Flow Measurement

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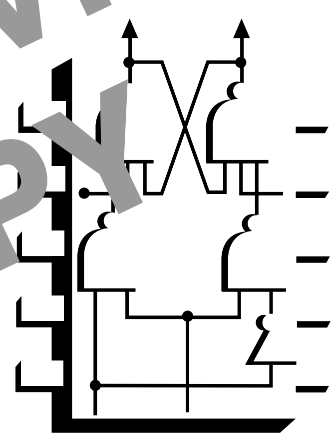
FLOW MEASUREMENT

Lesson One

Properties of Fluid Flow



TPC Training Systems

27501

Lesson

1 Properties of Fluid Flow

TOPICS

Importance of Flow Measurement
Basic Properties of Fluids
Fluids in Motion
Getting Fluids to Flow
Establishing a Pressure Difference
Ways of Indicating Fluid Flow Rate
Conditions Affecting Flow Rate
Reynolds Number

OBJECTIVES

After studying this Lesson, you should be able to...

- Explain the difference between density and relative density (specific gravity).
- Define fluid velocity, viscosity, and volume flow rate.
- Describe laminar flow and turbulent flow.
- Explain how static head, friction head, and velocity head differ from each other.
- Explain how pipe size, pipe friction, and fluid viscosity affect the measurement of fluid flow.

KEY TECHNICAL TERMS

Density 1.05 the mass per unit volume of a material
Relative density (specific gravity) 1.06 the ratio between the density of a liquid or solid and the density of water, or between the density of a gas and the density of air
Compressibility 1.07 a substance's ability to decrease in volume as pressure is applied
Viscosity 1.08 a fluid's resistance to flow
Laminar flow 1.13 smooth, layered flow
Turbulent flow 1.16 flow characterized by many small, swirling currents
Head 1.31 a pressure measurement expressed as the height of a column of liquid, measured from the centerline of the tap to the liquid's surface
Reynolds number 1.55 a ratio based on pipe size and fluid velocity, viscosity, and density

Material flow is involved in nearly every process industry. Flow moves material from one location to another and can add or remove heat. Liquid raw materials flow to a reaction vessel, finished product flows to a storage tank. Steam flows through heating coils, cooling water flows through condenser coils. Even solid materials flow in certain cases. In all these examples, the rate of flow must be controlled. By controlling flow rate, you can usually control reaction rate. Controlling the flow rate can also regulate other process variables—temperature and pressure, for example.

How flow is measured depends on the magnitude of the flow and the type of substance flowing. In the ten Lessons on flow measurement, you will study different kinds of flow-measuring instruments. You will see how flow control varies for solids, liquids, and gases. This Lesson covers the most important properties of fluid flow.

Importance of Flow Measurement

1.01 In many industrial plants, flow rates are critical. Often, accurate flow measurements can mean the difference between making a profit or taking a loss. In hospitals, inaccurate flow measurements can be deadly. Whether you work in industry or in health care, it is extremely important that you understand how flow rates are measured and how flowmeters operate.

1.02 For example, the flow of cooling water to industrial equipment and processes is critical in the proper operation of the equipment and in the continuity of the process. The interruption of cooling water flow to equipment—air compressors, hydraulic systems, and furnaces, for example—can cause extensive component damage. Inadequately or improperly controlled cooling of material in a process may result in physical or chemical changes that would cause the material to become scrap.

Basic Properties of Fluids

1.03 A *fluid* is a substance that flows when acted upon by a force—for example, gravity. The most common fluids are gases and liquids (air and water, for example). But finely divided solids (for example, flour and sand) can also flow. Therefore, they can be treated as fluids.

1.04 Process control deals extensively with *fluid flow*—the continuous, regulated movement of a liquid or a gas from one place to another. In order to understand fluid flow, you need to understand a few basic properties of fluids.

1.05 **Density.** The *density* of a fluid is simply the mass of a unit volume of that fluid. It is measured in units such as g/cm^3, kg/m^3, or g/l. For example, the mass density of gasoline is about 680 g/l. Mercury has a very high density, while common gases have very low densities. Table 1-1 lists the densities for some common fluids.

1.06 **Relative density (specific gravity)**. Some people confuse the terms density and *relative density*, formerly called *specific gravity*. Density is a "stand-alone" measurement. Relative density is a ratio of two densities and, therefore, is a unitless number. For liquids, relative density is the ratio between the density of a certain liquid and the density of water.

1.07 **Compressibility.** This term describes a substance's ability to decrease in volume when pressure

Table 1-1. Densities and weight densities of common fluids

	g/l	lb/ft^3*
Acetone	792	49.421
Air (at 1 atmosphere, 0°C)	1.29	0.0805
Alcohol (methyl)	810	50.544
Benzene	899	56.098
Bromine	3187	198.869
Carbon tetrachloride	1594	99.466
Chlorine (gas)	3.214	0.2005
Coconut oil	925	57.72
Fuming sulfuric acid	1838	114.70
Gasoline	680	42.432
Glycerine	1260	78.624
Helium (at 1 atmosphere, 0°C)	0.179	0.0112
Hydrogen (at 1 atmosphere, 0°C)	0.0899	0.00561
Kerosine	810	50.544
Mercury	13,600	848.64
Milk	1030	64.272
Water		
fresh	1000	62.4
sea	1025	63.96

* To calculate density in slugs per ft^3, divide weight density by 32.2.
Example: Density of acetone = 1.5348 slugs per ft^3

is applied. Gases compress (and expand) very easily, but liquids do not. Therefore, measuring gas flow and measuring liquid flow require slightly different methods.

Fig. 1-1. Fluid flows fastest at center of pipe

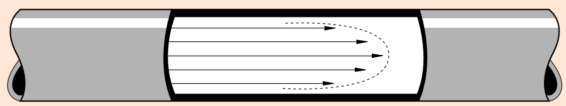
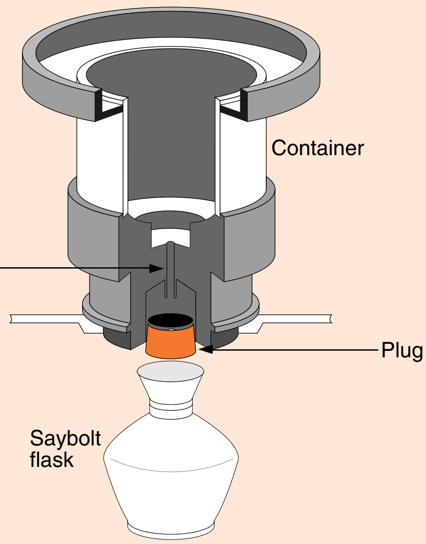


Table 1-2. Relative viscosities of selected fluids (using water at 20°C as base)

Fluid	Relative viscosity
Air at 0°C	0.017
Carbon dioxide at 0°C	0.014
Carbon tetrachloride at 20°C	0.9
Glass at melting temperature	10^5
Glass at working temperature	10^9
Glass at annealing temperature	10^{15}
Golden Syrup at 20°C	10,000
Glycerine at 20°C	83[illegible]
Mercury at 20°C	1.5
Olive oil at 20°C	[illegible]4
Pitch at 15°C	10^{12}
Steam at 100°C	0.013
Water at 20°C	1.0

Fig. 1-2. Saybolt universal viscometer



1.08 **Viscosity.** A fluid's *viscosity* is defined as its resistance to flow. Figure 1-1 shows a fluid moving through a pipe. Friction with the pipe wall causes the fluid to flow faster in the center of the pipe than it does near the wall. This causes layers of fluid to slip over each other. The amount of resistance to this internal slippage is the fluid's viscosity. Some fluids have a very high resistance (high viscosity), others very low.

1.09 As you can see, the higher a fluid's viscosity, the more difficult it is to get the fluid to flow. Imagine pouring a bucket of water, a bucket of honey, and a bucket of road tar. One pours freely, but the other two pour very slowly. You may even have to heat the tar before it will start flowing. Viscosity greatly affects the measurement of fluid flow. Table 1-2 lists the viscosities of some common fluids.

1.10 Viscosity is noticeably affected by temperature. Lubricating oils, for example, are assigned SAE numbers according to their viscosities at specified temperatures. (SAE stands for the Society of Automotive Engineers. You have probably seen SAE numbers on cans of motor oil.) But viscosity measurements may be expressed in units other than SAE numbers. In the metric system, a unit of measure often used for viscosity is the *poise* (1 dyne-s/cm^2). In the English measurement system, viscosity is often measured in lb-s/ft^2.

1.11 Another measurement system uses the *Saybolt Second Universal,* or SSU. Figure 1-2 shows the measurement device used in this system. The device is a Saybolt universal *viscometer* or *viscosimeter* (either word can be used). It consists of a special container and a flask. To use this device, you fill the container with the fluid to be tested, pull the plug, and measure the time it takes to fill the flask. If it takes 50 seconds, the fluid has a viscosity of 50 Saybolt Seconds Universal. (Some people say Saybolt Universal Seconds.)

Fluids in Motion

1.12 So far, most of this Lesson has dealt with properties of fluids in a static condition. Moving fluids have special properties, too. The study of fluids in motion and how they behave is known as *fluid dynamics*.

Fig. 1-3. Comparison of laminar and turbulent flows

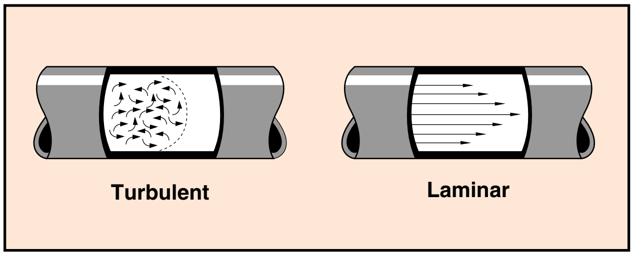
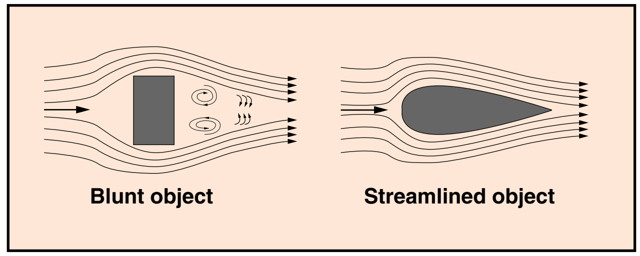


Fig. 1-4. Constant-velocity fluid flow around two objects



1.13 Fluids can flow in two distinct ways. The two kinds of fluid flow are laminar and turbulent. Laminar comes from a Latin word that means "thin plate." *Laminar flow* is a smooth, layered flow. The two kinds of flow are compared in Fig. 1-3.

1.14 In laminar flow, a fluid flows across a flat surface much like a deck of playing cards tossed onto a table. The bottom card sticks to the table, the next card moves a little farther, the third card moves a little farther than that, and so on. If you could see them, laminar flow patterns in a pipe or conduit would look like the concentric rings (actually nested tubes) that make up a tree trunk. But the concentric tubes of fluid are in motion. The central core of fluid moves the fastest, and the outermost tube (touching the pipe wall) moves the slowest.

1.15 Smoothly drawn flow lines on a diagram, called *streamlines,* show the shape of laminar flow. Thin trails of dye (or smoke) released into the laminar flow make the streamlines visible. An object that disrupts the flow pattern only slightly is said to be *streamlined.*

1.16 *Turbulent flow* lacks the smoothness of laminar flow. It is rough and irregular. It is made up of many smaller currents, swirling and weaving in all directions, often forming miniature whirlpools called *eddy currents*. Roughness in the flow path and changes in velocity or viscosity can transform laminar flow into turbulent flow. Turbulent flow causes considerable frictional resistance to fluid flow. In some applications, however, turbulent flow is desirable (for mixing fluids, for example).

1.17 Designers of process fluid distribution systems need to know about laminar and turbulent flow to create a system that operates as efficiently as possible. You need to know about these flow patterns so that you do not accidentally change the flow from one kind to another, thereby defeating the design function.

1.18 Some of the instruments you will learn about in these Lessons are suitable for laminar flow, some for turbulent flow, and some kinds can be used with either. For example, target meters and some orifices are used with laminar flow. Venturi tubes, flow nozzles, and other kinds of orifices are used with turbulent flow. For either kind of flow, you could use a pitot tube or rotameter. Magnetic and ultrasonic flowmeters are also suitable for both kinds of flow because they can measure flow rates without contacting or disturbing the process fluid.

1.19 Unless turbulence is needed, any object you place into a flowing stream of fluid should be as streamlined as possible. Figure 1-4 compares the flow patterns around a blunt object and a streamlined object. It takes less energy to push the fluid past the streamlined object because it offers less resistance to the flow.

1.20 The kind of flow you have in a pipe depends on several conditions: the fluid's velocity, viscosity, and relative density, and the size and smoothness of the pipe. Up to a certain velocity range, a fluid will flow in a laminar fashion. Above this *transition range*, the flow becomes turbulent. The range is higher for high-viscosity fluids and for very smooth pipes.

1.21 In many cases, fluid velocity determines whether or not an object inserted into the flow stream will change laminar flow to turbulent flow. Figure 1-5 on the following page compares the flow patterns around two kinds of objects, first at a low flow velocity, then at a higher velocity. Notice how laminar flow breaks down into turbulent flow when the velocity increases. These diagrams show why the interior surfaces of process fluid conduits must be clean and free from obstructions.

1.22 Fluids flowing through a pipe of uniform cross-sectional area maintain a constant velocity. But if the same fluid is forced to flow through a pipe with a gradually decreasing diameter, its velocity increases. This action is similar to water flowing through the nozzle of a garden hose.

1.23 Conversely, if a fluid flows through an enlarging section of pipe, the fluid velocity decreases. This effect can be seen more readily in open-channel flow, as in the case of a river slowing down as its channel widens.

1.24 These changes in velocity are related to another observable change—a change in the pressure exerted on the wall of the pipe. As the fluid velocity increases, the pressure on the wall decreases, and vice versa. This inverse relationship between fluid velocity and the pressure of containment is called the *Bernoulli effect*.

1.25 An equation derived from Bernoulli's principle shows a square root relationship between the flow rate and the differential pressure. The pressure differential is the difference in pressure at the two sides of the restriction. In the equation, the velocity of flow (v) is equal to a flow path constant (k) times the square root of the pressure differential (ΔP) divided by the density (D) of the fluid. Mathematically, this relationship is expressed by the equation:

$$v = k\sqrt{\frac{\Delta P}{D}}$$

If ΔP is expressed in lb/ft^2 and D is expressed in slugs/ft^3, the velocity will be in ft/s. The constant (k) has no units. The square root relationship between the flow velocity and the pressure differential causes a nonlinear output in many flowmeters.

1.26 A *venturi tube* is a device that makes use of the Bernoulli effect. A venturi tube consists of a tapered, narrowing section of pipe joined to a tapered, enlarging section. As the liquid or gas flows through the tube, its velocity increases, causing a pressure differential between the upstream and downstream flow. Fluid pressure is lowest at the point where the tube is most restricted, as shown in Fig. 1-6. Pressure taps are inserted upstream, downstream, and in the restriction. You can compare the pressure at these spots by looking at the mercury levels in each of the vertical tubes.

1.27 The venturi tube is constructed so that it has no projections or sharp corners placed in the flow path. Because of this construction, fluid flow can be measured without restricting the flow. Venturi tubes can be round, rectangular, or irregular in shape. Venturis are often used to measure the flow rate of steam, air, or other gases. Their only major limitation is their construction cost.

Application 1-1

One of the best known and most useful applications of the venturi tube is in the carburetor of an internal combustion engine. Its air passage is slightly narrowed at the point where air mixes with the gasoline. This increases the air velocity and lowers the air pressure, thus vaporizing the gasoline more completely—and improving overall engine performance.

Fig. 1-5. Laminar flow converted to turbulent flow by increasing flow velocity

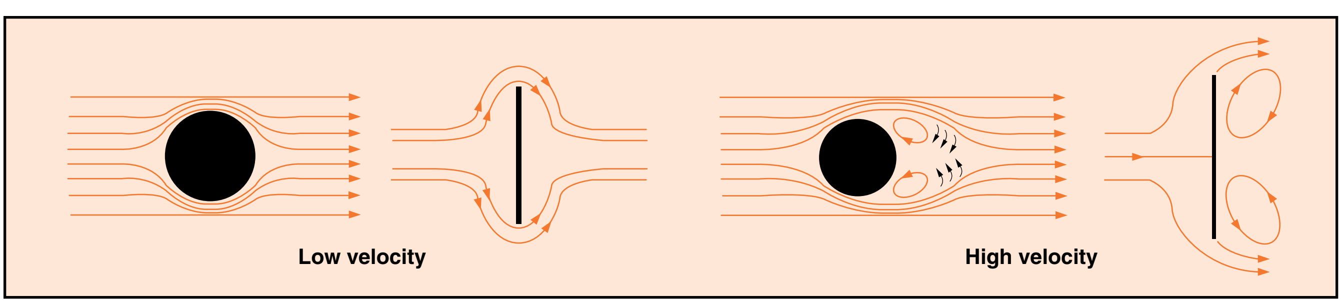


Fig. 1-6. Venturi tube with manometer attached

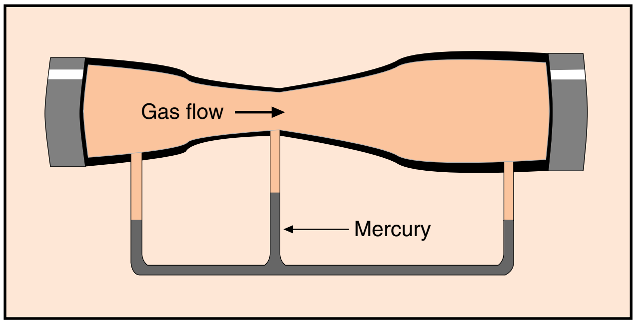
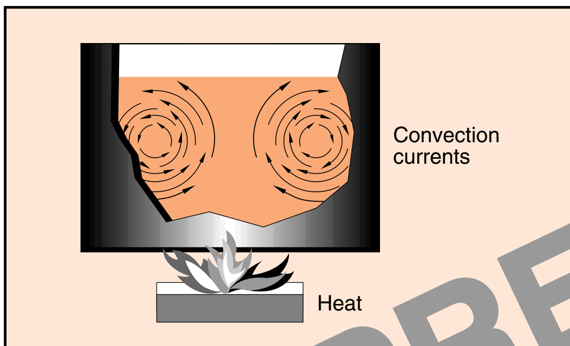


Fig. 1-7. Convection currents in heated liquid



Getting Fluids to Flow

1.28 Fluids are easy to set in motion. In a pipe, for instance, a slight difference in pressure between one end and the other causes the gas to move toward the low-pressure end. Even high-viscosity liquids begin moving easily in response to very small pressure differences. The only effect viscosity has is to reduce the speed at which the fluid moves through the pipe.

1.29 Pressure differences between one area and another in a contained fluid are often caused by slight differences in density within the fluid. These differences usually are due to uneven temperature distribution. The result is a circulation of fluid called a *convection current*. The heat in process fluids in large containers is often more evenly distributed through the action of convection currents, as shown in Fig. 1-7.

The Programmed Exercises on the following page will tell you how well you understand the material you have just read. Before starting the exercises, remove the Reveal Key from the back of your Book. Read the instructions printed on the Reveal Key. Follow these instructions as you work through the Programmed Exercises.

1-1. The mass of a unit volume of a fluid is its ________.	1-1. DENSITY Ref: 1.05
1-2. The relative density of a liquid is the ratio between the liquid's density and the density of ________.	1-2. WATER Ref: 1.06
1-3. A fluid flows more easily if its viscosity is ________.	1-3. LOW Ref: 1.09
1-4. A fluid that flows in smooth layers is an example of _________ flow.	1-4. LAMINAR Ref: 1.13
1-5. A fluid that flows in swirls and contains eddy currents is an example of ________ flow.	1-5. TURBULENT Ref: 1.16
1-6. If a fluid flows through a gradually converging pipe, its velocity ________.	1-6. INCREASES Ref: 1.22
1-7. In a venturi tube, the fluid pressure is lowest where the tube is ________.	1-7. NARROWEST Ref: 1.26
1-8. Uneven temperature distribution causes a(n) ________ current to circulate in a contained fluid.	1-8. CONVECTION Ref: 1.29

Establishing a Pressure Difference

1.30 In process fluid systems, there are two ways of setting up a pressure difference so that fluids can flow. One is by means of gravity, and the other is with the aid of a pump. Although you are probably familiar with both, a review of a few technical terms may be helpful.

1.31 In a simple gravity-fed system, the liquid is held in a tank or column with an outlet at the bottom, as shown in Fig. 1-8. The pressure at the outlet depends on the height of the liquid in the tank and the density of the liquid. The height of the liquid (the vertical distance from the centerline of the tap to the liquid's surface) is used as a pressure measurement, and referred to as *head.*

1.32 Head can be expressed in pressure units or as the equivalent height of a column of fluid. To convert the head of any liquid from linear units to pressure units (or vice versa), you must know the density of the liquid. The liquid's weight density in lb/ft^3 divided by 144 in^2 gives you the pressure in pounds per square inch (psi) at the bottom of a cubic foot of that liquid. To convert from linear to pressure units, you can use the following equation:

$$P = DH$$

where P = pressure

D = weight density

H = height.

1.33 **Sample problem:** What is the head in pressure units for a water system with a 25-ft vertical head?

Solution: The weight density of water is 62.4 lb/ft^3. Therefore:

$$P = 62.4\ lb/ft^3 \times 25\ ft$$

$$= 1560.0\ lb/ft^2$$

$$= 1560.0\ lb/144\ in^2$$

$$= \frac{1560.0}{144}\ lb/in^2$$

$$= 10.8\ psi.$$

1.34 If the liquid flow is pump-driven, additional terms are needed. The following definitions apply to any pumping situation, regardless of pump type.

1.35 **Static suction lift**. *Suction lift* is a term used when the source of supply is located *below* a pump, as shown in Fig. 1-9 on the following page. You can think of it as a "negative" pressure, or pressure below atmospheric pressure. The vertical distance (expressed in feet) from the centerline of the pump to the surface of the liquid to be pumped is the *static suction lift*. The intake of the pump may be several feet below the surface of the liquid, but this extra distance is not included when determining the static suction lift.

Fig. 1-8. Head is measured from centerline of outlet to surface of liquid

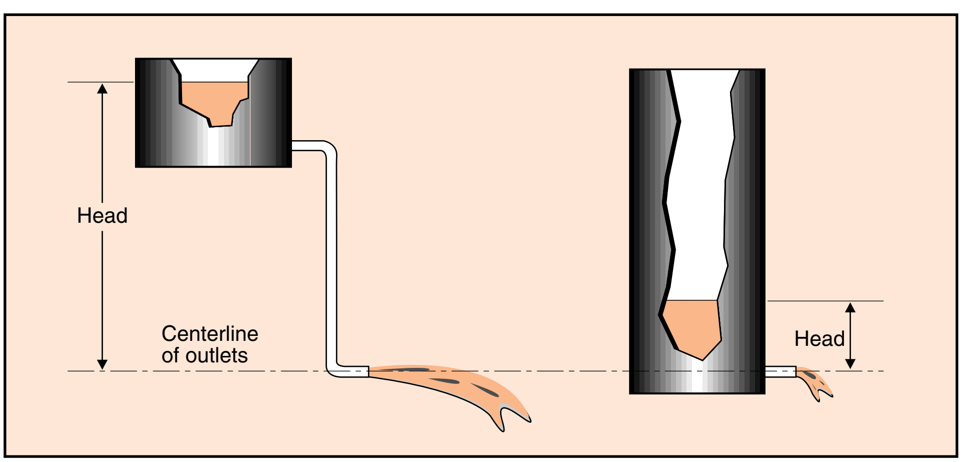
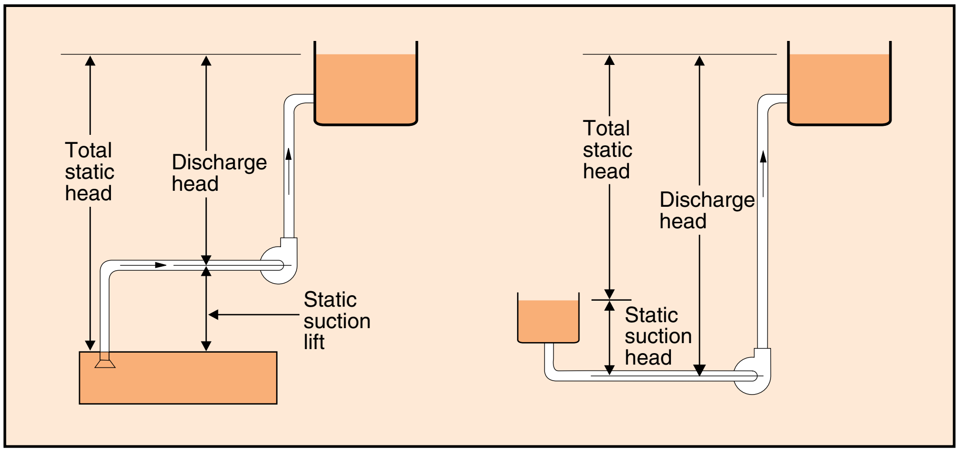


Fig. 1-9. Comparison of suction lift and suction head



1.36 **Static suction head**. This term is used when the source of supply is *above* the pump, as shown in Fig. 1-9. It is the vertical distance (in feet) from the centerline of the pump to the surface of the liquid that is to be pumped.

1.37 **Total static head**. As shown in Fig. 1-9, total static head is the vertical distance (in feet) between the surface on the input side and the surface on the discharge side. The total static head is calculated in the same way whether the suction level of the pump is above or below the pump centerline. If the point of discharge is above the surface of the liquid, as in Fig. 1-10, the horizontal upper arm of the pipe is considered the level of the free surface of the water.

1.38 These definitions do not apply when pumping liquids between any two places where the pressures differ. For instance, if you pump water from a source at atmospheric pressure into a vessel containing a fluid at 500 psig, that value becomes part of the total static head. In fact, it adds over 1150 effective feet of head to the real linear distance between the two liquid surfaces.

1.39 Similarly, if you are pumping liquid from a tank that is under vacuum and is below the pump centerline, the value of the vacuum would be included as part of the total static head. For every inch of vacuum, you can estimate approximately one additional foot of suction lift on the pump. On this basis, a 10-in vacuum would have a 10-ft suction lift.

1.40 One additional term is used. Suppose you open a drain hose at the bottom of a tank and point the hose upward. The stream of water will not rise to the free level of water in the tank due to friction loss within the hose. The distance it will rise is called the *velocity head* or *dynamic head*, as shown in Fig. 1-11.

1.41 An interesting device to illustrate the relationship among static head, velocity head, and friction is shown in Fig. 1-12 on page 14. It is a gravity system with a constant source of supply and an overflow drain to keep the surface at a constant height. If the valve is closed, the water level in each of the vertical pipes equals the level in the main container. But when the valve is opened, the standpipe levels will produce the descending pattern you see in the drawing.

1.42 If there were no friction in the horizontal pipe, all standpipes would be at the level of the first. Thus, the sloping line shows the pressure drop due to friction, sometimes called the *friction head* (H_f).

1.43 The liquid levels in the standpipes are maintained by pressures in the horizontal pipe. Pressure perpendicular to the direction of flow is called the *pressure head* (H_p). Notice how it gradually diminishes along the length of the horizontal pipe because of friction. The velocity head (the distance H_v) becomes larger or smaller as the valve is opened or closed. If the valve were opened wider, the standpipe levels would drop. Note that the total static head minus the friction head and the pressure head equals the velocity head.

Ways of Indicating Fluid Flow Rate

1.44 In working with process instruments, you may find the *rate* of fluid flow expressed in several ways. One of the most common is flow velocity, which you have already used in this Lesson. This measurement tells the distance that a particle of fluid moves in a unit of time. For example, a pipe may carry benzene at a flow rate of 50 ft/min. This simply says that a certain quantity of benzene moves a distance of 50 ft through the pipe in one minute. Elsewhere, crude oil may be moving down a pipeline at the rate of 10 mph, or 240 miles in a day. If you know the diameter of the pipe, you can also find the volume flow rate—that is, the volume of oil moved in a day.

1.45 You can calculate volume flow rate by using the following equation:

$$Q_{vol} = A \times v$$

where Q_{vol} = volume flow rate

A = cross-sectional area of the pipe carrying the fluid

v = flow velocity.

1.46 **Sample problem**: Suppose a pipe has an inside diameter of 2½ ft. Water flows through this pipe at the rate of 12 ft/s. What is the volume flow rate through the pipe?

Solution: $Q_{vol} = A \times v$

$= (\pi r^2) \times v$

$= 4.9\ ft^2 \times 12\ ft/s$

$= 59\ ft^3/s.$

Note: Always include the *units* of each value as well as the number. If necessary, convert one or more units to make the combination sensible.

1.47 Suppose you need to know the total volume of fluid delivered in a certain time period, say one day. You multiply the volume flow rate by the total time. This equation can be expressed as:

$Q \times t$ = daily volume

$= 59\ ft^3/s \times 24\ hr$

$= 59\ ft^3 \times 24\ (60\ min)$

$= 59\ ft^3 \times 24 \times 60\ (60\ s)$

$= 59\ ft^3 \times 24 \times 60 \times 60\ ft^3$

$= 5.1$ million ft^3.

1.48 Some control systems use still another index of flow rate, called *mass flow rate*, or *weight flow rate*. There are many measurement units that can be used for mass or weight flow rate, including kg/hr, lb/min, tons/hr, or g/s.

Fig. 1-10. Static head is not always measured to the free surface in a tank

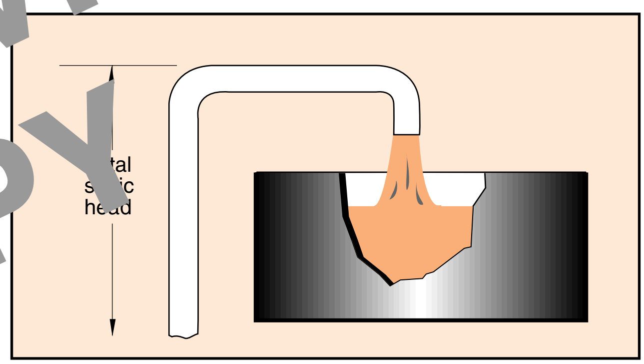


Fig. 1-11. Relationship between static head and dynamic head

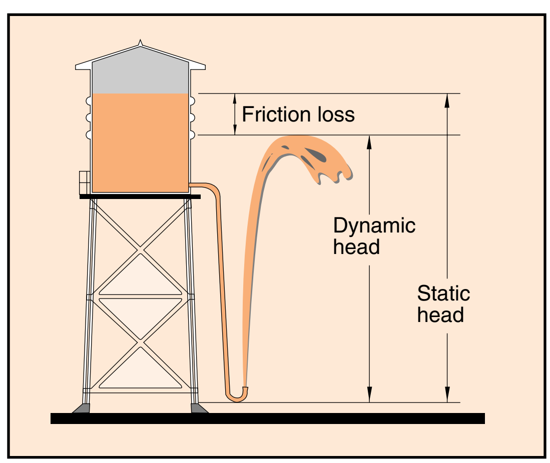
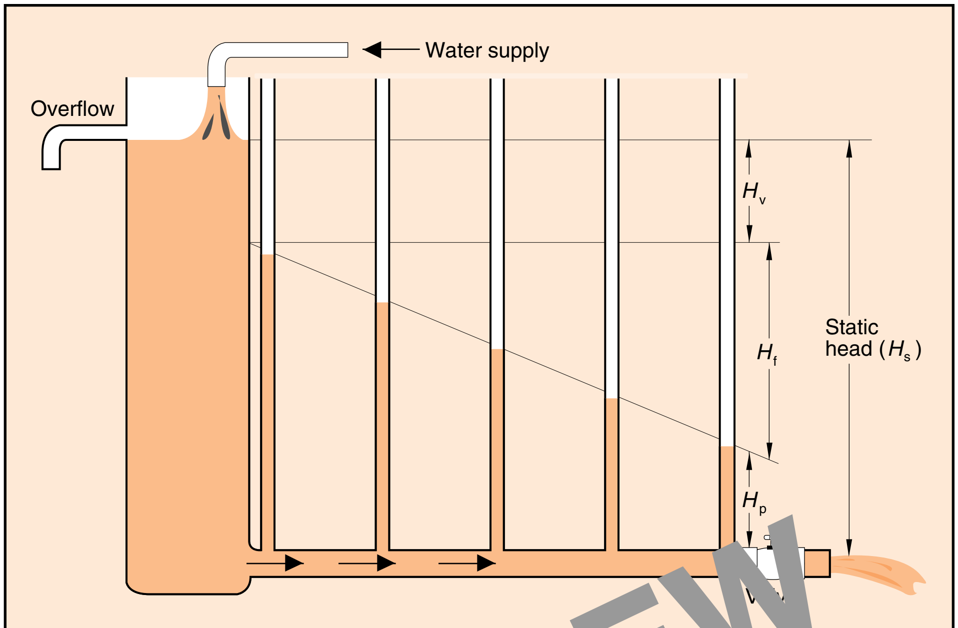


Fig. 1-12. Pressure head loss along length of pipe



1.49 You can calculate a mass flow rate if you know the volume flow rate and the fluid density. The formula for converting one rate to the other is:

$$Q_m = D \times Q_{vol}$$

where Q_m = mass flow rate

D = fluid density (mass per unit volume)

Q_{vol} = volume flow rate.

Of course, the same formula allows you to calculate the volume flow rate if you know the mass flow rate and the fluid density.

Conditions Affecting Flow Rate

1.50 The rate at which a fluid flows through a channel or pipe depends on three conditions: head, viscosity, and frictional resistance. You know that head generally increases the flow rate, while viscosity and friction decrease the flow rate. The higher the head, the greater the volume flow rate, if all other conditions remain constant.

1.51 The volume flow rate of a fluid in a pipe is directly affected by the pipe size as well as the pressure head. If you double the diameter of a pipe (and keep the same pressure head), the flow rate will be four times as great, because doubling the pipe diameter multiplies the cross-sectional area of the pipe by four.

1.52 Pipe friction opposes fluid flow. Because of friction, the flow is actually slightly slower near the

Table 1-3. Pressure loss for assorted sizes of wrought iron pipe (in psi/100 ft)

Gallons per minute	Nominal diameter in inches					
	1/2	3/4	1	1 1/4	1 1/2	2
1	0.9	0.2	—	—	—	—
2	3.2	0.8	—	—	—	—
3	6.9	1.8	0.6	—	—	—
4	11.7	3.2	0.9	0.3	0.1	—
5	17.8	4.5	1.4	0.4	0.2	—
6	24.8	6.4	2.0	0.5	0.3	0.1
8	42.6	10.9	3.4	0.9	0.4	0.1
10	64.0	16.5	5.1	1.4	0.6	0.2
12	90.0	23.1	7.1	1.9	0.9	0.3
14	120.0	30.4	9.6	2.5	1.2	0.4
16	—	40.0	12.2	3.2	1.5	0.5
18	—	48.7	15.2	4.0	1.8	0.7
20	—	59.2	18.3	4.8	2.3	0.8
30	—	120.0	38.7	10.2	4.8	1.7
40	—		66.0	17.4	8.2	2.9
50	—		98.0	26.1	12.4	4.3

walls of a pipe and faster at its center. If the discharge pipe of a storage tank is rough or corroded, pipe friction can be significant. The flow rate will improve when the pipes are cleaned and smoothed out. Table 1-3 gives the loss in pressure due to friction for various diameters of wrought iron pipe. The larger the pipe, the smaller the effect of pipe friction.

1.53 Viscosity, of course, also opposes fluid flow. The higher the viscosity, the lower the flow rate, all other conditions being equal.

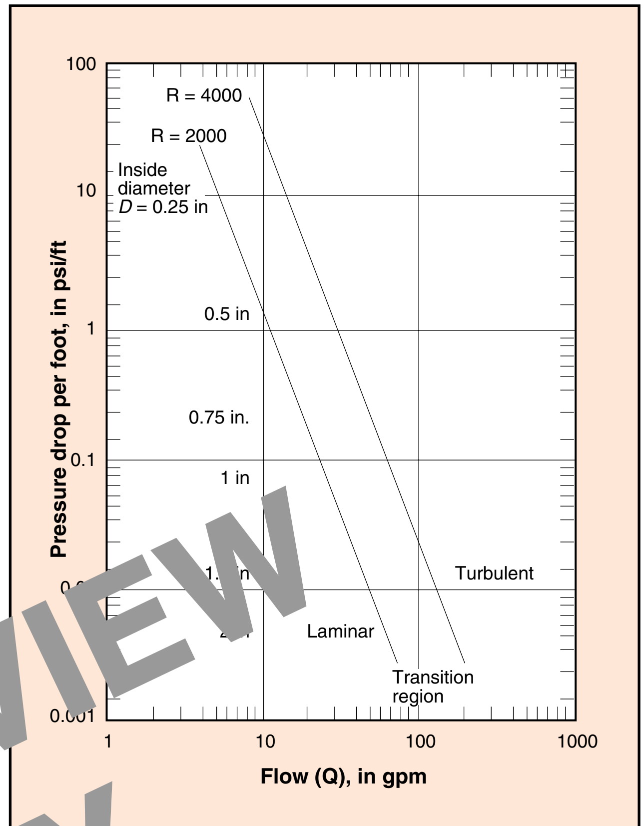
Reynolds Number

1.54 The *Reynolds number*, which you can find readily from graphs in piping handbooks, is important in the sizing of pipe, especially where viscous or heavy fluids are involved. Fig. 1-13 shows a graph of this kind. You don't need to know about Reynolds numbers in detail, but you should at least understand what they indicate when you see these numbers in pipe charts.

1.55 A *Reynolds number* is the ratio of a liquid's (or gas's) inertial forces to its drag forces. It is calculated by multiplying the velocity of the fluid by the diameter of the pipe and by the density of the fluid, and then dividing that value by the viscosity of the fluid. Reynolds numbers are low at low velocities and high viscosities.

1.56 At a low Reynolds number (up to about 2000), the viscosity and velocity of the fluid produce a

Fig. 1-13. Typical pressure-drop chart for smooth pipes of assorted sizes



smooth, laminar flow. Flow changes between laminar and turbulent in the range of Reynolds numbers between 2000 and 4000. At a Reynolds number above 4000, flow is turbulent, the smoothness of the pipe is extremely important, and piping design is critical.

1-9. The measurement of head can be expressed in ________ units or in ________ units.	1-9. LINEAR; PRESSURE Ref: 1.32
1-10. A pump operates with a suction lift when the fluid source is located ________ the pump.	1-10. BELOW Ref: 1.35
1-11. In a pumping system, the vertical distance between the input surface and the output surface is known as the ________.	1-11. TOTAL STATIC HEAD Ref: 1.37
1-12. Friction head is a term sometimes applied to ________ caused by friction.	1-12. PRESSURE DROP Ref: 1.42, Fig. 1-12
1-13. Flow velocity is the ________ a fluid flows in a unit of ________.	1-13. DISTANCE; TIME Ref: 1.44
1-14. The amount of fluid that flows past a point in a certain length of time is its ________.	1-14. VOLUME FLOW RATE Ref: 1.44, 1.45
1-15. To find the mass flow rate, you need to know the volume flow rate and the fluid ________.	1-15. DENSITY Ref: 1.49
1-16. The effect of pipe friction on the flow rate is ________ in a small pipe than in a large pipe.	1-16. GREATER Ref: 1.52

Answer the following questions by marking an "X" in the box next to the best answer.

1-1. Another name for the ratio of the density of a liquid to the density of water is

- ☐ a. density factor
- ☐ b. Saybolt number
- ☐ c. relative density
- ☐ d. viscosity index

1-2. The resistance of a fluid to movement or flow is its

- ☐ a. buoyancy
- ☐ b. cohesion
- ☐ c. compressibility
- ☐ d. viscosity

1-3. In what kind of flow do frictional resistance and eddy currents occur?

- ☐ a. Centerline
- ☐ b. Laminar
- ☐ c. Streamlined
- ☐ d. Turbulent

1-4. The kind of fluid flow in a pipe is determined by the size of the pipe, the viscosity and relative density of the fluid, and the

- ☐ a. fluid velocity
- ☐ b. fluid volume
- ☐ c. Saybolt number
- ☐ d. static head

1-5. As a fluid flows through a widening pipe, its

- ☐ a. flow becomes turbulent
- ☐ b. velocity decreases
- ☐ c. velocity increases
- ☐ d. volume decreases

1-6. The circulation of an enclosed fluid caused by uneven temperatures is called

- ☐ a. conduction
- ☐ b. convection
- ☐ c. head flow
- ☐ d. radiation

1-7. A pump that draws liquid from a lower level is said to operate with a

- ☐ a. static head
- ☐ b. suction head
- ☐ c. suction lift
- ☐ d. velocity head

1-8. Every inch of vacuum in a pumping system adds how many feet to the suction lift?

- ☐ a. 0.5 ft
- ☐ b. 1.0 ft
- ☐ c. 2.5 ft
- ☐ d. 5.0 ft

1-9. The distance that a piped fluid flows in a certain amount of time is its

- ☐ a. dynamic flow
- ☐ b. flow differential
- ☐ c. flow velocity
- ☐ d. volume flow rate

1-10. Which of the following helps liquid flow in a pipe?

- ☐ a. Compressibility
- ☐ b. Friction
- ☐ c. Head pressure
- ☐ d. Viscosity

SUMMARY

The basic properties of fluids are density, relative density, compressibility, and viscosity. These properties and others determine how fluids flow. The study of fluids in motion and their behavior is called fluid dynamics.

Fluid flow can be either laminar or turbulent. Laminar flow is smooth and layered. Turbulent flow is rough and irregular. The kind of fluid flow in a pipe depends on the size and smoothness of the pipe and on the velocity and viscosity of the fluid.

Fluids flow in response to differences in pressure. Viscosity determines how fast the fluid will move through a pipe, assuming pressure remains constant. A pressure difference can be established by means of gravity or with the aid of a pump.

Head is the pressure in a column of liquid and may be expressed in either linear units or pressure units. Total static head is the vertical distance (in feet) between the surface on the input side and the surface on the discharge side.

Fluid flow rate is expressed in several ways. One of the most common is flow velocity, which tells you how far a particle of fluid moves in a unit of time. Other ways include volume flow rate and mass flow rate.

Fluid flow rate depends on head, viscosity, and frictional resistance. It is affected by pipe size and by pressure head. A Reynolds number is a ratio based on the factors that determine flow rate. A Reynolds number below 2000 indicates laminar flow, and a Reynolds number above 4000 indicates turbulent flow.

Answers to Self-Check Quiz

1-1. c. Relative density. Ref: 1.06

1-2. d. Viscosity. Ref: 1.08

1-3. d. Turbulent. Ref: 1.16

1-4. a. Fluid velocity. Ref: 1.20

1-5. b. Velocity decreases. Ref: 1.23

1-6. b. Convection. Ref: 1.29

1-7. c. Suction lift. Ref: 1.35

1-8. b. 1.0 ft. Ref: 1.39

1-9. c. Flow velocity. Ref: 1.44

1-10. c. Head pressure. Ref: 1.50