A Practical and Realistic Method To Evaluate Filament-Wound Glass-Resin Pipe

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WHY FILAMENT WOUND GLASS-RESIN PIPE?

To establish specifications for filament-wound glass-resin (FWGR) pipe, it seems best to briefly review basic requirements. Filament-wound glass-resin pipe has been developed and is being widely used today as a replacement material to eliminate the age old problem of chemical attack that has long plagued iron and steel pipe. Chemical attack takes place both internally by the liquid or gas being conveyed, and externally by environmental conditions. The word "chemical" includes the actions of rust, corrosion and electrolysis. Other advantages of filament-wound glass-resin pipe, such as its light weight and ease of handling, are usually secondary in importance to its advantage of high chemical resistance.

In addition to chemical resistance, a material suitable as a replacement for steel must obviously have physical properties similar to steel and filament-wound glass-resin is a "tough" material. The word "tough" has been used rather than "strength", as an item can have great strength, yet be brittle and easily damaged on impact. There are, of course, a number of materials such as concrete, clay, PVC, polyethelene, and ABS which can solve one or more of the chemical-type problems, but lack the steel-like requirements of "toughness".

Filament-wound glass-resin pipe is indeed unique as it can provide both a wide range, highly chemical-resistant product, and yet exhibit the "toughness" of steel.

TODAY'S SPECIFICATIONS

While FWGR pipe can and should be all that has been stated, it is not magical. The desired result comes about only by wise use of methods and materials. Good, practical specifications are needed, yet there are few, if any, specifications presently existing that enable a user to adequately evaluate FWGR line pipe for use in the petroleum industry.

True, TENTATIVE API STANDARD 5 LR exists.[1] However, there is absolutely nothing in this specification that in any way covers chemical resistance. Even for pressure ratings, Standard 5 LR must be interpreted. Numerous tests, both short-term and long-term, steady-state and cyclic, have been worked out in detail; yet there is no way given to convert this data to actual pressure ratings, the buyer's terminology. The buyer can derive ratings with a slide rule and by developing his own conversion factors; however, it will be shown that other factors can completely negate the extrapolation of one or two months of test data to 12 years.

There is another specification entitled PROPOSED METHOD FOR THE IDENTIFICATION AND PRESSURE CLASSIFICATION OF MACHINE-MADE REINFORCED THERMOSETTING RESIN PIPE.[2] This specification goes into great mathematical detail, but to convert all of the test data to actual pressure ratings, one must multiply by a "Service Design Factor" and, as the specification says, "It is not the intent of this standard to give service design factors". Likewise, this specification overlooks the simple factor of corrosion resistance, although it states that the scope includes "pipes for conveying petroleum products, or corrosive fluids".

Various users have tried to work out their own specifications. One user has done a great deal of work on flow; he discovered that the smoothness of the internal surface of some pipes can change by a factor of four (4) after a simple 30-day tap-water flow test. Another user has done considerable work on ultraviolet tests, and some are starting to ask pertinent chemical questions.

GENERAL SPECIFICATIONS

In answer to the long felt need for realistic and practical methods to evaluate FWGR pipe, the attached evaluation chart (Table 1) was developed. It has the following features:

1. Comparison is on a total performance basis, including chemical and other life expectance factors, often overlooked.
2. The data is not difficult to compile, nor vague in interpretation. The results give the user a set of good, solid, practical data for evaluation and comparison. While most of the data can be obtained from the manufacturer, it can be checked by simple laboratory tests.
3. The chart serves as an excellent guide for the addition of specialized requirements, without overlooking the total picture.

The following sections describe each item in the evaluation chart, and explain why the data is important.

Chemical

Since chemical consideration is the prime motivation of FWGR pipe, some method must be adopted for chemical resistance evaluation.

Resin manufacturers have, for years, used water absorption coefficients as a general measure of chemical resistance; however, such tests require special equipment and would be difficult to evaluate from an end-users standpoint.

Some resin manufacturers publish a very lengthy list of chemicals, together with a go, no-go chart for two or three selected temperatures. Such chemical resistance tables are fine and some FWGR pipe manufacturers have reproduced them for their products. In reality, such tables give the user a feel for chemical tolerance, but often do not cover his specific need. Furthermore, such tables are difficult to check without going to elaborate and costly laboatory analysis.

This writer proposes a rather simplified approach. Chemical properties can be categorized as acids, alkalies, salts, and hydrocarbons.

ACIDS.—In the oil field are hydrogen sulfide gas and water, usually forming sulfuric acid in solution. Also, acid compounds are used in acidizing wells. Thus, to evaluate chemical resistance from acid attack, a 20 per cent solution of sulfuric acid is designated as test bath #1.

ALKALIES.—Alkali attack usually comes from the surrounding soils although it can be formed in low percentages in some solutions. Caliche soil, for example, is a mild alkaline mixture. One of the common strong alkaline chemicals is sodium hydroxide. A 5 per cent solution of sodium hydroxide is designated as test bath #2.

SALT BRINE.—Salt water is another solution common to the oil field. Concentrated salt brine makes up test bath #3.

HYDROCARBONS.—Hydrocarbons can, of course, be broken down into various components having many forms and combinations. Tests and evaluations can easily become quite complex, costly, and even more difficult to evaluate. As a practical simplification, use as sour a crude as is available. Almost any crude will give similar results with regard to attack on the resins used for FWGR pipe. Sour crude is designated as test bath #4.

SPECIAL.—In addition to the above series, the user can easily add any specific chemical bath for special applications. For example, one user, for the last four years, has been using FWGR to handle a 15 per cent sodium hypochlorite solution. Although he was reassured for this specific application, weeks of actual tests were run. Likewise, mining engineers have thrown sections of FWGR pipe into their chemical vats for months of observation.

FITTINGS.—Obviously, fittings are just as much a part of the total system as is the pipe. Similar chemical tests can, and should, be conducted for the fittings.

CONNECTION SEAL RINGS.—Some types of threaded connections use a seal ring of some material such as neoprene. In making the chemical tests as described above, on the pipe and fittings, such rings can also be tested at the same time.

In using the above specified chemical baths, the following procedure is recommended. Cut 4-6 in. lengths of the desired size pipe, such as 2-in., using typical samples from selected vendors. Slit the selected specimens lengthwise to give two identical half-shells, immerse one of the half-shells from each of the selected vendors in each bath at room temperature, approximately 77°F, for 1000 hours. At the completion of the 1000-hour test, clean and dry all samples and examine thoroughly, checking for inner and external surface attack. It is best to keep an additional sample of each type for comparison purposes.

A whitening of the inner surface indicates the chemical has removed the resin, exposing bare glass fibers. A darkening, or color change, of the external surface, indicates some form of decomposition.

Toughness

WEIGHT, F.W. GLASS.—The basic tensile strength of the wall of a FWGR pipe is almost entirely dependent on the quantity of glass. To evaluate the basic tensile strength of competitive products, one need only know the weight per foot of the filament wound glass content and be cognizant of the wind-angle vectors.

WIND ANGLE.—Because the hoop, or burst stress of a pipe under pressure, is twice the longitudinal or blowout force, filament winders generally use a wind-angle pattern that gives twice the hoop strength to the longitudinal or blowout. The "magical" wind-angle vector to do this turns out to be 35-1/4°, using circumferential as 0°. In achieving this vector angle, some vendors use a double angle pattern with a vectorial sum of 35-1/4°. The double angle pattern sometimes called "Hi-Lo", builds locking triangles, rather than a rectangular pattern from a single angle wind.

Thus, knowing simply the weight of filament wound glass per foot (not glass and resin) and assurance of proper wind-angle vectors, pipes can easily be compared for basic tensile strength.

RESIN, ELONGATION.—Glass strength is all well and good, but to achieve the "toughness" capability of the glass, the resin used must have elongation properties that allow the glass to do the work. Glass has an elongation of three to four per cent and the resin, to properly accommodate, should have an elongation in the neighborhood of 12 per cent, allowing for initial and subsequent stresses.

WALL STRUCTURE.—In achieving true "toughness", three methods are presently being used to eliminate a pipe's tendency to "weep":

1. Uni-Structure. Here the total wall of the pipe is filament wound with glass and resin, and special techniques are employed in the winding phase to break up and prevent weep capillaries. It is felt that this product tends to be more susceptible to impact, pressure surges, and ultimate weep.
2. Liners. The opposite approach to uni-construction is the use of a heavy inside liner material that is soft in nature and pliable enough to prevent weeping, even though the main wall be fractured or quite porous. The result is analogous to that of the old inner tube in the automobile tire. By definition, a liner is a material different from the glass and resin used in the main wall of the pipe.
3. Resin-rich Inner Surface. A third approach to toughness and the elimination of weep, is the technique of using a resin-rich inner layer. A resin-rich inner layer is nothing more than a thin layer of pure resin (having no glass content) on the inside of the pipe. With proper manufacturing techniques, this resin-rich layer: (1) eliminates the problems of weep or seep, (2) forms a molecular (chemical) bond to the main filament wound wall, and (3) does not introduce a new substance for chemical evaluation.

Resin-rich layers should not, and usually don't, contain plasticizers.

Pressure Ratings

Rated pressures are, at present, somewhat a vague term, since allowances for surges and safety factors are not specified. It is further recognized that safety factors differ for lower-pressure pipe (under 500 psi) compared to higher-pressure pipe (1000 psi and over). Below is a proposed specification for pressure ratings of 500 psi and lower. FWGR pipe in this classification shall meet the following.

STATIC.—Ten samples selected at random, shall be pressure-tested at five times the published rated pressure. This static pressure shall be maintained on each sample for a minimum duration of ten minutes. During this time, there shall be no weep, seep, leak, or burst. A weep shall be declared if, at any point on the surface of the pipe under test, a seepage of as much as one-thousandth of a milliliter of liquid or gas occurs over any square inch of surface. It is to be noted that the ten-minute duration test differs from a "linear-dump" technique.

LONG TERM CYCLIC.—The long term cyclic test procedure is outlined by the API STANDARD 5 LR. This one test is not simple to conduct or check. Vendors usually have the testing done by an outside facility and can furnish copies of the certified results to prospective users. A plot can then be made of the total cycles to failure, versus the cyclic pressure on log-log paper. With a straight line through the data points, extrapolate to twelve years. The resultant pressure at the twelve-year extrapolation point shall not be less than 2/3 of the published rated pressure.

To properly access this cyclic data factor, we need to have some idea of pressure surges in FWGR pipe. As an example, compare surges in long 3-in. pipe lines flowing at 3 ft/sec, for both steel and FWGR, using the following equation:[3]

$$\text{Since} \quad p = V\sqrt{\frac{wE}{g}\left(\frac{1}{1 + \frac{E}{E'}\frac{d}{t}}\right)}$$

The increase in pressure for a rapid valve closure in a long line is:

Steel = 168 psi increase (Max.)
FWGR = 75 psi increase (Max.)

The increase in flow for a simplex double-acting pump is 60 per cent over average,[4] an increase in flow of 1.8 ft/sec for an average of 3 ft/sec. The increase in pressure then becomes

Steel = 100 psi increase (Max.)
FWGR = 45 psi increase (Max.)

Another interesting comparison is the length of a pipe required to hold, by expansion, the increase in volume of one pump discharge with a pressure increase of 200 psi:

since:

$$L \cong \frac{t\,E\,V}{2\,P\,r}$$

therefore

Steel = 29,600 ft
FWGR = 715 ft

As the above data shows, pressure surges typically found in steel lines will be much less when using FWGR products. It should also be emphasized that cyclic testing is based on first detectable weep or seep, and does not mean a total line failure, in any sense, nor is the data based on any catastrophic failure, such as burst. The step from first detectable weep to actual burst pressure, would still be a large margin.

CAUTION—At this point it is again emphasized that long term cyclic data is valid only to the extent that possible "Mechanical" and "Life Expectancy" degradation factors, as explained later, are not found to be significant.

The maximum published pressure rating of a pipe shall be that value which meets or exceeds both the static and the long term tests as outlined.

It is to be noted that pressure ratings, in keeping with the above static and cyclic tests, are derived from actual pressures applied to the test samples and are not involved with either wall thickness or optional conversion factors. Thus, the user receives a product tested to his own terminology parameters, and it is left to the manufacturer to produce a product that meets the requirement.

ULTRAVIOLET SENSITIVITY.—To determine ultraviolet sensitivity, cut a single length of pipe in half. Subject half to an ultraviolet source of such intensity and duration, that an equivalent twelve year exposure to the ultraviolet portion of sunlight is achieved. At the end of the exposure, pressure-test the ultraviolet-exposed section against the half that was not exposed. The ultraviolet sensitivity or derating factor is defined as the failure pressure of the untraviolet-exposed section, divided by the failure pressure of the unexposed section. The published rated pressures shall be reduced by this multiplication factor. A factor greater than unity shall be cause for rejection of the test as due to either unreliable instrumentation or uncured pipe.

FITTINGS.—In any pipe system wherein fittings will be used, pressure ratings should be adjusted downward if the fittings carry a lower rating. Special consideration should be given to any molded fittings such as tees and ells.

Mechanical

FLOW FACTOR.—Relative flow factors can be checked by the following test: Procure, or make up, a 24-in. length of 2-in. pipe from each selected vendor, having all ends spigoted. Bond all specimens together with collars. Circulate tap water through the composite test sample pipe at a rate of 2 ft/sec for 1000 hours. At the completion of the test period, dismantle the individual sections and slit length-wise for visual inspection of the interiors. It is suggested that evaluation be based on a comparative rather than on an absolute flow factor basis. The absolute determination of flow factors, such as the Hazen-Williams coefficient, is fairly tedious and time consuming.[5] For absolute values, it is perhaps best to solicit this information from the individual vendors.

VACUUM.—In a typical flow line, there are usually times when vacuum surges are encountered. Generally speaking, the filament wound wall of a pipe of 2-in., 3-in., 4-in., or 6-in. size has ample rigidity to withstand vacuum pressures. The condition of failure due to vacuum has been encountered when an inner layer of the pipe, such as a liner, does not adhere well to the overlay filament wound structure. Under this condition, any small seepage of air through the outside filament wound structure, can cause inward collapse of the inner layer. Resin-rich inner layers do not exhibit this problem if they are molecularly bonded to the winding structure.

FIELD ASSEMBLY.—In assessing the composite value of pipe lines, consideration must be given to field work. For example, in cut-and-fit applications, such as around tank batteries, the user must be assured that the resulting connections are in keeping with all features of a typical line, minimizing the possibility of a "weak link in the chain." Interchangeability of fittings may also be required. Obviously, any evaluation of assembly conditions can only be made in accordance with user requirements.

Life Expectancy

In evaluating the long-term life expectancy of FWGR pipe, there are additional factors for consideration that should be investigated.

RESIN.—Most resins used for FWGR pipe are quite stable and have long-expected lives. Historical life data on the basic types of winding resins goes back well beyond data on filament-wound line pipe, as the manufacturers of the basic resins have been accumulating long-term data for many years. Most are in a position to assure the user of resin life in terms of 20 to 100 years, if, as they are quick to qualify, the manufacturing process of catalyzation and cure gives full cure to the resins involved.

RESIN CURE.—In producing FWGR pipe, the resins used are changed from a liquid state to a solid by a process called cure. Unless fully cured, the resin may appear hard but has not reached the intended, or final mechanical properties. There is a tendency for resins that are not fully cured to become more brittle as time goes on. Generally speaking, epoxies are more difficult to fully cure than are polyesters.

In conducting ultraviolet tests, one user employed a lamp having a high heat radiation output. Certain specimens actually showed a harder structure after the test than before.

Hardness can be checked with a Barcol meter and tests can be run by placing selected samples in an oven at 250°F for three hours, checking the Barcol reading before and after.

Obviously, any tests made on FWGR pipe samples having resin that is not fully cured, are of no value in making 12-year estimates.

PLASTICIZERS.—It is necessary to determine if any plasticizing agents, added to either the filament-winding resins or liners, have long-term degradation effects. As explained earlier, any long-term hardening of resins, or of liner embrittlement, completely nullifies long-term estimates. Such lines can be expected to exhibit early failure in the field.

Tests can be made in this regard by placing samples in specialized solvents, such as acetone. After a day, remove the samples and dry for three days. Recheck with a sharp pointed tool or knife to determine if any of the pipe material seems much more brittle than before.

The considerations of resin life, degree of full cure, and plasticizer additives, have been introduced to help the user in evaluation. Data developed from a few months or even a year of testing can be meaningless when extrapolated to twelve years, unless one makes certain that none of these long-term degenerative conditions exist. Thus, if the user can be assured that:

1. the resins used, be they polyester or epoxy, are truly of the high quality, long life type—
2. the filament winding process develops full cure and—
3. plasticizing or other such additives are not used,

he can well put his faith in the general specifications outlined previously.

FITTINGS.—It must be determined if fittings contain plasticizers or exhibit any properties which might reduce life expectancy. Any degradation factor must be taken into consideration and pressure ratings adjusted accordingly.

The evaluation chart (Table 1) has been found useful in appraising our pipe and comparing it to similar products. It lists five other types of filament wound pipe with our interpretation of their engineering properties and field applicability. The X's on the table indicate areas where it is believed that the user might want to do some checking.

TABLE 1

Evaluation Chart
FWGR Pipe

	MANUFACTURER				
A. CHEMICAL					
ACID (20% H_2SO_4) 1000 HRS.		X	X		
ALKALI (5% NaOH) 1000 HRS.					X
SALT BRINE (CONCENTRATED) 1000 HRS.					
HYDROCARBON (SOUR CRUDE) 1000 HRS.	X				
SPECIAL	X				
FITTINGS					
CONNECTION SEAL RINGS		X			
B. TOUGHNESS					
WEIGHT, F.W. GLASS per ft.				X	
WIND ANGLE, VECTOR	X				
Double or Single Pattern		X	X		
RESIN, ELONGATION			X		
WALL (UNI.-ST., LINER, RESIN-RICH)		X	X	X	
C. PRESSURE RATINGS					
STATIC, 10 Min. + 5	X				
LONG TERM CYCLIC, 12 Yr. Extr. X 3/2		X	X		
ULTRAVIOLET, 12 Yr. Factor X P.R.'S			X		
FITTINGS		X	X	X	
D. MECHANICAL					
FLOW FACTOR		X	X	X	
VACUUM (LINERS, ETC.)				X	X
FIELD ASSEMBLY (CUTS & FITS)					X
E. LIFE EXPECTANCY					
RESIN (MAKER DATA)	X				
RESIN CURE					
PLASTICIZERS				X	X
FITTINGS	X				

CONCLUSION

Among those using FWGR pipe, this writer finds that those not too familiar with the product often become needlessly concerned as to its applicability.

Unless opaque layers or dyes are used, FWGR pipe is normally translucent and "looks" fragile and weak. Actually the more transparent, the better and stronger the pipe.

The "threaded connection habit" will be around for a long time, yet there is nothing about the properties of FWGR pipe that favors threads. An adhesive bond is as near as one can come to a true "welded" connection with such pipe. All manufacturers of FWGR pipe have experienced small weeps or leaks. Here is a striking difference between FWGR and steel. Steel, being a homogeneous material, has the characteristic that any small seep or leak usually means the beginning of the end. Threaded connections may rust, but generally speaking, the man in the field interprets any leakage as impending disaster. With FWGR pipe, should a small capillary permit an initial weep or seepage, the odds are very great that before long, sediment will completely block up such spots. Capillary action such as this does not in any way indicate a weak or thin spot. Unless the filament wound glass strands are actually broken, all of the actual strength remains.

In conclusion, if the user will follow the described evaluation procedure in selecting vendors, he can be assured that the FWGR pipe selected is one of the finest and most durable products on the market today.

REFERENCES

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