Process Piping - Hydraulics, Sizing and Pressure Rating

An Online Continuing Education Course for Engineers

Course Number: M-4042

Credit: 4 Hours / 4 PDH / 4 CPD

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According to a 2004 American survey, as much as 30% of the total cost of a typical oil, gas and chemical process plant is in piping, piping components and valves. A significant amount of operating (energy) and maintenance cost is also associated with the flow of fluids through piping and its components.

The major steps in pipeline system design involve the establishment of critical pipeline performance objectives and critical engineering design parameters such as required throughput, origin and destination points, fluid properties such as viscosity and specific gravity, maximum allowable operating pressure (MAOP), and hydraulic calculations to determine pipe diameter, wall thickness, and required yield strengths.

Understanding how the fluid flows from one point to other is the foundation of process design and piping layout. The principles are not complex, but neither are they simple due to the interdependence of velocity, pipe diameter, length, fluid characteristics, pressure drop and friction. There are other factors that affect overall economics and safety.

This 4-hour course provides an overview of pressure drop calculation procedures and line sizing in a simplified manner. It is the third of 9 modules in a series that covers the entire gamut of piping engineering in an easy-to-learn format. All topics are introduced to readers with no or limited background on the subject.

The material is divided in two (2) distinct chapters as follows:

CHAPTER -1: PIPELINE HYDRAULICS

This chapter covers basic hydraulics definitions, terminology and flow characteristics of pipes. It discusses the various flow conditions, continuity equation, Bernoulli's equation, flow regimes, laminar flow and turbulent flow, Reynold’s Number (Re) and Moody’s Chart for hydraulic line sizing. Procedures are included for calculating pressure drop considerations using the Darcy – Weisbach Equation and Hazen – Williams Equation. Finally, it covers economic pipe sizing using the least annual cost approach.

CHAPTER – 2: DESIGN OF PRESSURE PIPING

This chapter deals with methods for computing pipe wall thickness. It describes the design conditions, pressure-temperature relationships, allowable stresses, theories of failure and the importance of hoop and longitudinal stress in pressure pipe sizing. It gives pertinent information for all relevant ASME/ASTM codes and thickness allowances along with examples. It includes annexure at the end that provides some solved examples.

CHAPTER 1

1. PIPELINE HYDRAULICS

Pipeline hydraulics deals with the flow and transportation of fluids in pipes. Gases and liquids are generally referred to as fluids.

Gases are classified as compressible fluids because they are subject to large variations in volume with changes in pressure and temperature. Liquids, on the other hand, are generally considered to be incompressible. Liquid density and volume change very little with pressure; however, liquids do show a variation in volume as the temperature changes.

1.1. Pipe Size

The size of a pipe dictates a system's capacity. Larger diameter pipes allow for higher mass flows of the materials provided. Other components of the pipeline system, primarily pumps and pressure management devices, are properly sized and positioned.

1.2. Pressure

The longer the pipe between the source and the destination, the greater will be the line pressure drop. Also, the smaller the pipe size for given mass flow rates, the higher will be the pressure drop.

The pressure drop in a pipe system determines the operating pressure of a pipeline, which in turn determines pump horsepower and operating costs. This is the main economic consideration that typically drives decisions on line size, the number of pumps and horsepower.

1.3. Fluid Characteristics

Specific gravity, compressibility, temperature, viscosity, pour point, and vapor pressure of the fluid are the primary parameters that dictate the design and operating parameters of a pipeline. These and other engineering design parameters are defined in the following sections in terms of their influence on pipeline design.

1.4. BASIC DEFINITIONS

1.4.1. Mass (m)

Mass (symbolized m) is a fundamental measure of the amount of matter in an object. The standard unit of mass is the kilogram (kg) in the International System (SI) and pound mass (lbm) in the (Imperial) U.S. Customary system of units.

The term "weight" is sometimes used synonymously with mass. Strictly speaking, the weight of a substance is a force (vector quantity), while mass is a scalar quantity. Weight depends upon acceleration due to gravity and hence depends upon geographical location. Weight is measured in pounds (lb) or, more correctly, in pound force (lbf) in US units. In SI units, weight is expressed in Newton (N). If the weight of a substance is 10 lbf, its mass is said to be 10 lbm.

The relationship between weight W in lb. and mass m is as follows:

$W = m\ g$

Where,

g is the acceleration due to gravity at the specific location.

At sea level, it is equal to 32.2 ft/s^2 in US units and 9.81 m/s^2 in SI units.

1.4.2. Density (ρ) and Specific Gravity

The density of a fluid is defined as the **mass** per unit volume.

Density (ρ) = mass (m) / volume (v)

Density is measured in lbm/ft^3 in US system units and kg/m^3 in SI units.

The density of fluid varies with temperature and pressure.

- Since density is inversely proportional to volume, density increases with pressure while volume decreases.
- Similarly, an increase in temperature decreases density, while volume increases.

The density of dry air is 0.07967 lbm/ft^3 at 32°F (0°C) at average sea level. It is equivalent to 1.29 grams per liter in SI units.

STP – Standard Temperature and Pressure is one atmosphere of pressure at 32°F (0°C). Typically, the value given for the density of air is at STP.

NTP - Normal Temperature and Pressure is defined at 68°F (20°C) and 14.7 psia (1atm). At NTP, the density will decrease and is nearly 0.0748 lbm/ft^3.

It is common to use the density of water at 39°F (4°C) as a reference since water at this point has its highest density of 1000 kg/m^3 or 62.4 lb/ft^3.

1.4.3. Specific weight (γ)

Specific weight refers to the **weight** per unit volume. It is referred to in lb/ft^3 in US units and N/m^3 in SI units.

Specific weight $(\gamma) = \rho\, g$

1.4.4. Specific gravity (SG)

The specific gravity of a liquid divided by the density of water at

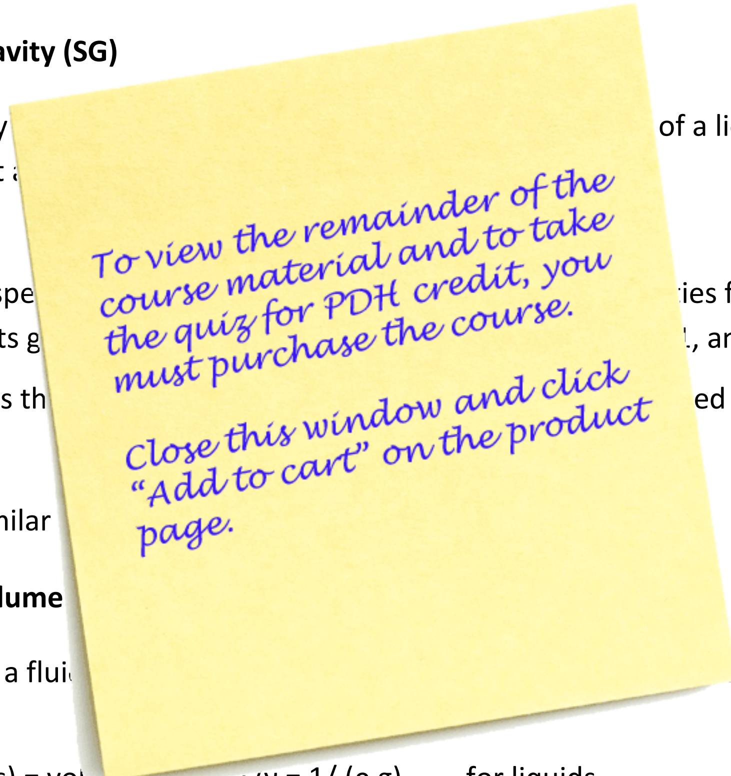
$SG = \rho_{liquid} / \rho_{H2O}$

By definition, the spe ies for the distilled petroleum products g , and 0.84, respectively.

For liquids, water is th ed as the basis.

$SG = \rho_{gas} / \rho_{air}$

Being a ratio of similar



1.4.5. Specific volume

Specific volume of a flui it weight or unit mass of a fluid.

Specific volume (vs) = volu $= 1/\gamma = 1/(\rho\, g)$ ----- for liquids

Specific volume (vs) = volume/ mass = $1/\rho$ ----- for gases

1.4.6. Viscosity

From the perspective of the pipeline design engineer, viscosity is best understood as a material's resistance to flow. It is measured in centistokes. One centistoke (cSt) is equivalent to 1.08×10^{-5} square feet per second. Resistance to flow increases as the centistoke value (and viscosity) increases. Overcoming viscosity requires energy that must be accounted for in pump design, since the viscosity determines the total amount of energy the pump must provide to put, or keep, the liquid in motion at the desired flow rate. Viscosity affects not only pump selection, but also pump station spacing. Typical viscosities for gasoline, diesel fuel and crude oil are 0.64, 5 to 6 and 10 cSt, respectively.