Fiberglass Pipe Design Considerations

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A Critical Process Systems Company

Fiberglass pipe design is greatly influenced by the process design, The process will generally determine the required corrosion liner resin selection and thickness, the design and operating temperatures, pressures, and vacuum.

Following a determination of the above criteria, the mechanical design of the pipe laminate structure begins. The laminate design will balance the economic benefit of various resin and reinforcement characteristics to meet the specified process design. Finally, the overall system is evaluated for proper support, expansion, and compliance with appropriate codes.

In the sections that follow, key relationships for fiberglass FRP pipe are highlighted. At the end, a life cycle cost comparison is shown to demonstrate the cost effectiveness of fiberglass pipe vs. steel.

Process Design:

Corrosion Requirements:

The anticipated concentration limits of the process stream needs to be evaluated for chemical corrosion resistance at temperature. Specific recommendations should be made by the resin manufacturer whenever possible. Fiberglass pipe is not subject to many of the corrosion problems associated with metal pipes, such as galvanic, aerobic, intergranular corrosion or pitting.

Resin Selection:

As noted above, specific recommendations should be made whenever possible. Fairly extensive data exists for a number of resin systems, while corrosion data is relatively scarce for others. General-purpose polyester resins should usually be avoided for chemical process piping. Corrosion grade polyesters provide an excellent value for many mildly corrosive systems. Vinyl ester resins provide additional corrosion resistance to strong oxidizing solutions while offering better mechanical strength and temperature resistance than the polyesters. Extensive corrosion resistance information is available for these resins.

Furan, phenolic and epoxy resins generally offer additional solvent and temperature resistance, sometimes sacrificing resistance to strong oxidizers. Corrosion data for these resins is generally more limited than for the polyester and vinyl esters, but particularly for conveying organics in acid environments, they can offer significant improvements. For all the above, resin catalyst and post cure should follow the resin manufacturer's recommendations.

Corrosion Liner Construction:

The corrosion liner refers to the inside portion of the pipe laminate including resin reinforced with a corrosion veil or veils, and chopped strand fiberglass mat. The veil(s) may be either a corrosion grade fiberglass (C-glass), or an organic veil such as polyester (Nexus), ECTFE (Halar) or graphite. An organic veil would be used in environments known to attack glass, such as sodium hydroxide, hydrofluoric acid, etc.

The veil when cured will vary from 0.010" to 0.027", at 10% to 50% reinforcement for C-glass or Halar, respectively, with polyester in between. The fiberglass chopped strand E-glass mat that backs up the veil forms the balance of the corrosion liner. This mat generally cures to 30% +/- reinforcement. The final corrosion liner may vary from as little as 0.040" for a C-veil and one layer of 1.5 oz/ft2 chopped strand mat, to over 0.250", depending upon the customer's understanding of the corrosive properties of the fluid contained. The standard (SPI) corrosion liner is 0.100", while many pulp and bleach manufacturers routinely use liners twice that thickness.

To avoid confusion, the corrosion liner and the corrosion allowance should be specified. Some specifications allow the use of the corrosion liner to be used in calculating required overall pipe wall thickness. Other specifications require the liner be treated as a sacrificial corrosion allowance and not to be used in any of the pipe structural calculations for pressure and vacuum handling capability.

Temperature Requirements:

The temperature handling capability of the various resin systems depends upon the corrosive nature of the process fluid. In general, corrosion grade isophthalic polyesters are suitable up to a temperature of approximately 120^o - 170^oF (50^o - 75^oC), while vinyl esters are suitable up to a temperature of 170^o - 210^oF (75^o - 100^oC). These ranges are general only. The specific system must be evaluated in light of the corrosion requirements, and later on for the mechanical requirements (supports, expansion, fatigue, etc.). Furan, phenolic and epoxy resins may offer slightly higher temperatures depending upon the system.

Pressure & Vacuum:

Fiberglass pipe is easily designed for the specific pressure or vacuum requirements of the system. It is common to specify pipe requirements by the design pressure of the system, using multiples of 25 PSIG (i.e., 25, 50, 75, 100, 125, or 150 PSIG design). Higher pressures can be accommodated when required. Fiberglass pipe is usually designed with a factor of safety = 10 for internal pressure and a factor of safety = 5 for vacuum.

Abrasion Resistance:

When required, additives such as ceramic fillers can be incorporated into the fiberglass pipe corrosion liner to enhance abrasion resistance. These systems have been used for many years in power plant and other services. In addition to fillers, additional layers or styles of veils may be considered.

Mechanical Design:

Structural Design Principles:

Due to the wide variety of available standards, there is no universal set of criteria for designing fiberglass pipe. The following equations and constants may be used in the mechanical design of fiberglass pipe. Acceptance criteria are based upon the most current revision of ASTM D2996 (Standard Specification for Filament Wound Reinforced Thermosetting Resin Pipe):

Poisson Ratio:

Ratio of the axial strain to the hoop strain. Usually reported as 0.30 for laminates under discussion.

Density: 0.055 lb/in3, or 1.5 gm/cm3
Specific Gravity: 1.5
Friction Coefficient (Hazen-Williams): 150-160
Surface Roughness (Darcy-Weisbach/Moody): 1.7 x 10-5 ft

Internal Pressure Rating:

Based upon the hydraulic design basis for static or cyclic conditions in accordance with ASTM D2992. The design basis is the hoop stress or strain that results in an estimated life of 100,000 hrs or 150 million cycles for static or cyclic conditions, respectively. Service factors are applied, usually 0.8 - 1.0 for cyclic and 0.50 - 0.56 for static conditions.

Thermal Conductivity:

1.0 - 1.5 BTU/(ft2)(hr)(oF)/inch for polyester/ vinyl ester pipe. The equivalent K factor is 0.083 - 0.125 BTU/(ft2)(hr)(oF)

Thermal Expansion:

May vary in the hoop and axial directions. Typical axial expansion for filament wound pipe at a 55o wind angle is 1.1-1.5 x 10-5 inch/inch/oF (or approximately twice that of steel).

Thermal expansion in piping systems may be accommodated by guides, expansion loops, mechanical expansion joints, anchors or combinations of the above. Use of these tools is similar to steel pipe design.

Fiberglass pipe has a very low modulus relative to steel (<5% of steel). This significantly improves the pipe's ability to handle expansion and contraction loads.

There are several tables available which specify the design modulus for calculating this expansion/ contraction force. Fiberglass reinforced pipe is an anisotropic material which results in different modulus values for tensile, bending and compression, and vary again depending upon the resin, reinforcement and reinforcement orientation used. Care must be taken to insure the appropriate modulus is used, and a ply by ply laminate analysis is generally appropriate. An example of these tables is shown in our Pipe Specifications.

Supports and Guides:

Proper support of fiberglass pipe is very similar to steel pipe support. Several key points to consider are the following:

- Avoid point loading
- Provide the minimum support width - bearing stress < 85 psi
- Protect against abrasion - use abrasion shields
- Support equipment and valves independent of the pipe
- Avoid unnecessary bending
- Avoid unnecessary loading in vertical runs and support vertical runs in compression where possible

Guides should allow movement in the axial direction only. Care should be taken to provide protection at all contact points using a steel or fiberglass saddle bonded to the pipe. Anchors must restrain the pipe against all forces. Anchors break the pipe system into component systems, which are then analyzed for expansion. Pumps, valves and other equipment can sometimes function as an anchor. Additional anchors may be required, and it is good practice to include them on at least 300 ft straight run intervals.

Guides and anchors function as supports. Supports are required to prevent excessive pipe deflection. For fiberglass pipe, a mid-span deflection of no greater than 0.5 inch generally results in acceptable bending stresses. If the deflection exceeds 0.5 inch, a safety factor on the bending stress of 8:1 is usually sufficient.

Buried Pipe:

Buried pipe design differs from above ground design in many respects. Most of these requirements are spelled out in Appendix A of AWWA Standard C590-88. Additional design details including pipe size, surge pressure, working pressure, service temperature, soil conditions, soil specific weight, depth of cover, and traffic loads will be required. Note that while the previous discussions have used ASTM service design factors of less than or equal to 1.0, the AWWA C950 specifies design factors which are the reciprocal of the service design factors and are always greater than or equal to 1.0.

Contact Composites USA for specific guidance in this area.

Joining Pipe:

Composites USA pipe may be assembled using either butt and wrap (fiberglass lay-up) or flanged construction. Factory sub-assembly is available and recommended for branch connections. The procedures for butt and wrap joining are similar to those shown for Class 1 duct, also on this web site. Thickness and width of the joints will vary depending upon the pressure classification and liner requirements of the system.

Cost Comparison:

Hydraulics:

Composites USA fiberglass pipe offers significant hydraulic advantages over steel pipe for the following reasons:

- Fiberglass pipe is smoother than steel.
- Fiberglass pipe stays smoother than steel
- Fiberglass pipe provides larger cross sectional flow areas

Fiberglass pipe has a smoother internal surface than steel pipe, with a Hazen - Williams roughness coefficient of 160 when new, or 150 used. Steel pipe, on the other hand, has a Hazen - Williams roughness coefficient of 120 when new, or 65 used. The far greater loss in smoothness for the steel pipe is due to scale build-up on the steel pipe. Note that even when the fiberglass pipe is used, it is still much smoother than new steel.

Composites USA, as do many manufacturers of fiberglass pipe, provide internal diameters for their pipe and fittings which match the nominal pipe size. Thus, an 18" diameter fiberglass pipe would have an 18" internal diameter, while an 18" diameter schedule 40 steel pipe would have a 16.88" internal diameter, providing only 88% of the flow area of its fiberglass counterpart.

These key differences are directly related to substantial cost savings available with the use of fiberglass pipe as shown below.

Costs:

The first cost (material) purchase price of fiberglass pipe and fittings for typical installations has been variously reported as 0.75 - 2 times the price of similar diameter stainless steel pipe systems. But first cost is only one piece of information in evaluating overall system cost. An evaluation of installed plus operating cost of piping systems usually generates a compelling case for the use of fiberglass pipe.

In addition to the material purchase price, evaluation of the total system cost considers the following:

A. Pipe Installation Cost

- Material purchase price (advantage - usually SS)
- Support requirements (supports, anchors, expansion joints - advantage FRP)
- Joint make-up times (cutting and welding - advantage FRP)
- Rigging requirements (light weight FRP vs. steel weights - advantage FRP)

B. Pipe Operating Cost

- Energy costs (pump horsepower requirements - advantage FRP)
- Maintenance requirements (painting, repairs, descaling, etc - advantage FRP)

C. Total System Life Cycle Cost

Summarizes the above costs over the anticipated useful life of the system using discounted cash flows or similar methods to assign a time value for future cash flows (advantage FRP).

Pipe purchase cost differentials can vary widely depending upon factors such as costs of stainless steel and pipe specification requirements. It is however, fairly straight forward for the consumer to obtain pricing for comparison. The rest of the factors are somewhat less straight forward and some additional information follows.

The standard method for joining Composites USA manufactured fiberglass pipe is with either flanged ends or butt and strap connections. Butt and strap is the industry method of choice for most severe corrosion services, and involves butting the fiberglass ends together and completing a wet fiberglass lay-up (strap) over the joint area. Although this is a procedure that takes skill and training to successfully complete, it is generally easier to learn than welding stainless steel.

The time required to cut, prepare and weld the two materials are as follows (budget purposes):

Hrs vs.Diameter	2"	3"	4"	6"	8"	10"	12"
FRP	0.50	0.70	0.90	1.20	1.80	2.50	3.00
Stainless	1.70	1.90	2.80	4.00	5.00	6.00	7.00

Operating Costs:

One of the key reasons to consider fiberglass pipe for any traditional carbon steel systems is its generally lower cost to operate, or horsepower requirements.

The discussion in the previous section called attention to the larger flow area generally available with fiberglass pipe (12% greater for the 18" diameter example given). This is one key reason why fiberglass pipe results in lower pumping costs. A second reason is fiberglass pipes lower coefficient of friction, 25% lower for new systems and twice as low for aged systems.

This fact allows the system designer to choose between down sizing the line (in fiberglass) or taking advantage of lower operating costs. These costs are usually significant and can be estimated as follows:

For the 18" diameter pipe mentioned above, assume 6,000 gpm traveling through a 2,000 ft long straight pipe system. Costs will be estimated for one year only (year #3). The process is repeated for each year of the estimated useful life of the system. Use of the Hazen-Williams relationships is used in the analysis below. Other formulas, such as the Colebrook equation may be used and should yield similar results.

1. First, Calculate the friction factor (for turbulent flow):

$$hf \text{ (ft H20/ 100 ft)} = 0.2083\ (100/C)1.85(Q\ 1.85/d\ 4.87),$$

Where C = roughness coefficient (150 for fiberglass, 65-135 steel depending upon condition) d = pipe inside diameter

2. Then calculate the total friction loss due to the pipe and fittings:

$$Hf = hf \times \text{Length}/ 100$$

3. Finally, calculate the horsepower requirements:

Horsepower (HP) = Flow (GPM) x Density of the fluid (Lb/ft3) x Hf / 33,000 (Conversion Factor)

Where the conversion factor is (33,000) HP = (1) foot-lbs/ minute

Inputting the fiberglass pipe values into the equations yield:

hf (ft H20/ 100 ft) = 0.2083 (100/150)1.85(6,000 1.85/18 4.87)
= 0.2083 (0.4723) (7.532)
= 0.740

Hf = hf x Length/ 100
= 0.740 x 2,000/ 100
= 14.8 ft water friction drop

HP = Flow (GPM) x Density of the fluid (Lb/ft3) x Hf / 33,000
= (6,000)(8.34)(14.8)/(33,000)
= 22.45

Substituting the values for steel pipe at 3 years old (C = 100, d = 16.88 inches):

hf = 0.2083 (100/100)1.85(6,000 1.85/16.88 4.87) = 2.14
Hf = 2.14 x 2,000/ 100 = 42.85
HP =(6,000)(8.34)(42.85)/(33,000) = 65

Annual operating costs are obtained by calculating the annual kW hours, adjusting for pump motor efficiencies, and multiplying against a cost of power. Using an 80% efficiency rating and a $0.05/kw-hour cost as typical, we can calculate the following operating costs:

Fiberglass pipe: = ($0.05)(22.45 HP)(24 hrs/day)(365 days/yr)/0.80 eff. = $12,291

Steel pipe = ($0.05)(65 HP)(24 hrs/day)(365 days/yr)/0.80 eff. = $35,587

Operating cost savings for fiberglass pipe in year #3 alone, $23,296

This procedure is then repeated for each year of the estimated useful life of the system. The costs are tabulated and procedures such as discounted cash flows or present values used to adjust future costs for risk or inflation. Use of year #3 values in the case above allows a quick ballpark estimate due to the steel friction coefficient in the middle of its useful range.

For a more rigorous analysis, the following steel friction factors can be used:

Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Yr 15
120	110	105	100	97	95	92	90	89	88	80