Piping Flow Rate Design for Retail Refueling Facilities

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I. Purpose

Piping selection considerations for a retail motor fuel dispensing facility should include a flow rate criterion to fuel vehicles at the maximum Environmental Protection Agency (EPA) allowable of 10 gallons per minute during peak traffic periods. High-volume consumers (e. g., commuters and commercial accounts), are sensitive to the time it takes to refuel their vehicles, and they represent a significant market segment. While hydraulic flow rate calculations may be made on a site-specific basis, the purpose of this paper is to describe the major factors that reduce flow rate, how the three most common materials used to manufacture piping affect these flow rate factors, and cite flow rate "rules of thumb" for small and large retail vehicle refueling facilities based on the most commonly used piping systems.

II. Scope

Underground pipe materials fall into four general categories: iron, copper, steel and non-metallic. Cast-iron is not practical for small diameter pressure applications. While copper may be used, it is not price competitive. This leaves steel and non-metallic piping as the system materials of choice. The first of these materials, steel, was the traditional choice for underground piping until the late-1960's when fiberglass-reinforced thermosetting plastic (FRP) was Underwriters Laboratories, (UL) Listed and solved the steel pipe corrosion problem. Later, in 1993, the first flexible thermoplastic piping system was UL Listed for petroleum products, alcohols and alcohol-gasoline mixtures. While several flexible systems are UL Listed, there are five that are widely marketed. Therefore, this paper is limited to flow rates that can be expected for steel, FRP and the five commonly marketed flexible thermoplastic piping systems.

III. Factors that Reduce Flow Rate

The flow rate of a fluid in a piping system is a function of the:

- Inside Diameter ("ID") of the pipe and its fittings (e.g., elbows, connectors and tees);
- Friction loss of the pipe bore surface (i.e., smoothness); and
- Turbulent flow rather than laminar flow (e.g., ID corrugations, ID diameter changes and changes in the direction of fluid flow).

The design challenge is to achieve the desired flow rate coupled with the most cost-effective piping system. Recognizing that larger diameter pipe and pipe fittings are more costly than their smaller diameter counterparts, the designer needs to investigate which piping system will achieve the desired flow rate in its smallest diameter configuration. This

will mean selecting a nominal size pipe with the largest ID for that size, the smoothest bore and fittings or piping connections with a minimum increase in fluid turbulence.

IV. Piping Materials

The piping material used will dictate the manufacturing and joint connection methods employed, both of which will result in different flow rate characteristics. Hence, the following discussion on manufacturing and installation methods for different materials will help describe inherent flow rate characteristics for each type of piping system.

A. Black iron steel: Black iron steel (i.e., not galvanized steel) and non-metallic pipes are the two materials recommended by the American Petroleum Institute ("API") and Petroleum Equipment Institute ("PEI") for underground petroleum piping systems.

- **a. Materials**: The most frequently used steel pipe is made to ASTM A106 or A53 requirements. Both ASTM A106 and A53 have identical chemical compositions, but A106 is subjected to more rigorous testing. Both are fabricated in Grades A and B; Grade B is less ductile but has higher strength properties and is therefore specified more commonly.
- **b. Manufacturing process:** Black iron steel is fabricated from a flat strip of metal rolled into a tube and sealed along the longitudinal seam by electric resistance or electric-fusion welding.

  Schedule 40 pipe has the "standard-weight" wall thickness and extra-heavy steel pipe malleable iron screw-type fittings/couplings are recommended by API and PEI for underground petroleum piping.
- **c. Pipe I.D., Friction, Turbulence:** The thickness of the steel material used in the manufacturing process determines the inside diameter (ID), a smooth wall bore characteristic is imparted by the rolled steel plate, and the external threaded couplings and tees do not restrict the pipe ID.

B. Fiberglass Reinforced Thermosetting Plastic Pipe (FRP)

- **a. Materials:** FRP piping systems contain glass fiber reinforcement embedded in cured thermosetting resin; hence, the term Fiberglass Reinforced (Thermosetting) Plastic describes the fiberglass material system. The glass fiber reinforcement within the material system provides the mechanical strength and the thermosetting resin cures to an irreversible hard matrix designed to be compatible with the fluid medium. Fire and building codes require that non-metallic piping be Listed by Underwriters Laboratories Inc. and meet UL 971 testing and third-party quality assurance protocols.
- **b. Manufacturing process:** The pipe is filament wound on a male mandrel in 15 to 40 foot lengths to minimize field connections, and fittings are filament wound or compression molded. High-strength glass fiber construction (i. e., 300-psig primary pipe) permits a thin wall design for typical 30-psig petroleum dispensing systems.
- **c. Pipe I.D., Friction, Turbulence:** The glass fiber thin wall material used in the manufacturing process determines the ID, the smooth wall bore characteristic is imparted by the cured resin and the larger diameter external couplings and tees (sized to cast iron pipe dimensions) do not restrict the pipe ID.

C. Thermoplastic Flexible Piping

a. **Materials:** Thermoplastic is also a non-metallic piping system that is UL 971 Listed for underground petroleum piping. This nonmetallic piping differs from FRP in two major areas. The first major difference is the type of plastic resin system used. Flexible pipe is manufactured with thermoplastic rather than thermosetting plastic resin which is a flexible polymer not unlike that used in certain hoses (e. g., automobile) rather than rigid structure like that of a traditional pipe. This flexibility enables a change in direction without using an elbow fitting, provided that the "sweep" is not less than the bending radius. However, thermoplastic pipe is relatively stiff having typical bending radii of 18 to 40 inches for 1.5 to 2 inch nominal diameter double wall pipe.

b. **Manufacturing Process:** Thermoplastic primary pipe is manufactured by using an extrusion process. Typically it is extruded with a material compatibility barrier first, next a reinforcing braid (e.g., nylon) and finally a covering material. The secondary pipe is typically manufactured from a polyethylene extrusion.

c. **Pipe I.D., Friction, Turbulence:** The second major difference is the use of metal rather than nonmetallic fittings. Metal fittings are pressed or clamped onto the pipe ends and typically machined to be mated with a threaded metal connection.

Therefore, the thermoplastic material used in the manufacturing process is sized to the mandrel and controls the ID, the smooth wall bore characteristic is imparted by the thermoplastic resin (but to impart resistance to underground overburden pipe crushing, one product has a corrugated surface) and the pipe-end fittings and tees are sized the same as (i.e., rather than larger than) the pipe ID, with one exception where the end fittings are smaller.

V. Nominal vs. Inside Diameter (ID)

Low cost, off-the-shelf underground pipe is manufactured in standard nominal sizes that range from 1½ to 4 inches for a typical retail vehicle refueling facility. However, the ID of these nominal sizes is not the same and differs for each of the materials used in the manufacture of pipe. Table A compares the nominal diameter of primary pipe in 1½ and 2 inch sizes with the actual measured ID:

Table A

Material	Internal Diameter (ID inches)			Piping ID	
Type	Nominal	Measured	End Fitting	< Nominal >	Nominal
Rigid Pipe					
Steel (5)	1.5	**1.61**	> 1.65		X
	2	**2.067**	> 2.067		X
FRP Mfgr A(6)	2	**2.21**	> 2.21		X
Mfgr B	2	**2.23**	> 2.23		X
Flexible Pipe (7)					
Marketer A	1.75	**1.65**	**1.375**	X	
B	1.5	1.5	1.5		
C	1.5	1.5	1.5		
	2	2	2		
D	2	2	**1.92**	X	
E	1.5	1.5	1.5		
	2.5	2.5	2.5		

Table A shows that the method employed in the manufacture of rigid pipe results in a larger than nominal ID, whereas the method employed by two of the five flexible pipes (i.e., rippled bore and/or pipe end fitting) reduces the nominal ID. However, to compare flow rates, the pipe bore friction loss (e.g., smoothness) is a factor that must be considered at the same time.

VI. Friction Loss

Friction loss increases with the flow rate in a straight pipe run and is typically expressed in terms of "feet per 100 feet" of pipe. Friction losses differ for fluids of different specific gravities, different pipe ID's and different pipe materials. Motor gasoline friction losses are developed (i.e., calculate or pump test) using a specific gravity of 0.78 to 0.85 (e. g., a 100° F flash petroleum solvent). Based on certain specific gravities, friction loss tables are developed for pipe materials and ID's. Table B follows with examples of friction losses for a ¾ Hp STP developing a flow rate of 40 gpm (8, 9, 10, 11):

Table B			
Material Type	Nominal ID	Friction Losses	
Rigid Pipe			
Steel Pipe	1 ½	14.0	_
	2	4.4	_
FRP	2	.3	-4.1ft/100ft
Flexible Pipe			
A	1.75	11.8	n/a
B	1.5	21.0	+7.0ft/100ft
C	1.5	21.0	+7.0ft/100ft
	2	4.2	» 0
D	2	5.07	» 0
E	1.5	37.5	+23.5ft/100ft
	2.5	n/a	n/a

Table B compares steel piping friction losses with nonmetallic piping losses. Rigid FRP piping shows the lowest friction loss; three flexible piping systems show friction losses higher than steel and two are comparable to steel piping.

VII. Pipe Fitting Flow Rate Losses

Pipe fittings are used to change direction and make connections in a piping system. These fittings cause friction and turbulent flow rate losses. Fittings that contribute the most significant losses include piping tees and elbows and, in some flexible piping products, pipe-end fitting attachment methods. Metal fittings are used with both steel and flexible piping systems, whereas FRP wound or molded fittings are used with FRP piping.

Typical Island Piping Configurations: The four common methods of piping layouts used for multiple dispensing islands are shown below:

a. Pipe in "series" i. e., pipe to the first island first, the second island second, etc.
b. Pipe in series to the first three islands and run a separate line from the pump to the 4th + island (i. e., 7th + dispensing nozzles).
c. Pipe in series to the first three islands and branch out with a separate pipe at the 2nd island to serve the 4th + islands.

d. Pipe a main line to the furthest island and "tee" off this "manifold" to the other islands.

Flexible piping systems typically use one of the first three methods and *rigid* systems use the "manifold" approach.

Tee Losses: In a typical four island facility, the flexible piping configuration will use layout #2 or #3 with a total of five tees per product line to achieve the maximum downstream flow rate. Rigid piping will use layout #4 and a total of four tees per product line.

Elbow Losses: While rigid steel and FRP piping systems use elbows to change direction in a piping run, flexible piping will bend if there is room to accommodate the bending radius. As a result, flexible piping will typically use two fewer elbow fittings than rigid steel or FRP systems.

Summary: On balance, rigid piping systems may experience one or more fitting flow rate losses over a comparably designed flexible piping system. For example, a two-inch FRP elbow has a friction loss of 6.2 feet/100 feet. However, the inclusion of fitting losses in Table B would indicate that the larger actual ID of FRP compensates for an additional fitting friction loss and results in the highest flow rate piping system.

VIII. Piping Flow Rate Rules of Thumb

The following guidelines on piping sizes to achieve 10 gpm dispensing rates during peak traffic periods at a minimum cost are general at best, because other unknown factors affect flow rates such as internal dispenser plumbing (e.g., 1 ½ inch shear valve, meter resistance) hose and nozzle (e.g., vapor recovery) restrictions:

a. Three dispensers: six nozzle fueling facility, ¾ Hp submerged turbine pump ("STP")
Design for 40 gpm flow rate i.e., 4 of 6 nozzles in service

Tanks approximately 100 feet from dispensers - use 2 inch FRP or 1 ½ inch Flexible piping
Tanks over 100 feet from dispensers - use 2 inch FRP or 2 inch Flexible piping

b. Four dispensers: eight nozzle fueling facility, 1½ Hp STP
Design for 60 gpm flow rate i.e., 6 of 8 nozzles in service

Tanks over 100 feet from dispensers, approximately 400 feet of piping run - use 2 inch FRP or 2 inch Flexible piping

c. Six or more dispensers: 12 or more nozzles, one or two 1½ Hp STP's
Design for 100+ gpm flow rate

Approximately 600 feet piping run - consider 3 inch FRP manifold and 2 inch FRP lateral piping

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