one day. For lining tubing, where the wellhead allows full id tubing access. the wellhead will not have to be removed.

APPLICATION INFORMATION

Surface Equipment

The surface equipment used in the operation is relatively simple with four basic parts: operators controls. power pack. the reel of tubing and the roller reduction unit. The process is illustrated in Figure 1 -3. The equipment footprint is similar to a coiled tubing unit. The roller reduction unit is the primary movement mechanism. A secondary design capable of handling the plastic strings involves a chain drive coiled tubing unit. Weights of the three components range from 2 tons to a maximum of 5 tons for the roller reduction unit. A lined sample of 5-1/2" casing is shown in Figure 4.

Hanging Weight to Keep the Liner Stretched During Installation

The plastic liner has an initial O.D. slightly larger than the steel pipe I.D. The roller reduction machine reduces the plastic pipe O.D. about 12 to 13%, and there is 2 to 3% spring-back. even with the weight applied. The temporarily preserved plastic O.D. is slightly less than the steel pipe I.D.. and the weight string helps preserve most of this diameter reduction (usually about 10% reduction is stable below the lowest roller). The amount of weight is calculated from the tensile strength of the plastic and is usually set at about 30% of the load strength (ultimate tensile at yield) of the plastic. The weight must not be so excessive that the plastic is yielded beyond its elastic limit. If the plastic has too much load applied (combined load from either from the total load of weight and pipe and/or from friction forces when pulling upward). then the spring-back memory of the reduced pipe is affected and the liner will not recover to fit tightly against the steel pipe I.D. It is this memory that controls plastic pipe recovery and tightness of fit of the plastic liner in the steel pipe. As the pipe recovers from the roller reduction and tension loads. the diameter will increase and the length will decrease.

Application of excessive weight can yield the pipe to the point where it does not recover fully. Ideal recovery (memory) to original shape afier reduction and application of tension is 98 to 99%. The recovery gives the plastic liner its ability to form the compressive fit that makes the liner self-hanging and helps prevent both collapse and collection of significant amounts of gas behind the liner via gas permeation. The length reduction during diameter recovery may be 1 to 2% of total liner length in the well. Steel also stretches and recovers. Typical stretch for steel is 3 to 6 ft in 5000 ft.

The active safety factor in plastic string integrity is about 70% when the weights are hanging at the surface. The safety factory decreases as the pipe is run into the hole. reduced by the added weight of the pipe. The minimum safety factor for the job is set by limiting the tensile loads on the pipe to no more than 75% of ultimate tensile yield (25% safety factor). The actual safety factor is actually higher than 25%, since the friction during running offsets the weight of the plastic pipe and the weights. In deviated wells. this offset can be significant.

Initial Plastic Pipe Diameter Needed

Calculation of initial plastic liner diameter for application in steel pipe is based on the amount of diameter recover). necessary after reduction. The 13% reduction was estimated from Rilsan and HDPE work in larger sires. Initial diameters of 2.5" O.D. and 2.6" O.D. have proved slightly loose and slightly tight. respectively, for the 2.441" I.D. of 2-7/8" tubing. The 2.5" had excessive weight applied downhole and the 2.6" was a surface test only. A general guideline sizing of 2.55" O.D. will be used for future Rilsan pipe lining in 2-7/8" tubing. Reduction amount can be decreased from the current 13%, although more friction during running would be expected. The increased friction would not be a problem with vertical wells. but could come into play in more deviated wells.

The weight needed to run the liners is a function of the tensile strength of the material at surface temperature. This generally translates to 30% of the tensile strength and is adequate to keep the pipe stretched in the elastic tensile range where diameter recovery is maximized. Keeping the annular volume to a minimum helps prevent any collapse due gas expansion during rapid depressuring.

Weight Systems

The weight applied to keep the reduced plastic pipe stretched is designed to hang below the plastic liner. It is retrieved through the liner via E-line, tubing or coiled tubing. The current weight system is acceptable ifthe well does not have to be lined to the bottom or plug location. Some "swallowing" ofthe weights at the end of the job can be accomplished in the short time of plastic relaxation/expansion when the tension is released. provided the plastic continues to be fed into the well from the surface and while the liner is loose enough to slide down plastic added to the well from the surface. The insertion ofestra plastic pipe at tension slack-off has not been proven in deviated wells (over 20°) at this time in the technology development. There is also some length redtiction (stretch recovery) as the plastic pipe expands outward.

Weight systems continue to be a point **of** work. The proven system of hanging the weights below the plastic liner is well known and acceptable if some ofthe weights can be swallowed during the last phase of liner installation, or if the liner does not have to run to bottom. Interior weights are more problematic due to weight transfer as the pipe rolls off the reel. Other ideas. such as addition of water as a weight for running velocity strings offers the opportunity to run plastic strings that can be returned to production by pumping out the bottom plug and reversing out the water. The water weight system may be most beneficial for velocity strings. Regardless ofthe weight system used. any I.D. restriction in the guide shoe at the bottom of the plastic string should be removed before the well is turned to production. Failure to remove the shoe creates a restriction in the flow path that will act as a downhole choke and interfere with optimum well operation.

Pipe Fusion

Most of the plastics used in the lining operations can be fusion "welded" by either electric or mechanically applied heat. Bond strengths are typically very close to the pipe strength. Usually only one fusion is required; at the guide shoe at the bottom of the plastic string.

Safety factor for fusion strength is set at a minimum of 90% ofplastic pipe body strength. This is copied from steel casing tolerance specitications of 12.5% tolerance in steel casing wall thickness. In a review ofthe liner and velocity string application, fusion strength has been identified as the primary risk area for technical success of the liner systems. Understanding the fusion behavior and finding a test for fusions is an important element to gain acceptance of the product.

Alternate Connections

Where braided overlays or sandwich construction with fibers are used. a mechanical joining system is necessary. Although several mechanisms have been explored. only the crimp connectors have been tested. The primary objective ofthe mechanical connector is to engage and hold the braid. Surface hangers are envisioned to be similar to of a standard coiled tubing hanger. Although mechanical connectors and hangers are feasible, every effort should be made to use a continuous piece ofthe tube and to use either integral outer body rub blocks. Supporting the plastic string along its length is a key to preventing elongation (stretch) at temperature over time.

Plastic Pipe Strength

Strength at temperature information is critical to designing a stable plastic pipe string for long-term operation. A significant effort is being made to include the plastic suppliers and formulators in the design process to increase Q/C ofthe liner application. Until we understand plastic pipe strengths at temperature. we are limiting our tight-fit lining efforts to wells with operating temperatures at or below about 210 to 220°F (99 to 104°C). Velocity string installations using composite liners should be capable of 250°F (121°C). The higher temperature rating for velocity strings is possible since little or no roller reduction or weight is needed to place a velocity string.

Requirements for strength at teniperature for the plastic liners depends on whether the liners must resist creep, the types of fluids being produced, and the wellbore configuration. The maximum required strength is during running. likely before the liners heat up. Once the weight is removed, the required strength is low. Liners with little or no residual stresses at bottom hole flowing conditions need less strength. For wells with low stresses, liners may operate much closer to maximum temperatures. Velocity strings that hang loosely must be supported to some degree to resist creep at temperature. Plastics will continuously elongate when tensile forces are applied at temperatures near their failure point, thus the requirements for strength may differ from a tight-fit liner to a velocity string in a vertical well.

Strength tests with running weights are being considered to define the operational envelope during placement ofthe liners and velocity strings. A basic approach to testing was discussed using whole plastic pipe sections suspended in a frame with a weight on the bottom of the pipe. This type of load application would allow a constant load application, exactly the same as during running. The pipe diameter change and stretch could be monitored over several hours or days if necessary. The test unit is not heated since the plastic pipe is at surface temperature when run and heat-up usually requires well flow (occurs after the weights are removed). Spring-back times will be tested with the same test. Information on plastic pipe spring-back is critical for determining how much pipe can be inserted after tlie weight tension is released.

Plastic pipe strength improvements have been made by co-extrusion techniques that wrap a braid of high strength Aramid fiber into the area between the two plastics. When properly combined, the composite material has significant benefits in burst pressure. reeling, tensile strength, gas permeability resistance and chemical resistance. There may be an associated loss in fusion potential. but the effects are minor in many cases.

The pipe. as shown in Figures 5 and 6, has a HDPE or nylon outer shell. with a strength braid and a 0.050" inner layer of Fortron. Tensile strength of the materials is *7.000* to 8,000 psi and weight is about 0.5 lb/ft *(0.75* kg/m) in a 2" O.D. (5.1 cm) and 1.5" I.D. (3.8 ctn) configuration.

Hanging the Plastic Pipe in the Well

Tight-fit liners are self-hanging. although seals at either or both top and bottom have been installed for specialty applications. Top seals in these cases are fusion bonded plastic caps that fit within the Ilange seal area (do not interfere with the flange seal installation or operation. Bottom seals include specialty packers and plugs that have been proven to set in the plastic. tightly compressing it against the steel. These packers and plugs have been tested and shown to be capable of resisting both pressure and tensile/compressive loads without movement in the plastic or plastic movement in tlie steel.

Hanging plastic velocity strings in steel pipe installations present a different set of requirements than with tight-fit liners. The most appropriate methods for plastic velocity string hang-off from the surface is a modified slip arrangement that inserts into a slip bowl in the wellhead. below the master valve. Downhole hang-off can be accomplished with a slip bore in a wireline set packer. The idea for the hang-off is illustrated in Figure 7.

A CS-type fishing neck can be molded or fitted to the top of the velocity string in the hanger assembly to improve running and pulling. Multiple packers could be set to achieve liang-off ofseveral short strings or a continuous string could be set if the selected plastic material had sufficient strength at working temperature and a low creep rate. Creep rate is important with the application of any plastic that will retain tensile stress. regardless of its installation temperature. To resist creep. a simple. secondary support system is being investigated. Partial plastic string support using rub blocks. similar in nature to packer rub blocks, indicate that creep and be substantially offset and well operation can be improved.

The idea of rub blocks to help support the light weight velocity strings (0.3 to *0.5* lb/ft - 0.44 to *0.75* kg/m). would be useful if a suitable method can be developed to calculate number needed and attach the rub blocks downstream of the roller box or chain drive installation unit. The number of blocks needed is directly proportional to the weight of the plastic string in the well. The weight is taken to be the weight in air, although steel pipe size, well trajectory and other wellbore factors typically decrease this weight by 10 to 15%. Attachment will be done below the roller box of chain drive unit, Either solvent bonding or locally applied heat can quickly attach the rub blocks. Both systems are used currently for reliable attachments of saddles in plastic pipelines.

Deviation

The effects of well deviation may hamper the placement oftight-fit liners. but they do not appear to hinder plastic velocity string installation. In a test with a 2-7/8" well that had a total deviation of 60o, the tight-fit liner was inserted to 23o before insertion was stopped by effects of friction from the pipe and multiple profiles combined with reduction oftensile application from weight vector loss.

Insertion of a liner into a deviated well will be assisted by less weight and friction of the plastic in contact with steel and resisted by lower resistance of the plastic to buckling. Velocity string insertion may likely be modeled by a coiled tubing program with a change in material modulus to reflect the type of plastic liner being used.

Gas Permeation

Gas permeation of elastomers is a simple migration of gas through tlie structure in response to a pressure differential. The amount of gas invasion of an elastomer depends upon the type and permeability of the material at tlie working temperature, time of exposure, differential pressure, area of the material surface exposed, type of gas. and the gas viscositq. Almost all elastomers and plastics are permeable to some small degree and therefore are vulnerable to gas invasion. although most are not damaged by the process. Even high strength steel is gas permeable at an extremely slow rate. at very high pressures and to gasses with small atomic structures such as hydrogen and helium. For elastomers, the gas permeation ranges from minor in Teflon, moderate in natural rubber and severe in products such as silicones and flurosilicones. Plastic lining inaterials such as HDPE are moderately affected by gas invasion, but materials such as nylons and poly ketones are much less affected.

Permeation of any material by gas does not, in itself: present a structural problem unless the gas chemically or physically reacts with the material. The major potential problem, that of seal blistering or liner collapses, arises when the pressure on the inside ofthe lined pipe is suddenlv lost; a condition known as explosive decompression. If the near surface ofthe material has less strength than the differential pressure applied from the trapped gas trying to escape from the pores of the structure and the near surface is low permeability; the gas can overcome the tensile strength ofthe material. forming bubbles or blisters on the nearest low pressure surface. If sufficient gas volume is built up behind a liner. the liner may be temporarily bulged inward until the gas is vented to a low pressure. Because the bulging does not yield the pipe, the liner will flex back against the pipe when the pressure vents.

Liner collapse potential in pipelines and in downhole applications are vastly different. Historically, the liners used in pipelines are a loose fit. allowing more gas storage area behind the liner and are often so thin that the pipe hoop strength that pushes the liner back into place is too low to effectively flex the pipe outward following explosive decompression. In downhole plastic lining, the tight-fit liners are typically a minimum of 17 SDR (standard diameter ratio) as opposed to 26 SDR or more in most surface pipeline applications. Gas storage area in a downhole application is very small. Since volume expansion. by ideal gas law. reduces pressure linearly. a 10 cc connection void space under the liner would need only double to half the pressure. For this reason, gas pertneation downhole is expected to be nil. Performance in over 230 wells, some with 5+ years of service in CO, production wells. have not found one incidence of downhole liner collapse related to gas pcrmcation.

Most oilfield examples of explosive decompression damage are surface equipment with seals: BOP blind and pipe ram surfaces. stuffing bos seals. annular preventer elements, etc. Although downhole elastomers may also be contaminated by gas. they are less prone to damage because of higher strengths than seal elastomers and much slower decompression times. Blistering potential for HDPE was tested in 1997. Two pressure vessels were used in an experiment that used 10 1" square by 0.25" (SDR of 17 for 5.2" plastic liner) pieces of HDPE. One pressure vessel was charged with nitrogen gas to 1500 psi and the other was charged with CO_2 to 670 psi. The vessels were held pressurized at nominal 75°F for 3 months and then depressured in 10 seconds. The vessels were immediately open and the HDPE inspected. No evidence of gas blistering or shape change was seen in any ofthe test samples. This lab result *was* confirmed with 5+ years of HDPE use in the Bravo Dome Field in New Mexico. Although several liners ofthe 35 initially installed were later removed for workover purposes (liquid loading, etc.). no direct problems from CO2 gas production through the liner uere reported. This also corresponds with favorable use of the HDPE lined. jointed steel tubing that is commonly used in CO, operations.

Common liner materials, HDPE, Nylon. and poly ketones, may be slightly gas permeable. usually much less permeable than cement, which is three orders of magnitude more permeable than steel.

For liners, surface blistering potential and collapse potential are separate issues. Blistering is a function of the strength of the surface at temperature. Collapse potential is a function of trapped gas volume and stored hoop strength of the tight-fit liner. Minimizing void space behind the liner minimizes the chance for any type of collapse.

Velocity strings should be unaffected by gas permeation, since backside venting is assured by the design. Blistering is not expected to be a problem because of the strength of the materials used in velocity strings.

Backside Fluid Venting and Pressure Monitoring

The amount of gas permeation through the liner materials by methane. nitrogen or CO, is very small. however, to minimize reluctance ofgoverning agencies, it will may be necessary to incorporate the Safety Liner grooves. Figure 6. in injection and disposal wells. The Safety Liner allows positive. automatic venting of any gas collected through the wall of the liner. It is necessary in pipelines, but viewed as a specialty need in downhole applications.

The safety liner doe, allow monitoring of the annular region in a tight-tit liner application, provided the bottom of the liner is sealed and the liner is not punctured.

A test in an Alaskan well in a water-alternating-gas flood will address gas permeation issues in the downhole environment. The test will be very significant since it will be run at the very edge of the working temperature limits of the polymers tested. The safety liner annular grooving will also allow monitoring of the annulus. Early tests suggest that a SDR of I7 may be needed tor incorporation of safety liner grooves in plastic liner that is used downhole. Work is continuing on this issue. .

Backside venting from a plastic lined well, whether using the Safety Liner or not, is from an annular access valve in the surface tree. Historically. gas vented from lined wells has been ultra-small volume; typically estimated at less than a cubic foot a week at bottom hole pressures of 200 psi (surface pressure less than 20 psi) for a 2200 ft deep. 5-1/2" cased CO_2 well lined with HDPE.

Velocity strings, because they are not a tight-fit application with trapped annuli, do not require venting unless sealed at top and bottom. Very long strings may need some venting if completely sealed at one end.

Velocity String Design

Velocity strings (also called siphon strings) usually are secondary tubing additions that are designed to reduce the effective flowing diameter of the well and subsequently increase flow velocity. The primary intent in running a velocity string is to assist the well in unloading liquids in the gas flow without resorting to artificial lift. By occupying part of the tubing tlow path; the gas velocity can be raised to exceed the "critical" velocity necessary to lift the liquids.

Traditional approaches to velocity strings have been to insert steel coiled tubing and tlow up the annulus between the coiled tubing and the jointed tubing. Although the steel velocity string method is effective, it has several drawbacks that can be overcome by using a plastic velocity string.

1. The steel is easily corroded by CO_2 and may have a very short life. Failure requires a fishing job and success at fishing dropped coiled tubing is only moderate.
2. Steel tubing presents an increased friction pressure drop. especially when corroded. Friction drop. which acts as a back pressure on the formation, may decrease production rate.
3. When a coiled tubing velocity string is installed. access to bottom hole with wireline tools is lost.

Plastic velocity strings may eliminate all three of these problems. The CO_2 resistance of the plastics has been proven in years of CO_2 production and injection service with plastic lined tubulars. Friction drop in the plastics is approximately 1/5th that of new pipe and a full order or magnitude or more less than corroded steel tubing. Since the plastic pipe may easily be made in any size, the flow path may be up the interior. which will allow wireline access.

Plastic velocity strings, with their extremely smooth bore. will also work with plunger lift when the well is properly configured to isolate the annulus.

PRODUCTION OPERATIONS WITH PLASTIC LINED PIPE

Flow Improvements

Flow improvement with plastic liners has been documented in low-pressure gas wells. even though the diameter has been reduced slightly by placing the liner. In most low-pressure wells, any friction in flowing gas through the tubing will decrease the production rate by holding a backpresstire on the formation, preventing full application of drawdown to the formation. Friction is a resistance to flow and is created by roughness of the tubing surfaces and turbulence at upsets (diameter changes) in the flow paths such as couplings. Evidence of the turbulence effect at couplings is seen in increased corrosion on the upward (pin) end of the connection in jointed pipe completions that have CO_2 in the produced gasses. The corrosion is a secondary effect of the coupling turbulence. but demonstrates its presence. Ttie turbulence creates a small eddy effect on the surface just downstream (above) the connection gap. The water that is held on the pin end by the eddy is CO_2 saturated, and the resultant carbonic acid results in increased corrosion. Figure 10.

Lining the pipe with a tight-fit liner eliminates much of the friction because of the smooth wall of the plastics and elimination of diameter upsets at the joints. Field response of low pressure gas wells have shown increases ranging from

5% to over 20% without any other stimulation ofthe well.

Polishing tubulars has been documented to increase flow in instances where the well is "tubing limited." In tests with mechanically polished. steel tubing. the effect of the friction reduction reportedly lasts from I to 3 years before fouling over. depending on well conditions. Similar increases have been seen with polymer-coated tubulars. None ofthe plastic liner applications have exhibited significant fouling from produced fluids.

Attempts have been made *to* history match the performance of plastic lined gas wells. but the actual response is still slightly above the predicted response. More data on flow behavior is needed before the tlow can be successfully modeled.

MECHANICAL ACCESS THROUGH PLASTIC LINED WELLS

The plastic lined wellbores offer a significant advantage over plastic coated tubulars in since the plastic liners and velocity strings are very resistant to cuts by slick line, E-line, coiled tubing. small diameter pipe (HWO tubulars) and general abrasion by tools and produced solids. In tests on the well lined to 23o deviation. the following tool string runs were recorded:

1. Slickline runs at 600 ft/min
2. E-line runs at 300 ft/min
3. Coiled tubing runs at 300 ftimin
4. Both aluminum and steel tools. many with clearances of only 0.15" to 0.2" were run repeatedly.

No cutting or abrasion marks were recorded with the downhole TV camera or noted when the well was pulled

It is known that wireline will cut any material including steel if pulled through at sufficient rate in a dogleg or deviated section. In these areas, a slower wireline speed is advised.

Wireline and tubing have been run through several of the lined wells without damaging the liner. **In** one case. a patch plastic liner was used to isolate an upper section of perforated interval and a lower zone was hydraulically fractured. 'There was no apparent damage *to* the patch liner (Rilsan) from the high rate proppant containing slurry pumping or from the application of fracture pressure.

Artificial Lift Through Plastic Lined Strings

Plastic lining, and in some cases, plastic velocity strings can improve the lift of fluid from **a** well. Artificial lift mechanisms such as plunger lift may show improvements in lift efficiency and longevity because ofthe slick. consistent I.D. bore offered by the plastic lined tubulars.

Although not tried yet. concentric plastic strings. because of their lightweight and extrusion ability can be configured with independent power fluid flow paths. Fitting the strings with jet or hydraulic pumps should not present a problem The advantage of this approach is that the entire string can be coiled in and out ofthe well with minimum production disruption or rig time.

Flow Path Shape Modification

Probably one ofthe greatest advantages to extrusion-molded pipe is the ability to change the flow path. This is a paradigm shift away from the standard round flow paths of steel pipe. An examination of well production problems highlights the area ofunloading fluids from low-pressure gas wells. All wells are slightly deviated at some point in their flow path. In consistently deviated sections, even deviated *to* a few degrees, slow will stratify in any wellbore where the fluids move at a velocity below that which will create turbulence. Gas flow will segregate to the top section ofthe wellbore and liquids may drain down the low side. The corrosion trench seen in many flowing wells by downhole TV cameras documents this. Traditional approaches to this problem have been to use smaller tubing strings. which can produce higher friction and more backpressure on the well. Plastic pipes have been recently produced that use a shape change *to* increase turbulence or remix the fluids by spinning the gas without markedly increasing friction. Figure 11 shows one approach. a rifled spiral that turns one revolution every 40 *to* 80 feet. The purpose is *to* spin the gas without using a smaller pipe I.D.

Another flow path modification idea is a two chambered plastic pipe that could be used with a jet pump. gas lift, or with a surface controller that could pump gas into the secondary chamber to change the effective flowing diameter of the main flow path as needed. Where liquids were building up. the secondary chamber would be inflated, reducing the size of the primary flow path and increasing velocity to achieve lift until the well was unloaded. The secondary chamber could then be deflated. allowing production more flowing area and less friction.

Thermal Insulation

In some cases of liquids condensing from gas as it cools during expansion and heat loss. the insulating benefits of plastics may add insulation. In other cases. temperature loss from produced fluids may affect the formation of scales and paraffin. Additional thermal insulation may be effective in reducing these problems.

Heat loss is a function of the thermal conduction of the materials and the temperature difference.

Conduction is the only method of heat transfer within the body of opaque solids such as pipes. If temperature at one end of a metal rod is raised, heat travels to the colder end. Liners and velocity strings, as shown in Tables 2 and 3. have much lower thermal conductance than either steel or rock.

Heat convection is conduction between two objects that are in contact. Thus, conduction between a solid surface and a moving liquid or gas is actually convection. The motion of the fluid may be natural or forced. Reducing the motion of the fluid cuts the heat transfer. In a tight-fit liner, annulus circulation is prevented.

Radiation is different from both conduction and convection, because the substances exchanging heat need not be touching and can even be separated by a vacuum. The higher the temperature. the greater the amount of energy emitted. In addition to emitting. all substances are capable of absorbing heat. The absorbing, reflecting, and transmitting qualities of a substance depend upon the wavelength of the radiation..

Although vacuum insulated tubing offers the best insulation. heat loss from the couplings may reduce the total insulation significantly. The insulation benefits offered from plastic liner and velocity strings, although not as effective in insulation benefit per foot. are more consistent because they do not have couplings.

Work currently is focusing on reducing heat loss in plastics by the addition of isolated air pockets in the walls of the liner. Early tests with prototype pieces have shown an approximate heat transfer of 1 Btu/(hr °F ft^2)/in.

Corrosion/Erosion Resistance

Corrosion resistance with the plastics is a function, like steel, of temperature, exposure time and chemical species in contact. Selection of the plastic liner or velocity string should be for long term exposure to produced fluids at the temperatures and pressures expected. Some materials. such as nylons. are short lived in contact with HCl and other mineral acids. Wells lined with these materials can still be acidized via coiled tubing or by using lower concentrations of the acids.

Chemical reaction between the plastics used for liners and velocity strings are very low. Multi-year studies of pipeline liners have shown stability to oil, water and gas.

Erosion to the plastics by produced fluids or solids is exceptionally low. The plastics used in this application have much better erosion resistance to oil field solids than does steel. Applications of HDPE lined slurry pipelines (mine tailings) have shown expected 20-year life. Steel lines in these applications will be eroded through in a few months.

Liner Removal

The method of removing plastic strings will depend upon how they are installed in the well and the type of material.

For tight-fit strings, a rip cutter marketed by Charlie Hailey Tool Company in Oklahoma City, has been used to slit the liner for removal. The tool is only required where the steel string cannot be pulled from the well. i.e., casing lining. The tool is conveyed via wireline. The slit enables the stored stresses in the pipe to relax. The pipe curls in on itself and can be removed from the well in long sections.

For tubing lining, removal is simplified since the plastic will separate at the joint when the joints are unscrewed. A quick saw or knife cut may be necessary to complete the separation.

Velocity strings may be reeled out of the well in a single piece since there is little or no outward bonding force holding the liner to the pipe. This type of removal is similar to removal of a conventional coiled tubing velocity string.

Stand Alone Installations

Using plastic liners by themselves can be done if the requirements of the application are within the performance ability of the plastic. When initial or recompletion designs using the plastic strings in open hole or cemented applications are considered, a different set of stresses will apply. Since plastic lacks the burst and collapse strengths of steel, the applications are limited. However, because of their excellent corrosion and erosion protection abilities, some behavior modifications may be acceptable to gain the benefits of the plastic strings.

Table 1

Plastic	Material Descripti on	Known Experience in Oilfield	Approx Work Tensile Stren.	Max Temp I (Time depen ent)	Liner Potentii in Steel Tubular	Hanging String Potential	Potential Problems or Benefits
HDPE –	Polyethylene – numerous forms of the material	Reasonable to Good. Temp limited. Some collapse *of* thin wall liners, in pipe lines, solvent damage to a few liners. 5+ year experience downhole. Excellent water performance and reliability in injection wells	3200 psi	150°F	Limited tc shallow liners (to 5,000 ft), least cost liner	Very shallow application (few hundred feet ın cool wells	Soften at BHT>150°F, ncreased chemical attack Excellent for njectors and disposal wells
ChemPex	Cross linked HDPE.	Should be an extension of HDPE, with more strength and resistance.	3800 psi	200 to 210°F	Mod. dept liners *8* vented liners	Very shallow applications n most cases.	Same ipplications as HDPE but with better strength ind chemical esistance
Rilsan	Nylon 11 naterial	Very good. Monitored 5 year performance in pipelines with H_2S, CO_2, gas, oil and water.	*6200* psi	210°F to 220°F	Mod deptt liners & vented liners	Moderate depth applications to 3000 ft?)	Better resistance o H_2S and chemicals. rvoid acids. Has water dsorption ssues
Argaloy	Nylon	Some pipeline experience vith oil, gas and water. 8 nonths + run time so far.		180°F	As a co-extruded iner in a stronger outside shell	As a co-extruded iner in a stronger outside shel	Very low friction, loes absorb ome water, oesn't affect erformance
Capron	Nylon 6	Unknown – need more nformation about stability following water idsorption on a free surface . Will be used as sandwich material with Carilon.	5000 to *5500* psi	240°F	Typically a outer shell n co-extrusion	Typically a niddle or outer shell ir o-extrusion	All nylons dsorb some rater, erformance Rer??. Avoid cids and low H
Fortron	Polyphenylene sulfide	Good resistance to gasoline. Need more nformation on applications at higher emperatures. Used as a o-extrusion – tye-layers re a problem		250°F	As a co-extruded iner in a tronger outside hell	As a co-xtruded ner in a tronger utside shell	igher emperature erformance, ood chemicai esistance, xpensive
Carilon	Polyketone	Good, but supply is mited. Very stable to water and gas. No problems with bonds to Nylons. Best as a co-extrusion for velocity strings?	8300 psi	285°F+	Deeper ners possible	onger trings ossible, xpensive	xceptional rength and mperature sistance.
PVDF		Excellent resistance for chemical and temp. Was tested for a stand alone liner and found too brittle. May have coextrusion potential.					gher cost per ot *for2 5"* be Was brittle reduction
Carilon-Capron-Carilon with aramid ber raids	Co-extrusion	The best bet for a velocity string when combined with fibers.	000 psi ensile or 2" OD, .55" ID.	210F With peak to 240F		As a velocity string, little or no weight needed to place. Rolls and traightens best of all	ost is tractive for gher corrosion nospheres 6

Table 2

A general table of R values of heat transfer is shown. The vacuum insulation value depends on several factors (annular flow, coupling insulation, etc.) and *is* shown as a wide range.

insulating Material	R-Value
Vermiculite	2.3
Cellulose	3.1-3.7
Glass Fiber	3.2 - 3.6
Rock Wool	3.3 - 3.7
Polystyrene	3.6 - 5
Polyethylene	4 - 5
Urethane Foam	5.5 - 6
Vacuum	20 - 30
Vacuum + reflective surfaces (reduces radiation)	30+ ?

Table 3

The Thermal Conductivity Coefficients of a Number of Oilfield Insulating Materials

Material	Thermal Conductivity Btu/(hr ^oF ft^2)/in
Water	4.6
High density poly (HDPE)	*2.7*
Steel	400
Rock	17
Urethane foam	1
Nitrogen gas (w/convection)	1.5 to 3.6
Nylons	1.8
Vacuum Insulated Tubing	0.06

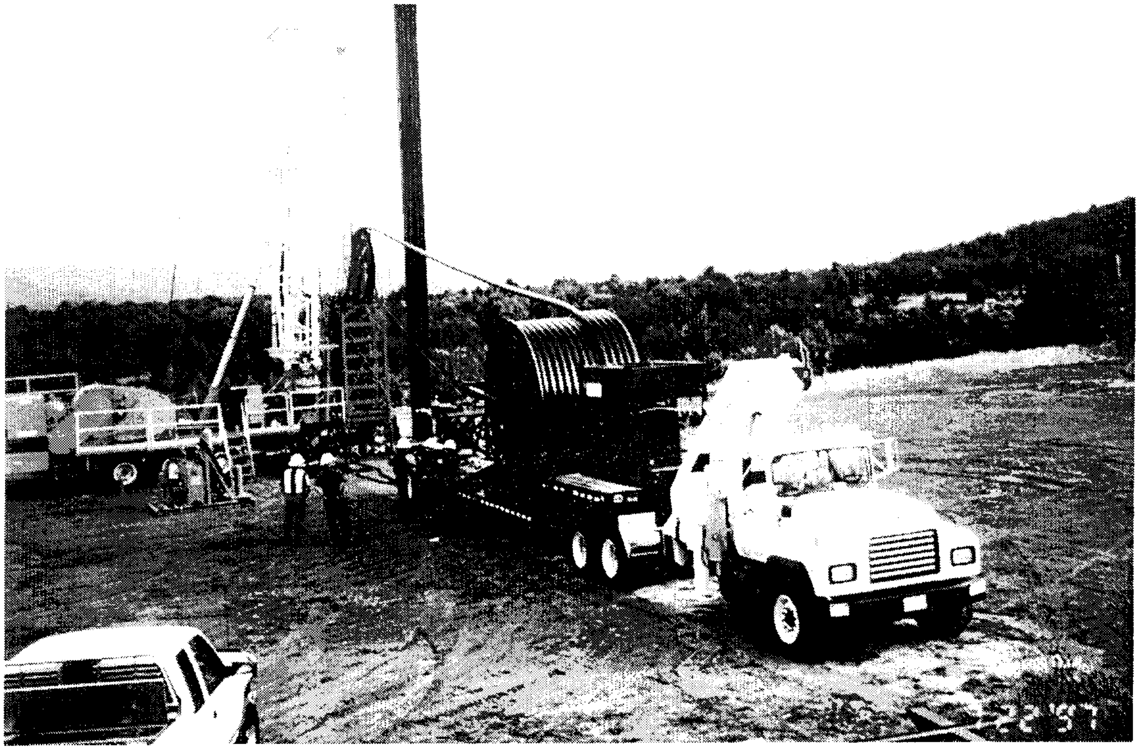


Figure 1 – Land Based Liner Equipment Using 5 2" Diameter High-Density Polyethylene (HDPE) to Line a Well with 5.5" Casing (4.95" I.D.)

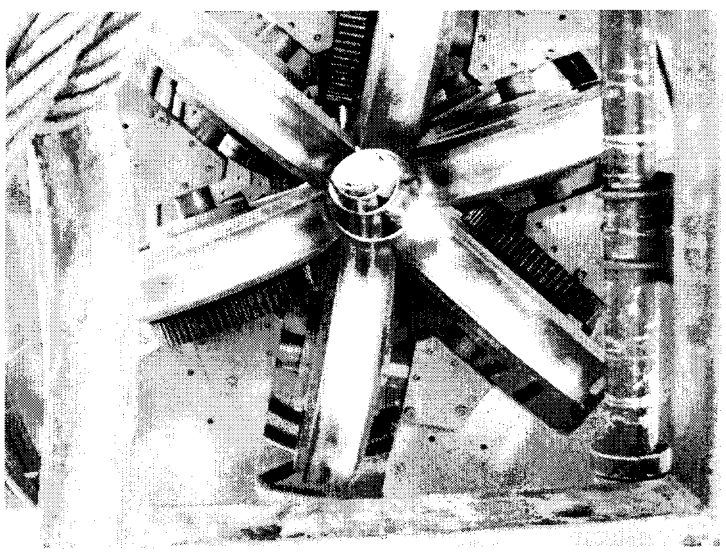


Figure 2 – Roller Reduction Unit, End View. 6 Wheels Per Bank

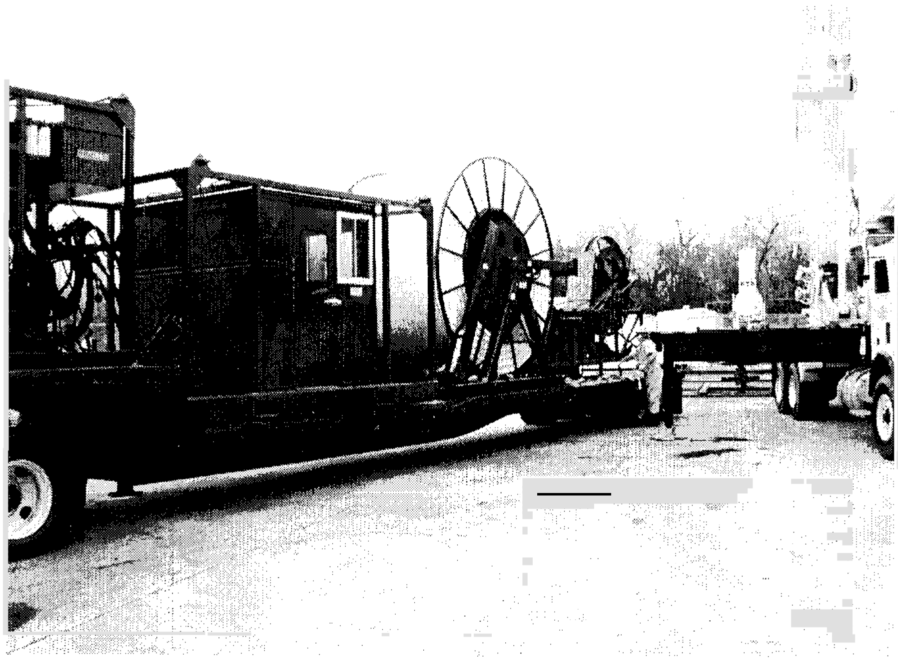


Figure 3 - 2-7/8" Roller Reduction Unit Before Rig-Up. Single float contains the power pack, operator's cab, reel with 9000 ft of 2.5" Rilsan plastic liner and the roller reduction unit.

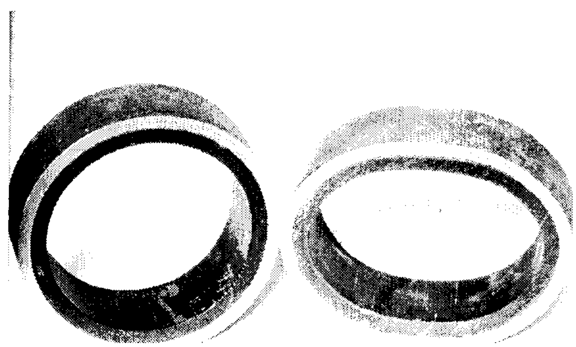


Figure **4** - Two Views of HDPE Lined 5-1/2" From a Downhole Test. A laboratory-applied load has crushed the sample on the right. No separation of the liner was noted. Moving the tight-fit liner from the steel casing required 100 lb per linear inch.

Figure 5 - A Co-Extruded Composite. Outside Surface Showing Fiber Winding

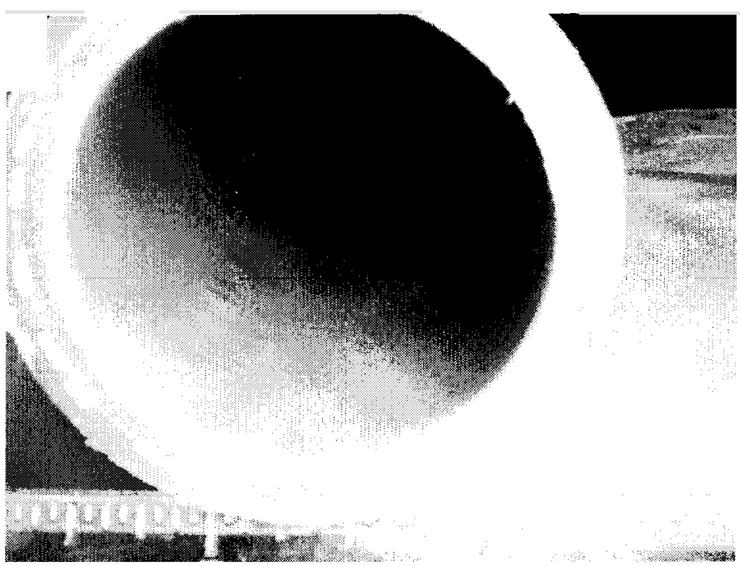


Figure 6 - End View of Co-Extruded Plastic Composite

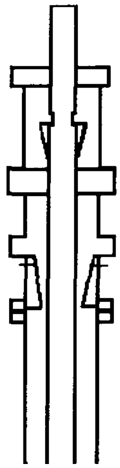
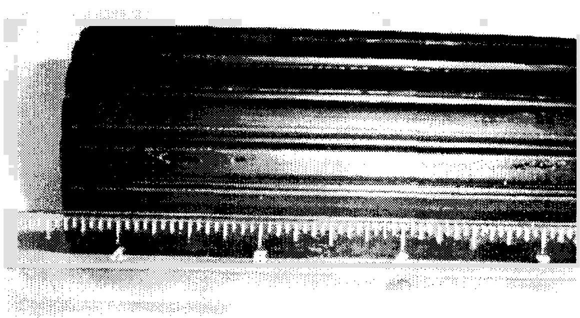
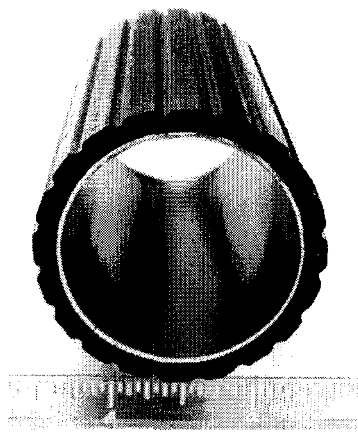


Figure 7 - Conceptual Design for a Surface Hang-Off of a Velocity String in a Low Pressure Well
A downhole barrier set (plug and/or kill fluid) will eliminate the need for a snubbing valve set.





Figures 8 and 9 - Safety Liner Grooves in the Outside of a Plastic Liner. The grooves severe as a flow path for fluid/pressure trapped behind the liner.

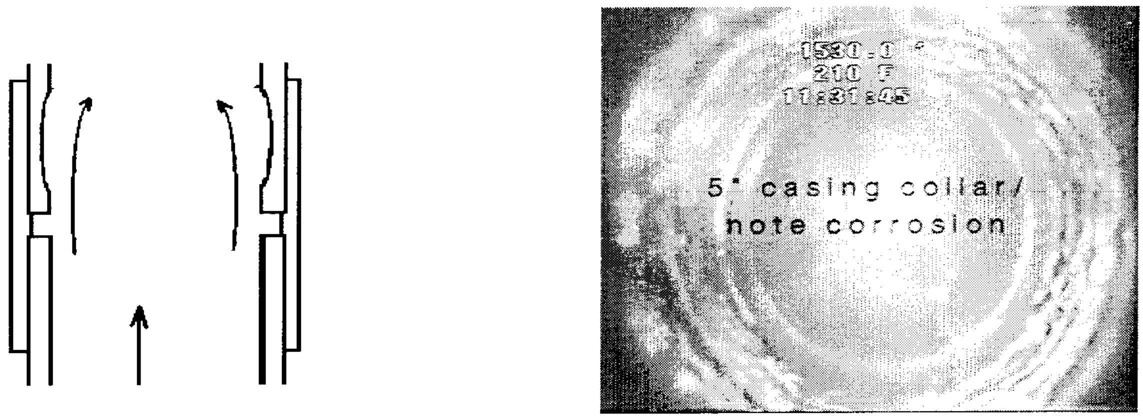


Figure 10 - Corrosion (schematic leftand, downhole photo right) on the Pin End of Tubing. Caused by Turbulence that keeps with pin end of the pipe wetted with water at low flow rates.

Figure 11 - Spiraling Grooves in an Extruded Liner. The grooves are designed to spin the gas and prevent separation of either produced water or water of condensation during production.

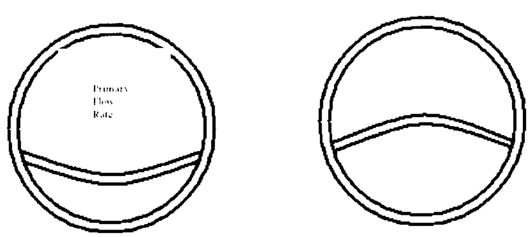


Figure 12 - A Two-Chambered Flow Path. The secondary chamber can be inflated by surface-applied gas pressure, changing the effective flowing diameter of the primary chamber.