Glass Reinforced Plastic Tubular Goods for Corrosion Resistant Service

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INTRODUCTION

Glass fiber reinforced plastic materials have, in the past decade, gained broad acceptance as a superior material for performance in highly corrosive environments. Their advantages and disadvantages as compared to metals in pipe and other tubular goods are as follows:

Advantages	**Disadvantages**
(1) High strength	(1) Low modulus versus metals
(2) High strength to weight ratio	(2) Higher initial cost
(3) Excellent corrosion resistance throughout entire wall	(3) Limited temperature service
(4) Good fatigue properties	(4) Strength properties are highly directional
(5) Directional properties permit efficient design	(5) Closer support spacing
(6) Easily cut and assembled	(6) More susceptible to mechanical damage
(7) Nonconductor - no electrolytic corrosion	(7) Generally flammable
(8) Low thermal conductivity	(8) Limited fabrication and machining possibilities
(9) Light weight - less expensive to transport and handle	

The excellent corrosion resistance will, in most instances, far outweigh any disadvantages where corrosion is a problem. The following discussion shows how the raw materials are utilized to give best strength and how tubular goods are tested to give performance ratings.

RAW MATERIALS

The plastic resins used with glass filaments are primarily limited to those that can be polymerized in situ. With these resins the glass strands can be impregnated before the resin is polymerized and thus, thorough wet-out, good bond of resin to glass and low void content (all of which are important to best properties) are obtained. Resins of this type are referred to as "thermoset" and differ from "thermoplastic" in that they cannot be melted after polymerization is complete, by application of heat. Because of this feature, thermosets have much greater strength retention at elevated temperature and will not "balloon" or permanently deform if their temperature rating is not exceeded. Like any organic materials, they will decompose if subjected to extreme temperature for a prolonged period of time. The most commonly used thermoset resins are discussed in the following paragraphs.

EPOXY

Of this type, the bisphenol A-based epoxies are the most predominantly used resins. They are available in a broad range of molecular weights, can be "B" staged for specific winding operations or can be wet wound. Epoxies are among the strongest plastic materials commercially available and have excellent corrosion resistance and high adhesion to most other materials. A large selection of cross linking agents are available; of these, the most often used are the acid anhydrides, aromatic and aliphatic amines, and catalytic materials such as the Lewis acid complexes. With this broad selection of resins and curing agents, the fabricator has wide latitude of product and process design and thus can highly automate for best uniformity and reproducibility of product.

POLYESTER

These resins are the condensation product of glycols and ethylenically unsaturated dibasic acids dissolved in a monomeric material such as styrene, vinyltoluene, di-allyl phthalate, methyl methacrylate, etc. By addition of a catalyst just prior to use, the monomer reacts with the unsaturated polyester by the vinyl polymerization mechanism. The reaction is usually quite rapid, very sensitive to heat and catalyst concentration and cannot easily be arrested or "B" staged such as some epoxy reactions can. The polyester polymerization is more difficult to control in high production automated filament winding systems and therefore is primarily used for hand fabricated pipe, ducts, and similar applications.

Polyesters can be made from a broad selection of raw materials to produce properties such as self-extinguishing, good acid resistance, good flexibility, etc. They are generally somewhat lower in tensile and flexural strength than epoxies and are not resistant to strong solvents and strong caustics. The general purpose, low cost polyester resins such as used for boats, furniture and decorative purposes are not suitable for high strength corrosion resistant applications. A polyester having good resistance properties is approximately as costly as the epoxies; the user should not expect any substantial economic advantage by selecting a polyester pipe over an epoxy pipe.

PHENOLICS

Phenolic resins were among the first synthetic plastic materials produced commercially; their use dates back many decades. They are basically the condensation reaction of phenol and formaldehyde. When cured, they have excellent high temperature performance, good acid resistance and usually are brown to black in color. They must be cured at elevated temperature and moderate to high pressure to prevent foaming and porosity. The latter features limit their use in filament winding processes; therefore these resins are the least desirable of the thermosets mentioned.

GLASS REINFORCEMENTS

Practically all glass used in strand, roving, cloth, or chopped strand mat form is E glass. The chemical composition of E glass is approximately:

Silicon Dioxide	52-56 Per cent
Calcium Oxide	16-25 Per cent
Aluminum Oxide	12-16 Per cent
Boron Oxide	8-13 Per cent
Sodium and Potassium Oxide	1- 4 Per Cent
Magnesium Oxide	0- 6 Per cent

The virgin tensile strength of E glass is approximately 500,000 psi, with a modulus of elasticity of 10.5×10^6 psi. This glass was originally developed for the electrical industry and, as such, has excellent dielectric properties but only moderate chemical resistance, especially to strong inorganic acids. The ease with which E glass fibers can be drawn and large volume production make it the most economical glass reinforcement material available. Other glass compositions are available having better acid resistance but their cost is two to five times that of E glass and their use would greatly increase the cost of the product.

DESIGNING FILAMENT WOUND STRUCTURES

When designing with reinforcement filaments embedded in a plastic resin, several factors must be considered. The more important of these are the angle of the reinforcement to the applied stresses, the tensile strength of the resin, the strength of the bond between the resin and the filaments, and the ratio of reinforcements to plastic by volume. Much basic research has been carried out by many laboratories to establish the parameters of good design considering these and other factors. The ideal design aligns the glass filaments to utilize their tensile strength to the best advantage.

In a simple closed-end piping system the hoop stress is twice that of the axial stress. The optimum angle of reinforcement to absorb these stresses is 35-1/4° from the normal to the axis of the pipe. The ideal angle of reinforcement for a torque tube would be 45°. When pipe or tubular goods are to be submitted to additional external stress as well as internal pressure such as encountered in down-hole tubing, axial glass filaments are added to absorb the applied external tensile load. Figure 1 shows the tensile strength versus angle of reinforcement for an epoxy glass filament matrix. Note that as the angle of applied stress approaches 90° to the longitudinal direction of the filament, the ultimate tensile strength falls below that of the epoxy resin itself. This reflects the strength of the bond between the glass fiber and the resin. It is, at best, approximately one-third to one-half that of the resin itself and is the weakest point in the matrix. From this data and data from short term burst and cyclic test work, an allowable stress is developed and the glass pattern and wall thickness calculated for given conditions of end use. The greatest strength for a given wall thickness is obtained when the glass fibers are uniformly tensioned and laid parallel to each other. It was noted while discuss-

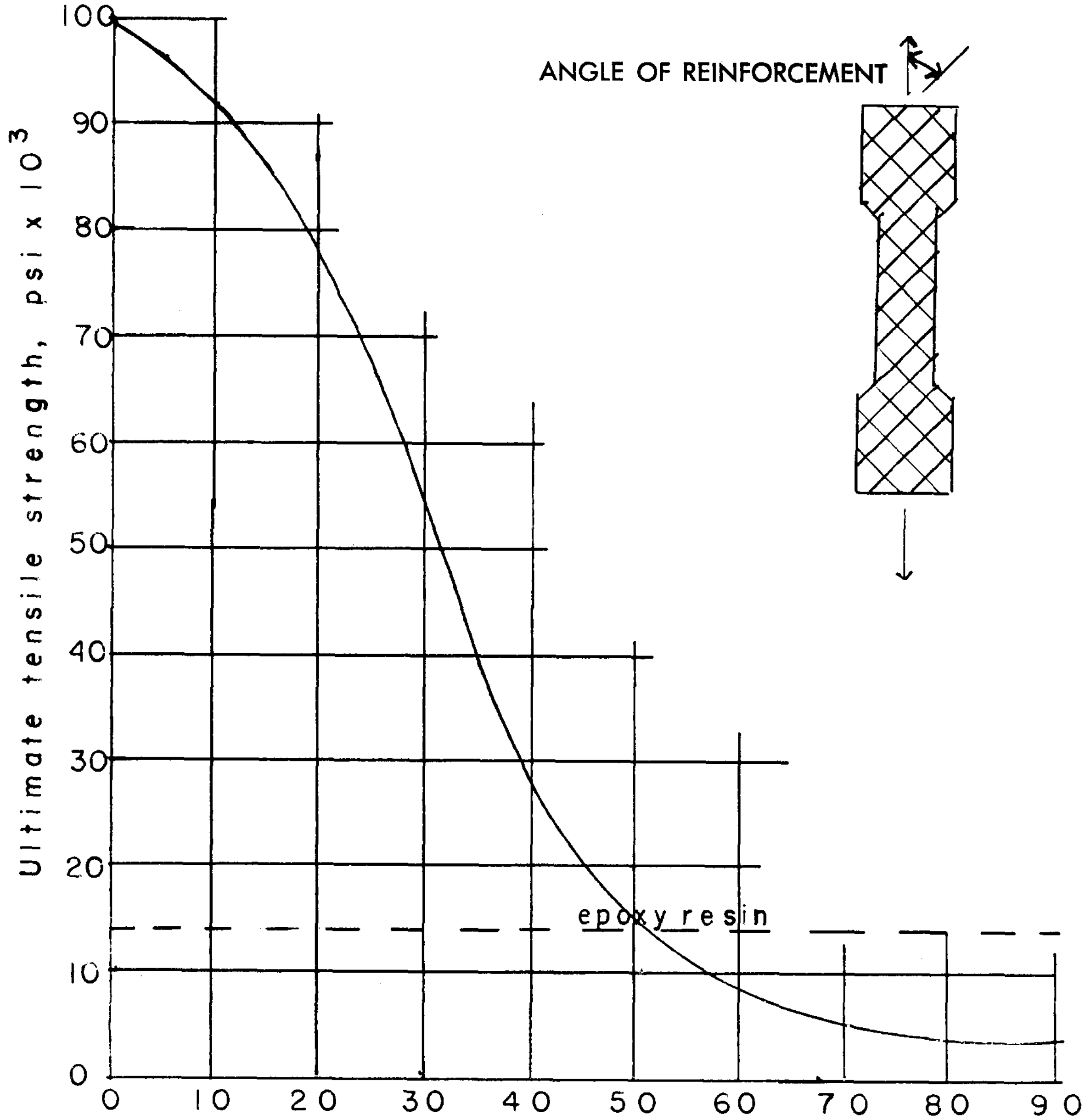

FIG 1 Tensile strength versus angle of reinforcement

ing raw material that the virgin tensile strength of E glass is 400,000 to 500,000 psi. Subsequent handling during a winding process abrades the glass and reduces this strength to a usable 200,-000 to 250,000 psi. If the glass were to be spun into a roving or woven into a cloth, the usable tensile strength would be reduced still further because of crossed fibers abrading each other and crimping during the weaving or spinning process. Thus, the engineer can design with far greater reliability and confidence when the product is made by a machine filament-winding process.

TESTING AND RATING OF GLASS FIBER REINFORCED TUBULAR GOODS

Rating for Pressure

Because of the hetrogeneous nature of glass reinforced plastics, the test methods to develop rating cannot be the same as those applied to metals. Failure of a glass filament reinforced plastic pipe under internal pressure is normally by weeping, rather than catastrophic. These weeping failures start as a fracture between the resin and glass at the interface and propagate under repeated cyclic or long term static pressure through the pipe wall creating a minute fluid path to the outer surface. Since failures of this type are a function of time, pressure, and frequency of cyclic loading, short term pressure to burst are not valid for rating unless extremely large safety factors are applied. A more valid method of rating long term performance is the cyclic loading method developed by the manufacturers of glass reinforced plastic pipe, now adopted by the American Society for Testing and Materials and described in detail in procedure ASTM D-2143-63T.

Using this test method, pipe is pressurized from approximately 60 psi to some preselected high pressure at a rate of 25 cycles per minute as shown in Fig. 2. The pipe specimen should be at least 10 times its diameter in length and tested under free-end condition. Data from several pressure levels are plotted on a cycles-to-failure curve and projected to 1.5×10^8 cycles which corresponds to 100,000 hours (11.4 years). By this method of regression analysis, the allowable hoop stress for a given resin system, glass pattern, and winding condition can be established using one size of pipe and ratings calculated for other diameters using the formula $S = \frac{P\ (D^1 - t)}{2\ t}$ where

S = Hoop stress, psi
P = Internal pressure, psi
D_1 = Average outside diameter, inches
t = Minimum wall thickness, inches

Static pressure testing is performed as described in procedure ASTM D1598-63T. A schematic of the test apparatus is shown in Fig. 3. Figure 4 shows a plot of data obtained on glass filament reinforced epoxy pipe having an inside diameter of 2.235 in. and a wall thickness of .070 in. Also shown is a regression analysis for similar pipe under static pressure conditions and a comparison with data accumulated on 4-in. I.D. pipe over a period of two years under environmental test conditions. In the latter, a test loop was installed and monitored at the Southwest Research Institute, San Antonio, Texas, with sections approximately 220 ft long maintained at pressures of 600, 450, 300, and 150 psi, and at a temperature of 140°F to 160°F. Pipe which has ratings established by this method should be of particular interest to petroleum producers since cyclic loading from reciprocating pumps and high pressures are more frequently encountered in this industry than in most others.

Corrosion Resistance Testing

Of equal importance to the user is the resistance of the reinforced pipe to attack by the contained fluid. One method of testing currently being considered by ASTM as an established procedure is to cut specimens from the pipe to a 3-in. length, seal the cut edge with an epoxy coating to prevent wicking along the fibers and immerse in the test fluid at various temperatures up to the rating of the pipe. Several sections are immersed and a specimen is withdrawn at predetermined intervals to determine strength retention by pulling in hoop tension. The tensile test is conducted on 1/2-in. long rings cut from the center of the 3-in. long test specimen to eliminate any effect of attack on the cut end and exposed glass fiber.

Tests of 1 month, 4 months, and 16 months are used to plot a curve of strength retention versus time. Generally, a leveling of the strength retention curve will be noted after the first few months. A retention in strength of 90 per cent after 1 month, 70 per cent after 4 months, and 55 per cent after 16 months is considered acceptable, bearing in mind the specimen is exposed from both inside and outside. One-month data will usually give a reasonable projection of corrosion resistance but definitely should be confirmed by 4-month data and readjusted for temperature limitations, if necessary, after 16 months.

Over four years of test history in our laboratories, compared with actual test installations, some of which date back 10 years, have indicated these tests are valid and probably somewhat on the conservative side. 85 per cent to 90 per cent strength retention was found on pipe from one installation after four years service, and 70 to 75 per cent on a second after six plus years service. Laboratory tests with a similar fluid showed approximately 85 per cent retention after 16 months.

CASE HISTORIES AND COMPARABLE COSTS

Costs

Typical costs of a central battery using an aggregate of 1850 ft of 3, 4, and 6-in. pipe with

SCHEMATIC DRAWING OF CYCLIC PRESSURE TEST EQUIPMENT

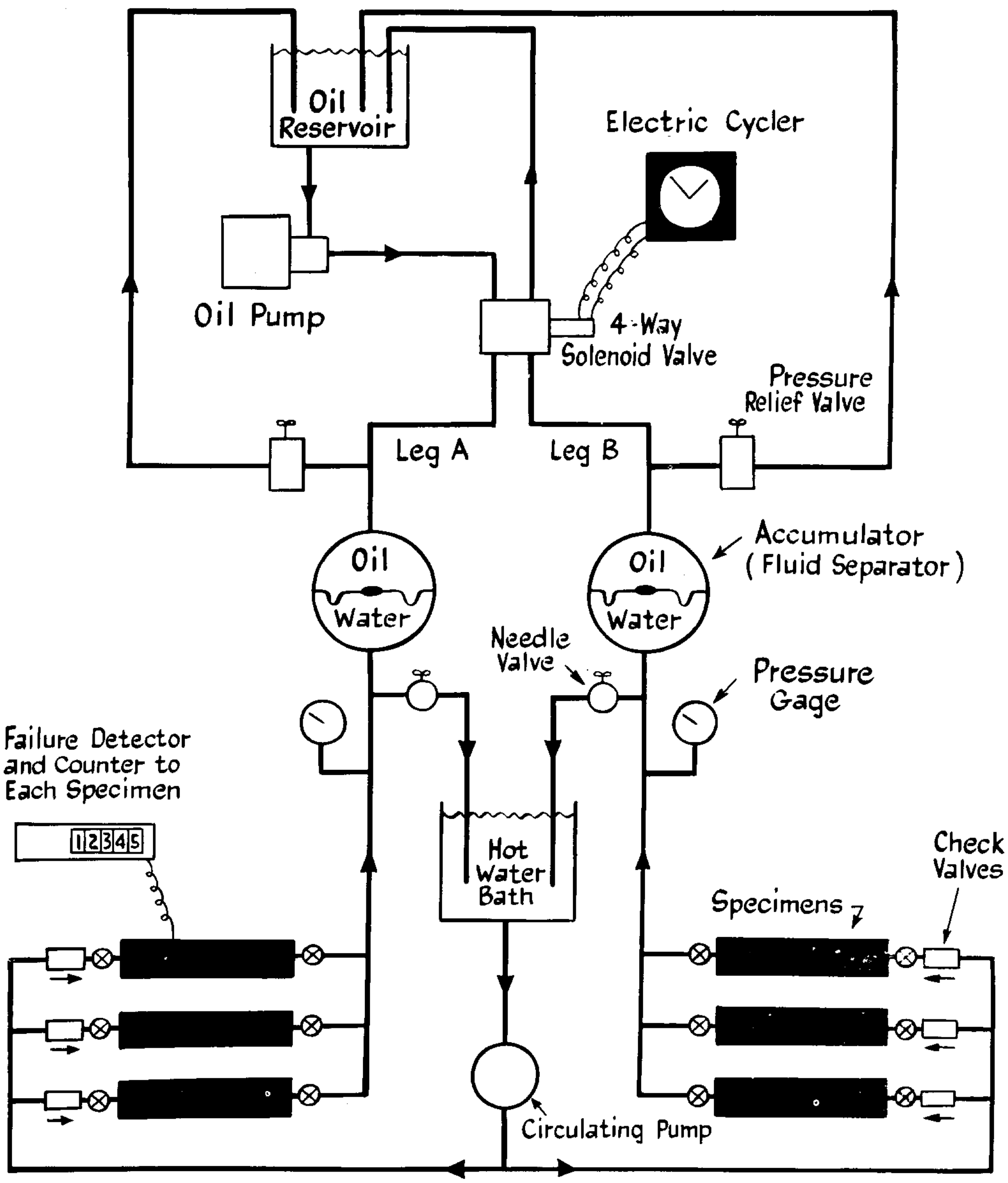

FIG 2

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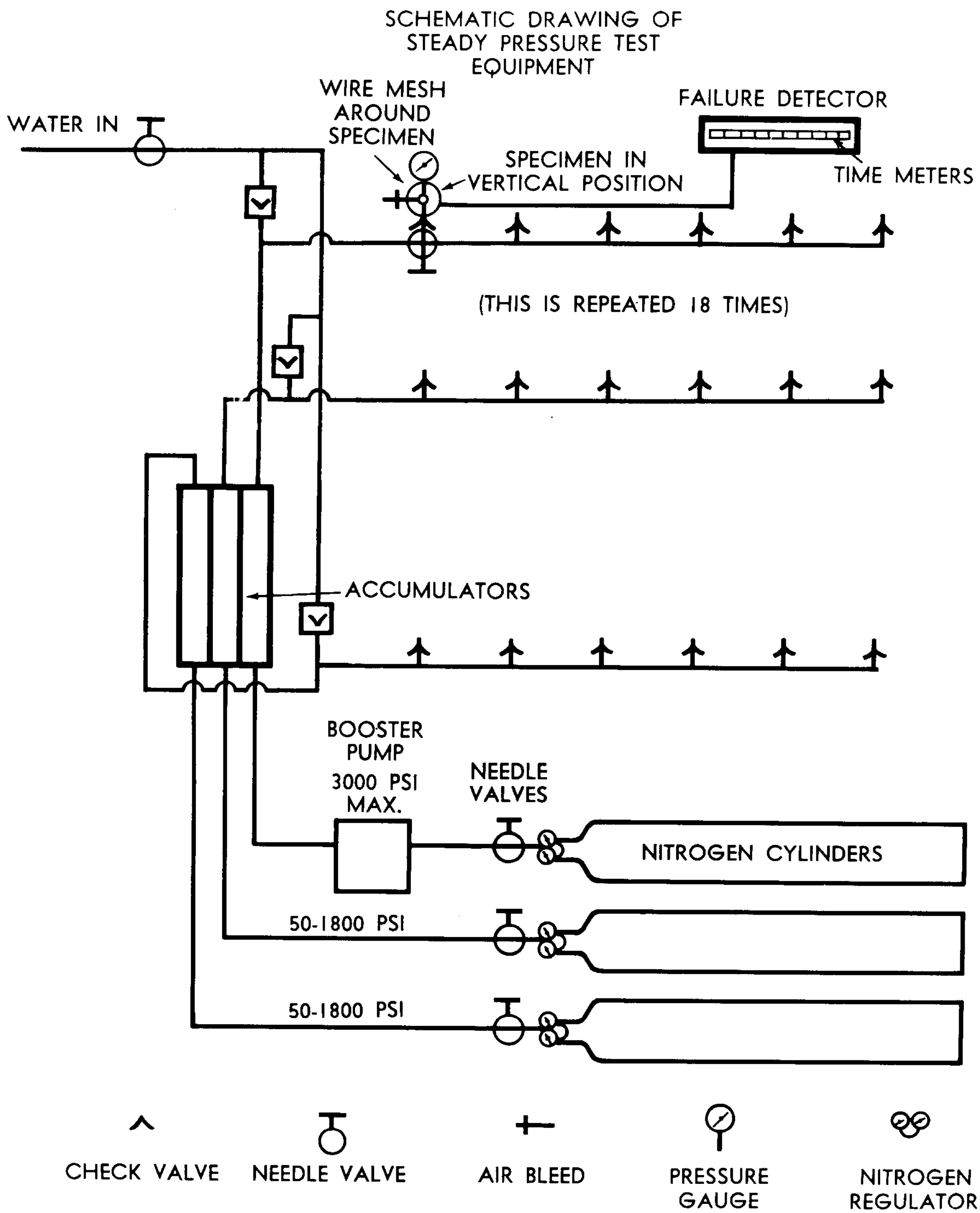

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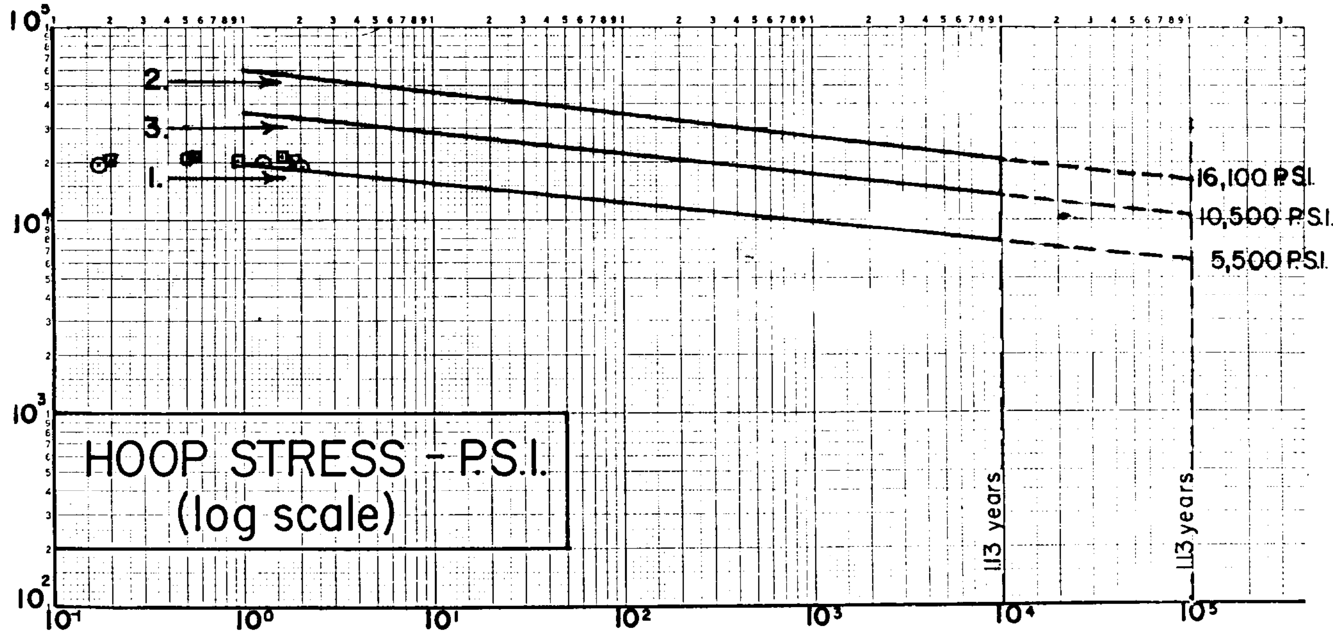
FIG 3



1 — Cyclic Pressure @ Room Temperature — ASTM D2143-63T

2 — Steady Pressure @ 73.4°F — ASTM D1598

3 — Environmental Test @ 150°F

— Installed July 1959, removed for cyclic test July 1965. Location — Western Oklahoma; Service — Salt Water 10-50 psi & 110°F

□ — Installed June 1962, removed for cyclic test May 1966. Location — West Texas: Service — Oil at 40 psi

Figure 4 -- Hoop Stress versus Hours to Failure Performance Curves for Long Term Performance Red Thread Pipe.

208 assorted victualic and threaded fittings were calculated for bare steel, plastic coated steel, and glass reinforced bonded joint epoxy line pipe and shown as follows:

System	Material Cost	Labor	Total Cost
Bare Steel	$5,640.46	$1,500.00	$ 7,140.46
Coated Steel	$7,955.02	$2,100.00	$10,055.46
Epoxy Pipe	$8,503.66	$1,200.00	$ 9,703.66

A similar calculation was made for a conventional tank battery layout as follows:

System	Material Cost	Labor	Total Cost
Bare Steel	$1,176.36	$ 450.00	$ 1,626.37
Coated Steel	$1,793.27	$ 600.00	$ 2,393.27
Epoxy Pipe	$1,940.02	$ 300.00	$ 2,250.02

In addition to much longer service life under severe corrosion conditions, additional savings may be realized by increased flow due to larger I.D. and lower friction factor. An excellent example of savings to be realized where corrosion is a problem can be shown where a prefabricated glass reinforced epoxy pipe water leg replaced plastic coated steel. The plastic coated steel, today's cost approximately $265.00 plus installation, had to be replaced at 6-month intervals. A prefabricated epoxy pipe leg cost $386.00 and has been in service six years. Over this period $3180.00 would have been spent on plastic coated steel, showing a savings of $2794.00 on material alone.

Other savings may be realized in the reduction or elimination of a paraffin or scale problem. Again, the smooth bore and low thermal conductivity of the plastic pipe will frequently alleviate paraffin build-up. One installation where eight bare steel flow lines each had to be steamed eight times a year was replaced with glass fiber reinforced epoxy pipe. The lines averaged 1200 ft in length and the cost was $10.00 per steaming per line. After four years' service, the epoxy pipe had not required any treatment. Money saved in this case is as follows:

	Per Foot	Total
4 Years	$0.266	$2,560.00
10 Years	$0.665	$6,400.00

If the epoxy pipe will go 10 years without treatment, the savings from the paraffin problem alone will nearly cover the cost of the pipe, not taking into account any advantages realized by solving corrosion problems.

Another paraffin problem, although not completely eliminated, showed an even more drastic savings. Approximately 300 ft of pipe was hot oiled 16 times a year during cool weather at a cost of $50.00 each. Use of epoxy pipe reduced treatment to once a year for an annual savings of $750.00.

Most types of scale will not adhere to the smooth I.D. of epoxy pipe. Scale build up may occur if flow is extremely sluggish, but since adhesion is low, a gentle tapping will usually break loose the scale for easy flushing out or dumping. An excellent comparison is noted in one Southwest Texas disposal system where three steel lines that had been plugging with scale every six months were replaced with epoxy pipe. Lines A (1200 ft) and B (600 ft) were gravity fed and flow was extremely slow, approximately 250 BWPD. Line C (2500 ft) moved approximately the same volume with a pump over a 2-hour period. Lines A and B still scaled up approximately twice a year but have the advantage over steel in that they can be disconnected every 100 ft (victualic couplings were installed) and the scale merely dumped out. Line C (on pump) had no scale after 18 months.

Cost of 0.125-in. wall steel pipe was $1505.00; the epoxy pipe $3311.00. The cost of replacing the steel every six months for the 18-month period then was $4515.00 or a savings of $1204.00 which more than covered the cost of dumping scale from lines A and B. Additional savings will, of course, be realized with time since the epoxy pipe will be usable for many years.

Other unique savings may also be realized. One such case has been described in the **Oil and Gas Journal.**[1] Here, 4-in. epoxy pipe was inserted in an old cement-lined steel gathering line buried under valuable cotton crop land. A savings of $2500.00 in ditching and crop damage costs was realized and made possible by the light weight and better flow factor of the epoxy pipe.

SUMMARY

Glass fiber reinforced plastic tubular goods have definite economic advantages where corrosion of metallic materials is a problem. Other unique features may result in additional savings. Proven performance and well developed test methods for realistic ratings are established. Limitations are primarily those of high temperature and extremely high pressure. Sound engineering back-up and a growing trend toward industry standardization of ratings and test methods should make this type product even more attractive to the petroleum industry.

REFERENCES

1. W. B. Bleakley, **Oil and Gas Journal** (August 8, 1966)