APPLICATION OF SPOOLABLE COMPOSITE PIPE TO OIL & GAS INDUSTRY FLOWLINES

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ABSTRACT

In early 2000 Hydril Advanced Composites Group introduced an alternative for standard piping products to the industry. Initially utilized for flow lines, the product, called Spoolable Carbon (Fiber) Reinforced Epoxy (SCRE), has had rapid and widespread acceptance for that application. Other applications that the product has been used for include production tubing and injection strings. Early utilization has been limited by production capacity limitations.

This SCRE is a continuous length advanced composite pipe that is delivered, stored and deployed on a spool. It provides corrosion resistance to both the flowing media and the environment. Additional advantages of SCRE include an inherent resistance to fouling and pressure losses, lightweight, a reduction in the number of connections and fittings required and ease of installation.

Regardless of the price of gas and oil, the driver for selecting SCRE is clearly economic. All operators are interesting in reducing both capital and operating expenditures. When considered on an installed cost basis SCRE offers significant advantages. One operator reports that the installation cost of 2-inch – 1,440 psi SCRE product is approximately 70% of the installed cost of alternative products. This paper seeks to review the development and commercial introduction of SCRE and to review, in general terms, some of the applications in an oil and gas environment that have proven successful.

This paper concentrates on flow line applications. Other potential oil and gas industry applications are being developed some of these are mentioned along with an indication of their development status.

INTRODUCTION

During the late 1960's a continuous composite pipe was conceptualized and the process/apparatus for its manufacture became the subject of several patents [1, 2]. The process involved the continuous manufacture of a tubular product produced using a liner (of various descriptions) over wrapped with a composite structural laminate. One version of the product was manufactured and displayed at the Tulsa Oil Show in 1968. For various reasons, the product never became viable although some of the machinery and processes used in its manufacture are being used to make finite length product today.

In recent years, this early product concept has been developed and commercialized and is being used widely in the oil and gas industry in a variety of applications. For purposes of this presentation, only flow line or pipeline applications are considered although other applications are mentioned. Development of SCRE was accomplished under a National Institute of Standards and Technology (NIST) /Advanced Technology (ATP) [3] joint venture project. The five-year / five million dollar NIST/ATP Project [4, 5] resulted in the development of

- Improved filament winding / manufacturing technology including:
  - Improved fiber placement
  - Improved fiber wet-out
  - Improved understanding of the variables that affect product quality.

- Improved understanding of material variables including:
  - Development and characterization of an enhanced aromatic amine cured epoxy resin system.
  - Development of perhaps the largest database of composite material characterization data in the industry.
  - Development of a curing system and in-line cure monitor (patented).

  Predictive design software with more than adequate accuracy.

PRODUCT DESCRIPTION

The product is described as illustrated in Figure 1 and referred to as Spoolable Carbon Reinforced Epoxy (SCRE). It consists of a continuous cylindrical extrusion of thermoplastic material that is structurally supported by an integral (the liner is bonded to the laminate) composite laminate consisting of continuous lengths of carbon and glass fibers in an enhanced aromatic amine cured epoxy. The carbon and glass fibers are arranged to form an intra-laminar hybrid construction that mitigates the time-dependant failure mode common to fiberglass composites. An outer "scuff" or wear layer of glass fiber in epoxy is applied as an outer coating.The product is produced on equipment much like the original apparatus patented in the late 1960's.

The result is a flexible, yet rigid, light weight, corrosion resistant engineered product that is stored on a reel or spool for storage, transport and deployment. Engineered because the properties of the finished product can be easily designed for specific application needs.

Specifications for the 3-inch inside diameter SCRE product are depicted in Table 2. Table **3** provides a comparison between the SCRE and comparable (flow area and pressure rating basis) steel and cement-lined-steel products. Experience shows that while the SCRE product is more expensive on a unit (per/foot) basis, it can offer significant economic advantage in most applications when the installed costs are considered. Additionally, when properly applied, the SCRE is chemically resistant to the Fluid being controlled and resistant to external corrosion. It also provides a smooth internal surface that resists surface build-up (fouling) and eliminates the need for pigging in most applications.

CONNECTIONS

No piping product can be successful unless it includes field installable reasonably priced connections. For flow line and pipeline applications, the SCRE utilizes a pipe to pipe splice that can be completed in the field and ANSI B 16.5 Lap Joint Flanged end connections. This connection is combination and improvement of techniques used in joining fiberglass pipe for more than thirty years. It offers benefits such as:

- No reduction in the flow path.
- Full tube-body pressure rating.
- A transition from the tube body to the flange.
- Fluid wetting is restricted to the liner material.
- Field installation.
- Elimination of flange "clocking" issues.

WHY A SPOOLABLE COMPOSITE FLOWLINE?

The bottom line is economics. Reduced installed and/or Life Cycle cost. While the SCRE is more expensive on a unit (per foot) basis in most applications, however; it can be significantly less expensive when installation costs are considered.

In addition to the savings realized during installation, the SCRE provides:

- A light weight easily handled product
- A reduction the number of connections.
- Corrosion resistance – inside and out
- A reduction in the number of fittings required
- High fatigue resistance
- Low flow resistance and anti-fouling inside diameter.

APPLICATION EXAMPLES

Since its commercial introduction in April 2000 more than 200,000 feet of SCRE has been produced and installed as oil and gas flow lines or pipelines. In service product ranges from 1.00 to 3.00-inches in inside diameter with pressure ratings from 750 psi to 3,750-psi maximum allowable operating pressure (MAOP). Maximum allowable operating temperature ranges from 140 to 240 ^{0}F.

Following are general descriptions of some of the applications.

WATER ALTERNATING GAS (WAG)

An oil company operating in the Permian Basin has a number of fields that have been producing for more than 60 years. In one field, a WAG system is being used to improve production rates. This system poses a corrosion problem. While plain carbon steel can be used to convey dry CO_2, wet CO_2 necessitates pipe with some degree of corrosion resistance. Therefore, 316 Stainless or plastic lined steel pipe is required downstream of the WAG switching station. Not only is the pipe expensive, but the joints required are also costly. To reduce the long lengths of exotic piping, the WAG switching station is traditionally placed in near proximity to the well. This often results in two carbon steel lines to each injection well: one for (dry) CO_2 and one for water.

As a cost saving alternative, SCRE rated to 2,160 psi **MAOP** has been installed in a single line configuration and has operated for approximately 18 months. The brine at 1,650-psi is alternated with 100 % CO_2 at 1,800-psi SCRE has also been installed as a part of a CO_2 flood. Typically the lines handle 100 % CO_2 at pressures up to about 2,160-psi and 140 °F.

WATER INJECTION LINE APPLICATIONS

The most common application has been water injection lines for re-injection of produced waters (brines). Produced water is generally quite corrosive and often contains some hydrocarbons and in some cases small percentages of CO_2. In some areas there is also concern about external (soil induced) corrosion. Water Injection lines have been installed using several different methods.

Surface

In an area with very close well spacing (~80 feet) SCRE was installed directly on the ground and routed around existing surface installations. Changes in direction were accomplished by taking advantage of the flexibility (minimum bend radius) of the pipe. The operator selected the SCRE because the fluid and soil are both corrosive and the light weight of the product made it possible to install the lines without the use of heavy equipment. The lines are operating at between 600 and 1,000-psi.

In other surface installations, the operator has elected to install the product on supports above the ground. This decision resulted in part because of the number of crossing pipelines buried in the area. The SCRE was pulled directly from the shipping spool onto the pipe supports and clamped in place using supports that avoid abrasion and point loading. In some cases the supports are concrete sleepers about 6-Inches high. The use of sleepers makes the pipe more visible for maintenance.

Buried Installations

Buried installations of water injection lines are accomplished by the standard trenching method and also by plowing the SCRE into position.

Depth of burial varies depending on the location of the application. In Western Canada pipelines are typically buried to a depth of ~6.5 feet (~2-meters) to get below the permafrost. Surface risers are supported on metal channels anchored to bedrock to avoid permafrost heave. Standard trenching techniques are used and often multiple lines are placed in the same trench. When necessary, narrow trenches are used for single lines. This pipe is laid along side the trench and then lowered into place by hand. In other areas, with no permafrost, the depth of burial is as little as 12 ~inches.

In installations that are plowed in, the SCRE is laid on the ground and feed to the shoe on the plow. The shoe is designed to ensure that the minimum bend radius of the pipe is not exceeded. In a typical plow in installation in Western Canada, the pipe is installed at a depth of ~6.5 feet (~2-meters) at a rate of approximately 1-mile (5,280 feet) per hour.

In some buried applications, the SCRE has been placed inside a corrugated polyethylene pipe as it is plowed into position to provide a temporary, but protected, flow line. When the need for the line ends, the SCRE is recovered by pulling it back onto a storage spool for reuse with minimal disruption -of the right-of way.

PRODUCTION GATHERING LINES

Inmost cases flow lines handling hydrocarbons are buried. The thermoplastic liner material is selected for compatibility with the produced fluids and to provide the temperature resistance required by the application. At least one major operator has selected a 3-inch x 1440-psi SCRE for such an application that is non-corrosive on the basis of reduced cost of installation.

GAS LIFT INJECTION LINES

At least one operator has installed 2-inch x 1440-psi SCRE lines as part of a gas lift system. The SCRE is used to control the ~1,000-psi gas being used to enhance production. Often the gas used is untreated (corrosive) produced gas.

PIPELINE REHABILITATION

As wells and reservoirs age their production volumes often decrease but become more aggressive from the standpoint of corrosion. In a number of instances inserting a SCRE pipe inside the corroded steel line has rehabilitated pipelines that are otherwise not suitable for service. The rehabilitated pipeline has a reduced flow area but is corrosion resistant. The SCRE, unlike a thermoplastic liner, provides stand alone pressure resistance that is independent of the condition of the corroded pipeline. Rehabilitating pipelines is less expensive than replacing an existing pipeline because there is but limited trenching required and there is no need to disturb most of the right of way. Access is required only at the ends to be connected and in some instances at changes in direction if the radius of curvature is less than the minimum bend radius of the SCRE.

There are several methods for inserting a SCRE in an existing pipeline. The most common method involves blowing a wire-line through the pipeline. If necessary, the wire-line is used to pull a stronger line into place. The line is used to pull the SCRE into place. Lines have also been "inserted" into the existing line using a steel coiled tubing unit injector.

It should be noted that the SCRE is an "engineered product". Diameters are easily altered during manufacturing to fit the specific size of the existing pipeline to maximize the resulting flow area.

This approach is a cost-effective means to repair corroded pipelines. The resultant reduction in flow area is often found to be acceptable for existing conditions. The resultant line is a corrosion resistant stand-alone full-pressure pipeline.

Pipeline rehabilitation has been accomplished on land locked pipelines and shallow-water Gulf of Mexico lines. In shallow waters, the lightweight SCRE is held in place and protected by the corroded steel line.

PORTABLE FLOWLINE AND MEASUREMENT UNIT (PFAMU)

One operator has a developed a unique method of using the SCRE. His field has a number of wells that do not produce consistently. The wells are normally shut in and are no longer connected to production pipelines. These wells experience a build-up of pressure (and fluids) over a period of time. Bleeding the pressure, and recovering the salable hydrocarbons was traditionally accomplished by laying a temporary steel pipeline (discreet length joints of steel pipe with hammer union connections). This operation can be dangerous and costly.

In order to increase production while reducing costs, the operator developed the PFAMU trailer. Each PFAMU trailer includes a choke, gas-fluid separator, gas-water and oil volume measurement equipment, a gas accumulator; a nitrogen tank; and a powered spooler with 1,500 ft of SCRE. The PFAMU is used to bleed pressure /vacuum hydrocarbons from wells that cannot be economically produced by other means.

The PFAMU system is mated to the well; the SCRE **is** then pulled to the nearest producing well and teed into the production flow line. The choke is opened and the well is allowed to produce. While producing, the separated gas is used to fill the gas accumulator and the gas/oil/water ratios are measured and recorded. When the hydrocarbons have been produced and pressure has bleed down, the well is shut in. The gas accumulator is used to purge the CFCT line of the oil and gas. Nitrogen is used to purge the gas from the SCRE. The SCRE is then recovered to the spool to await the next operation.

To allow maximum utilization and safety, the SCRE is a 1.5-inch inside diameter product rated for 3,750-psi MAOP. Connectors are integral (wound in) using a field installation procedure. The product is a standard SCRE flow line that has been modified by adding to the scuff layer thickness.

The PFAMU allowed the operator to recover approximately $22,000 in oil equivalent products per well during the first month of operation. Improvements were made to allow greater oil equivalent recovery and a second trailer has been placed in service. . Each trailer is able to produce a minimum of one idle well per day. The operator expects to recover approximately $1,000,000 in oil equivalent products per trailer during **2001** at a significant reduction in operating costs. The SCRE goes through at least one "pay out and recover cycle" (a fatigue cycle involving SCRE bending with no internal pressure and dragging the **SCRE** across the ground) every day. After more than 60 days of operation only slight scuffing of the outer surface was observed.

OTHER APPLICATIONS

SCRE has been and is being developed for other oil and gas applications including:

- Coiled Tubing. SCRE coiled-tubing has been used in a number of injection applications and to perform pipeline surveys that could not economically be performed using alternative methods. This product is available but commercial applications have not been actively sought.

- Production Tubing. Production Tubing is a variation of Flowline and coiled tubing products. In some applications, standard Flowline has been used as specialty tubing. This product is available but commercial applications have not been actively sought.

- Umbilical Tubing More than 15,000 feet of 0.50 inside diameter – 10,000 psi MAOP tubing for umbilical applications has been produced to date. Some cabling has been accomplished. This product, being developed with a partner, requires further development.

- Composite Treating Iron A finite length product designed to replace "Chicksan" loops in high-pressure temporary flow lines is being developed. The product features metallic quick connect end fittings, integral strength monitoring features and a removable protective covering. This product requires further develop ment.

CONCLUSIONS

A tubular product conceptualized more than thirty years ago has been developed and commercialized. SCRE has become widely accepted by both major and independent oil operators for use in general flow line applications. Marketing efforts have been concentrated on How line applications because of the size of the market and relatively low risk of failures.

During 2001 and subsequent years efforts will shift to other oil and gas applications including production tubing, coiled tubing, umbilical tubing, risers and high pressure (15,000 psi) temporary flow lines.

During the last two quarters of 2000 sales and installations were limited by the single production line-plant capacity. Steps were taken to increase production throughput on the existing line to the present level of approximately 125,000 feet /month. In addition, a second production line has been build and installed. The second line will allow expansion of the product line to 3.5-inch and 4-inch inside diameter products and increase production levels to 250,000 feet/ month. A third line is planned for later in 2001 year.

REFERENCES

1. US Patent 3,769,127 "Method and Apparatus for Producing Filament Reinforced Tubular Products on a Continuous Basis." Goldsworthy et al. 1973
2. US Patent 3,956,051 "Apparatus for Making Fiber Reinforced Plastic Pipe." Carter. 1976
3. NIST/ATP Project 94-02-0038 "Spoolable Composite Tubing Joint Venture"
4. Lundberg, Chris et al "Manufacturing Process Development for Spoolable Composite Tubing" Paper presented at the ACS Energy Rubber Group Conference, Houston, TX January 1998
5. Walsh, T.J. et al "Advances in Manufacturing Technology for Spoolable Composite Tubing" Paper presented at Composites Materials for Offshore Operations – 2. Houston, TX October 1997

Table 2
Specifications for 3-Inch **Flow** Line

Maximum Allowable Operating Pressure			750 psi	1440 psi
Equivalent ANSI Pressure Rating			ANSI 300#	ANSI 600#
Nominal Geometry	*Outside Diameter*	Inches	3.36	3.42
	Inside Diameter	Inches	2.96	2.96
	Inside Flow Area	Square inches	6.88	6.88
	Wall Thickness	Inches	0.20	0.23
Nominal Weight & Density	*Linear Weight (in Air)*	Lbs./foot	1.17	1.41
	Linear Weight (in Water)	Lbs./foot	0.31	0.43
	Density	Lb/in^3	0.049	0.052
Flow Coefficients	*Hazen-Williams*		150	150
	Darcy-Wiesbach		0.0004	0.0004
	Manning		0.009	0.009
Coefficient of Friction	*OD of Tube in Dry Steel Conduit*		0.5	0.5
Axial Strain at MAOP	*With End-Cap Effect*	Inches/inch	7.8E-04	1.1E-03
	Without End-Cap Effect	Inches/Inch	-2.5E-03	-3.9E-03
Thermal Conductivity		BTU/hr/sq.ft.-in/deg F	3.0	3.2
Resin Tg		Deg F	212	212
Mechanical Performance	**Max. Operating Pressure**	Psi	750	1440
	Nominal Axial Tensile Rating	Lbs.	11,000	15,000
	Minimum Ultimate Crush	Psi	TBD	TBD
	Minimum Bend Radius	Inches	***56***	***57***
Temperatures	*Minimum Installation Temperature*	Deg. F.	-20	-20
	Maximum Operating Temperature	Deg. F.	140	140
Factory Acceptance Test Pressures	*Hydrostatic Test Pressure (min)*	psi	1125	2160
	Quick-Burst Test Pressure (min)	psi	2250	4320
Recommended Service		Flowlines for Brine & Petroleum Products Compatible with HDPE liner (PE3408)		
Materials of Construction	*Liner Material*	High-Density Polyethylene (PE3408)		
	Fiber Reinforcement	E-Glass and Carbon-Fiber **Roving**		
	Composite Matrix	Amine-Cured **Epoxy** Resin		
	UV Inhibition System	Carbon Black in Epoxy Resin		

Table 3
Comparison with Alternative Products
Pipeline Estimates Based on a One-Mile Line

DESCRIPTION	3"SCRE	3" SCHEDULE 80	3" CEMENT-LINED SCHEDULE 80
PRODUCT			
Inside Diameter, in.	2.96	2.90	2.52
Outside Diameter, in.	3.42	3.50	3.50
Flow Area, in^2	6.88	6.61	4.99
Liner Weight, lb./ft	1.41	10.25	11.75
Nominal length, ft	6,800	30-32	30-32
COSTS (1)			
Unit $/ft.	$8.50	$3.10	4.53
Installation, $/ft.	$0.15	$16.00	22.60
Total Installed Cost, $	$8.65	$19.10	27.13
Total Installed Cost, $	$45,672	$100,848	$143,246
Number of Joints	2	166	166
Total Pipe Weight, lb.	7,445	54,120	62,040
Min. Install Bend R, in.	52"	2280"	2280"

Note: 1. Based on a straight pipeline one-mile (5,280-feet) in length. Time estimates based on established practices and charged at $40.00/hour.

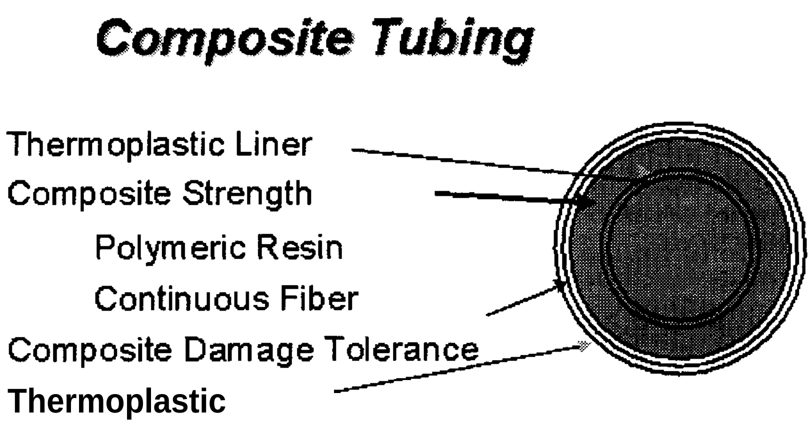

Figure 1 - SCRE Definition