FIBERGLASS PIPE'S FRINGE BENEFIT

Fiberglass pipe commands a well-established, solid market in the chemical process industries. This is largely due to the material’s resistance to chemical attack and corrosion. Few engineers realize, however, that this same inertness enables fiberglass to compete favorably with carbon steel pipe even when transporting fluids, such as water, that are not considered particularly corrosive.

This is because the surface of fiberglass pipe is quite smooth. Roughness causes friction, and fluid-flow operating costs are driven in large part by the frictional resistance of the pipe.

Not only is the roughness of fiberglass low to start with; it also remains essentially constant throughout the life of the pipe. The roughness of carbon steel pipe, on the other hand, rises (see p. 175).

Look at the equations
The attractiveness of fiberglass pipe is apparent when one makes flow calculations, because fluid-flow equations include a term that takes friction into account. Consider, for instance, the Darcy-Weisbach, Manning, and Hazen-Williams equations, all of which can be found in fluid-mechanics handbooks.

The friction factor in the Darcy-Weisbach equation is calculated based on an absolute-surface-roughness parameter. Fiberglass pipe has an absolute surface roughness of $17 \times 10^{-6}$ ft, whereas a typical initial (i.e., even before degradation) value for commercial steel pipe is considerably higher: $150 \times 10^{-6}$ ft. As for the Manning equation, the roughness-related Manning $n$
Composite materials, such as fiberglass, have been used in piping systems for more than 40 years. These products were developed in response to significant corrosion problems with metallic pipe in the chemical process industries. More recently, composites have found applications in the aerospace and automotive industries, where high strength-to-weight ratio is the primary design goal and corrosion resistance is secondary.

Fiberglass pipe, made in diameters from 3/4 to 144 in., is a tubular product containing glass fiber reinforcements encapsulated in cured thermosetting resins. Unlike thermoplastics, these resins are chemically cross-linked during the curing cycle, which fosters corrosion resistance and in general allows higher operating temperatures. The resins used most commonly are isophthalic polyesters, vinyl esters, and epoxies. Each has its own particular advantages in various chemical environments and applications.

The upper temperature limits of these materials ranges from 150 to 300°F. The upper pressure limit varies from 25 to 3,500 psig.

A broad range of fiberglass fittings is available. Elbows, for instance, can be short-radius for process piping or long-radius for drainage applications.

Full-sweep elbows are available up to 30 in. dia., whereas larger-diameter ones are usually manufactured by mitering and joining sections of pipe to form long arcs. Mitered elbows may have as many as four sections to improve flow characteristics (the greater the number of mitered sections the lower the flow resistance, because the fluid path more closely approximates an arc). A tapered fiberglass pipe in manifold headers is available, to reduce frictional resistance developed by several size reductions. Pipe and fittings are connected by adhesive joints, fiberglass overlaps, flanges, pipe threads, or mechanical elastomeric joints.

Fiberglass double-containment pipe meets U.S. Environmental Protection Agency regulations for buried lines handling hazardous fluids. In addition to fluid conveyance, fiberglass ductwork is utilized in chemical-process plants where corrosive vapors are present in the process stream.

The development of national standards for fiberglass pipe has increased the acceptance of this material in the marketplace. In the U.S., for example, the American Soc. of Testing and Materials (ASTM), American Water Works Assn. (AWWA), American Petroleum Institute (API), and Underwriters Laboratories (UL) have all developed end-user specifications for fiberglass pipe.

![Taper of a pipe compensates for decrease in amount of fluid passing through it](image)

SUSAN COHEN

factor for fiberglass pipe is 0.009, compared to 0.014 for new steel.

In the Hazen-Williams equation, the roughness coefficient $C$ is inversely proportional to the roughness of pipe. Fiberglass pipe has a measured Hazen-Williams coefficient of 150 to 160, 150 being frequently used for design purposes. Unlined steel pipe has a when new value of 120 or 130, which degrades to 65 in many applications over time; designers frequently use a compromise value of 100.

The fluid-flow economies of using fiberglass pipe emerge regardless of which of the three equations is used. For simplicity, our examples below use the Hazen-Williams equation. While not as technically correct for all velocities as the other two, the Hazen-Williams equation has gained wide acceptance in water and wastewater applications due to its simplicity, and a considerable body of friction data in such applications has been accumulated.

Before going to the examples, however, another reason for the fluid-flow attractiveness of fiberglass pipe should be pointed out — it offers not only smoother walls but also a larger effective flow area. Its inside diameter (I.D.) is typically greater than that of typical steel pipe because of thinner walls. This thinness is due to the strength of the fiberglass material, plus the lack of need for a corrosion allowance when calculating the wall thickness. The larger effective flow area lowers the capital cost for piping while also in itself reducing frictional resistance of the pipe, other things being equal.

**Flow economics**

The savings with fiberglass pipe can be realized in either of two ways. The engineer can in many cases downsize the pipe diameter while maintaining the original flowrate. Or if he or she elects to maintain the same diameter, fiberglass pipe will consume less pump horsepower for a given flowrate.

Example 1: Consider a Schedule 40, 14-in.-dia. (I.D. = 13.126 inches) steel line transporting 3,000 gpm of water. Assume an average Hazen-Williams $C$ coefficient of 100 for steel pipe and 150 for fiberglass pipe. Determine the equivalent diameter for fiberglass pipe at the same flow rate.

Step 1: Calculate the steel-pipe head losses using the Hazen-Williams equation:

$$h = [42.7 Q/(C(D^4)^{0.65})]^{0.55}$$

where $h$ is the friction loss in feet of water per 100 ft of pipe, $Q$ is the flow rate in gallons per minute, $C$ is the Hazen-Williams coefficient and $D$ is the pipe inside diameter (ID) in inches.

$$h = [42.7(3000)/(100)(13.126^{0.65})]^{0.55} = 2.04 \text{ ft/100 ft}$$

Step 2: Equate the head losses and back-calculate the diameter required for fiberglass pipe:

$$2.04 = [42.7(3000)/(150)(D^4)^{0.65}]^{0.55}$$

so $D = 11.25$ in., or nominally 12 in. Thus, in this particular application a 12-in.-dia. fiberglass pipe has the same friction loss as a 14-in. steel pipe.

Example 2: A 3,000-ft, straight-run (no elevation changes) 8-in.-dia. pipeline
is to deliver 1,200 gpm of industrial waste water on a year-round basis. For these conditions, the Hazen-Williams C coefficient for fiberglass pipe is graphed in the box on page 175 as a function of time and has an average value of 126 during the first year of the project life. The fiberglass pipe has an internal diameter (ID) of 8.35 inches. Schedule 40 steel pipe has an ID of 7.98 inches. The density of the water is 8.34 lb/gal. The cost of power is $0.05/kwh (equivalent to $0.0375 per horsepower-hour). Determine the first-year operating-cost savings for using fiberglass pipe rather than steel.

Step 1: Calculate the friction head loss using the Hazen-Williams equation:

(a) For fiberglass pipe:
\[ h = \left(42.7(1.200)/(150)(8.35)^{1,05}\right)^{0.85} \]
\[ h = 1.59 \text{ ft/100 ft} \]

This amounts to 47.7 ft for the entire 3,000-ft system.

(b) For steel pipe:
\[ h = \left(42.7(1.200)/(126)(7.98)^{1,05}\right)^{0.85} \]
\[ h = 2.74 \text{ ft/100 ft} \]
or 82.2 ft for the 3,000-ft system.

Step 2: Calculate pump horsepower demand:
\[ H_p = \frac{QmH}{33,000} \]
where \( H_p \) is the horsepower required, \( m \) is the fluid density in pounds per gallon and \( H \) is the friction head loss for the system.

(a) For fiberglass pipe:
\[ H_p = \frac{(1,200)(8.34)(47.7)}{33,000} = 14.5 \text{ hp} \]

(b) For steel pipe:
\[ H_p = \frac{(1,200)(8.34)(82.2)}{33,000} = 25 \text{ hp} \]

Step 3: Calculate the first-year operating-energy requirements, assuming that the overall efficiency of energy usage is 80%:

(a) For fiberglass pipe:
\[ \text{Energy consumption} = \frac{H_p(24 \text{ h/day})(365 \text{ days/yr})}{365 \text{ days/yr}}/0.80 \]
\[ = (14.5)(24)(365)/0.8 \]
\[ = 159,000 \text{ hp-h} \]

(b) For steel pipe:
\[ \text{Energy consumption} = \frac{(25)(24)(365)/0.8}{274,000 \text{ hp-h}} \]

Step 4: Calculate the first-year operating cost:
(a) For fiberglass pipe, the cost is 159,000 x $0.0375, or $5,960.
(b) For steel pipe, the cost is 274,000 x $0.0375, or $10,275.

Accordingly, usage of fiberglass pipe saves about $4,300 in the first year.

Note that this same calculation can be completed for each year of the project life, using the appropriate Hazen-Williams C coefficients from the graph on the next page. A personal-computer spreadsheet program facilitates the procedure.

The power savings rise in subsequent years, because the coefficient for the steel pipe is a function of the increasing surface roughness. Figure 1 illustrates the horsepower demand for the steel and fiberglass pipes during 20 years of operation, assuming that the energy cost stays constant. While the horsepower demand with fiberglass pipe is constant, the demand with the steel pipe increases from 25 to about 60 hp.

Many engineers do not allow for excessive corrosion build-up or increased power consumption in the initial pump sizing calculations. If sufficient horsepower is not available at the pump and the line is not cleaned regularly, the net flow in the steel pipe will decrease. Due to inherent limitations of centrifugal-pump performance curves, a variable-speed pump may be necessary to meet such a large variation in head loss.

The long view

The most complete approach to pipe-selection economics is Life Cycle Cost (LCC), which considers all present and future costs. The present (installed) outlays and future operating cost are put on the same footing by discounting the latter to a common basis. Thus, LCC is nothing more than the summation of the installed cost and the Net Present Value of all future costs discounted by an appropriate discount rate. The cost of capital or the best alternative investment rate may be used as a discount rate.

Example 3. Assume that the lifetime of
WHY STEEL-PIPE FRICTION GOES UP

The increase in steel-pipe friction over time is due to corrosion and tuberculation on the internal pipe surface. Tuberculation is the process whereby mounds of corrosion product build up and cover areas where corrosion pits have been developing. This not only increases surface roughness but also reduces the effective internal diameter of the pipe.

The rate of friction increase varies greatly with the fluid being pumped. Even when the fluid is water, the increase is a function of water quality (measured in terms of pH or the Lang velier index) and differs significantly from one water source to another.

The effect of internal corrosion on flowrates has been studied extensively with regard to municipal water mains, where historical measurements are available. As shown in the graph at right, which pertains to an 8-in. municipal water pipe, degradation of the Hazen-Williams coefficient for steel pipe is a logarithmic function of time, and it increases flow resistance most rapidly for new or recently cleaned pipes. Industrial-water lines can be expected to show at least as much change, since water quality is often less than that for municipal water systems. And, of course, the same is true for lines carrying industrial wastes.

Such wide variations in flow resistance (head loss) present a design dilemma for the engineer. If he or she ignores the existence of internal corrosion, the delivered flow rate will decline over time unless the line is frequently cleaned. If, instead, a long-term Hazen-Williams coefficient is used in the design calculations, a larger pump and perhaps a throttling valve will be necessary to maintain a constant flow rate, especially during the early years of the project life. Throttling valves consume horsepower and increase operating expenses.

A third alternative is to install a variable-speed pump or driver to compensate for the large head differential between the new and old steel pipe. Variable speed pumps increase the initial cost of the system.

Because of corrosion and tuberculation, the Hazen-Williams coefficient for steel pipe declines with time

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the operation in Example 2 is 20 yr, that the cost of energy remains constant, and that the cost of capital is constant at 10%. Calculate the life-cycle cost for each type of pipe.

To accomplish this, first, calculate the installed cost of both materials. The following data are available: The steel pipe, namely A-53 Schedule 40, 8-in. dia., has an installed labor and material cost of $2,081.60 per 100 ft. The cost for 150-psi filament-wound fiberglass pipe is $2,904 per 100 ft. These costs assume a labor charge of $24/h, and do not include trench excavation, a pump system, valves, fittings, or cathodic protection for the steel pipe.

Steel-pipe installed cost = ($2,081.60/100 ft)(3,000 ft) = $62,448

Fiberglass pipe installed cost = ($2,904/100 ft)(3,000 ft) = $87,120

The installed cost represents the initial outlay for the project. Each year an outlay will also be required for power, as calculated in the previous example. These annual cash flows are shown in Figure 2. Figure 3 shows, as a matter of interest, the cumulative cash flows.

The life cycle cost is then calculated from

\[ LCC = \frac{c}{(1 + r)^T} \]

where \( c \) is cash outflow incurred in year \( t \) and \( K \) is the discount rate. Using a discount rate of 10% with the cash flows shown in Figure 2, the numbers for the steel pipe are factored in as follows:

\[ LCC = 62,448/1.10^0 + 10,275/1.10^1 + 12,200/\ldots + 25,400/1.10^{20} = \text{\$207,900} \]

The LCC for the fiberglass pipe is calculated in the same manner:

\[ LCC = 69,120/1.10^0 + 5,960/\ldots + 5,960/1.10^{20} = \text{\$119,900} \]

Although the installed cost of the fiberglass pipe is 10% higher than that of the steel, the total Life Cycle Cost is 42% less when all costs over the project life are considered. This differential cost is due to higher flow resistance (head loss) in the steel pipe.

This example used the present cost of electric power throughout the economic calculations. Actually, however, electric power rates in the U.S. are expected to escalate due to increased fuel expenses and the cost of implementing federal clean-air legislation. As the cost of power increases, the Life Cycle Cost advantages of fiberglass pipe become greater.

In addition to the energy cost advantages, other savings result from the purchase of a smaller electric motor and pump system. Moreover, fiberglass pipe does not require cathodic protection or protective coatings for corrosive soils.

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Industrial
Fiberglass
Specialties,
Inc.
521 Kiser Street
Dayton, OH 45404
(937) 222-9000
Fax: (937) 222-9020