



Liquid Pipeline Hydraulics

An Online Continuing Education Course for Engineers

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Liquid Pipeline Hydraulics

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Introduction to Liquid Pipeline Hydraulics

This online course on liquid pipeline hydraulics covers the steady state transportation of liquids in pipelines. These include water lines, refined petroleum products and crude oil pipelines. This course will prove to be a refresher in fluid mechanics as it is applied to real world pipeline design. Although many formulas and equations are introduced, we will concentrate on how these are applied to the solution of actual pipeline transportation problems.

First, the liquid properties are discussed and how they vary with temperature and pressure are analyzed. The pressure in a liquid and liquid head are explained next. Then the classical Darcy equation for determining pressure drop due to friction in liquid flow is introduced and a modified more practical version is explained. Common forms of equations relating flow versus pressure drop due to friction are introduced and applications illustrated by example problems. In a long distance pipeline the need for multiple pump stations and hydraulic pressure gradient are discussed.

Next the pumping horsepower required to transport a liquid through a pipeline is calculated. Centrifugal and positive displacement pumps are discussed along with an analysis of the pump performance curves. The impact of liquid specific gravity and viscosity on pump performance is explained with reference to the Hydraulic Institute charts. The use of drag reduction as a means to improving pipeline throughput is explored. Batching of different products in a pipeline simultaneously, with minimum commingling, is discussed next. The internal design pressure in a pipeline and the hydrostatic test pressure for safe operation are explained with illustrative examples.

1. Properties of Liquids

Mass is the amount of matter contained in a substance. It is sometimes interchangeably used in place of weight. Weight however, is a vector quantity and depends upon the acceleration due to gravity at the specific location. In the English or US Customary System of units (USCS), mass and weight are generally referred to in pounds (lb). Strictly speaking we must refer to mass as pound-mass (lbm) and weight as pound force (lbf). Mass is independent of temperature and pressure. In SI or Metric units, mass is measured in kilograms (kg). As an example, a 55 gal drum of crude oil may weigh 412 lbf or has a mass of 412 lbm. For the purpose of discussion in this course, when lb is used, it is intended to mean lbm.

Volume is the space occupied by a particular mass. It depends upon temperature and pressure. For liquids, pressure has very little effect on volume compared to gases. Volume of a liquid increases slightly with increase in temperature. In USCS units volume may be expressed in gallons (gal) or cubic feet (ft³). One ft³ is equal to 7.481 US gal. In the Oil and Gas industry, volume of petroleum products is measured in barrels (bbl). One bbl is equal to 42 US gal. In SI or Metric units, volume is expressed in liters (L) or cubic meters (m³). One m³ is equal to 1000 L. A useful conversion is 3.785 L to a gal of liquid. Volume flow rate in a pipeline may be stated in gal/min, bbl/h, bbl/day or m³/h.

Density of a liquid is defined as mass per unit volume. Therefore, like volume, density also depends upon temperature and pressure. Density decreases with increase in liquid temperature and vice versa. In USCS units density is stated in lb/gal or lb/ft³. In the petroleum industry, sometimes density is expressed in lb/bbl. In SI or Metric units, density is expressed in kg/L or kg/m³. If the mass of a 55 gal drum of crude oil is 412 lb, the

density of the crude oil is $412/55 = 7.49$ lb/gal. In contrast water has a density of 8.33 lb/gal or 62.4 lb/ ft³. In SI units, the density of water is approximately 1000 kg/m³ or 1 metric tonne/m³. The term specific weight is also sometimes used with liquids. It is calculated by dividing the weight by the volume.

Specific Gravity is defined as the ratio of the density of a liquid to that of water at the same temperature. It is therefore a measure of how heavy the liquid is compared to water. Being a ratio, specific gravity is dimensionless. Considering the density of water as 8.33 lb/gal and a sample of crude oil with a density of 7.49 lb/gal we calculate the specific gravity of the crude oil as $7.49/8.33 = 0.899$. Sometimes, specific gravity is abbreviated to gravity. Since the density of a liquid changes with temperature, the specific gravity also depends on temperature. Since density decreases with temperature rise, the specific gravity also decreases with increase in temperature. For example, if the specific gravity of a petroleum product is 0.895 at 60 degF, its specific gravity at 100 degF may be 0.815. The variation of specific gravity with temperature is approximately linear as shown in the equation below.

$$S_T = S_{60} - a(T-60) \quad (1.1)$$

where, S_T is the specific gravity at temperature T and S_{60} is the specific gravity at 60°F and a is a constant that depends on the liquid. Charts are available that show the specific gravity versus temperature variation for various liquids. See "Flow of Fluids through Valves, Fittings and Pipes", Crane Company, 1976.

In the petroleum industry, the term API Gravity is used often to describe the gravity of crude oils and refined petroleum products. It is based upon a standard of 60 degF and API gravity of 10.0 for water. For lighter liquids such as gasoline and crude oil, the API gravity is a number higher than 10.0. Therefore, the heavier the liquid is compared to water, lower is

the API value. A typical crude oil is said to have a gravity of 27 deg API. Consider for example, gasoline with a specific gravity of 0.74 (compared to water = 1.00). The corresponding API gravity of gasoline is 59.72 deg API. Similarly diesel with a specific gravity of 0.85, has an API gravity of 34.97. Conversion between specific gravity and API gravity can be done using the following equations.

Specific gravity = $\frac{\text{API}}{141.5 - \text{API}}$ (1.2)

or $\text{API} = \frac{141.5}{\text{Specific gravity}} - 131.5$ (1.3)

Subst. It must be noted that the above equation is only valid for liquids. It must be noted that the above equation is only valid for liquids. Gravity used in

Example

(a) Calculating

(b) Converting

Solution

(a) From equation (1.2)

$$\text{Sg} = \frac{\text{API}}{141.5 - \text{API}}$$

(b) From equation (1.3)

$$\text{API} = \frac{141.5}{\text{Sg}} - 131.5$$

Viscosity of a liquid represents the resistance to flow and is defined by the classical Newton's equation that relates the shear stress in the liquid to the velocity gradient of flow. When liquid flows through a pipeline the velocity of liquid particles at any cross-section varies in some fashion depending upon the type of flow (laminar or turbulent). Generally the

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