PROCESS CONTROL SYSTEMS

9

LEARNING ACTIVITY PACKET

BASIC FLOW MEASUREMENT AND CONTROL

IST™ AMATROL
INTEGRATED SYSTEMS TECHNOLOGY

B270-XD

LEARNING ACTIVITY PACKET 9

BASIC FLOW MEASUREMENT AND CONTROL

INTRODUCTION

Flow measurement and control are used in most types of process control systems. Regardless of what process variable is being controlled (e.g. temperature, level, pressure, etc.), flow is usually the manipulated variable.

This LAP covers the different units used to measure flow and various types of flow sensors. It also covers how flow is controlled in automatic closed loop systems.

ITEMS NEEDED

Amatrol Supplied

1 T5552 Process Control Learning System

School Supplied

1 Water Supply (10 Gallons)

1 Loop Calibrator or Multimeter

FIRST EDITION, LAP 9, REV. A

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SEGMENT 1

INTRODUCTION TO FLOW MEASUREMENT

OBJECTIVE 1 DESCRIBE THE FUNCTION OF FLOW MEASUREMENT AND GIVE AN APPLICATION

Read This

Flow measurement is the measurement of the volume or mass of material that passes a given point during a specified time period. Flow is frequently the manipulated variable in a control loop, regardless of the controlled variable (e.g. level, pressure, temperature, pH). For example, maintaining the level in a tank often requires controlling the flow into or out of the tank, or sometimes both.

It is also possible for flow to be both the controlled and the manipulated variable. For example, figure 1 shows a flow sensor measuring the flow of liquid in a process system. The flow sensor sends a signal to a transmitter, which sends its output to a controller. The controller then sends a signal to the valve via an I/P converter to control the flow at the desired rate.

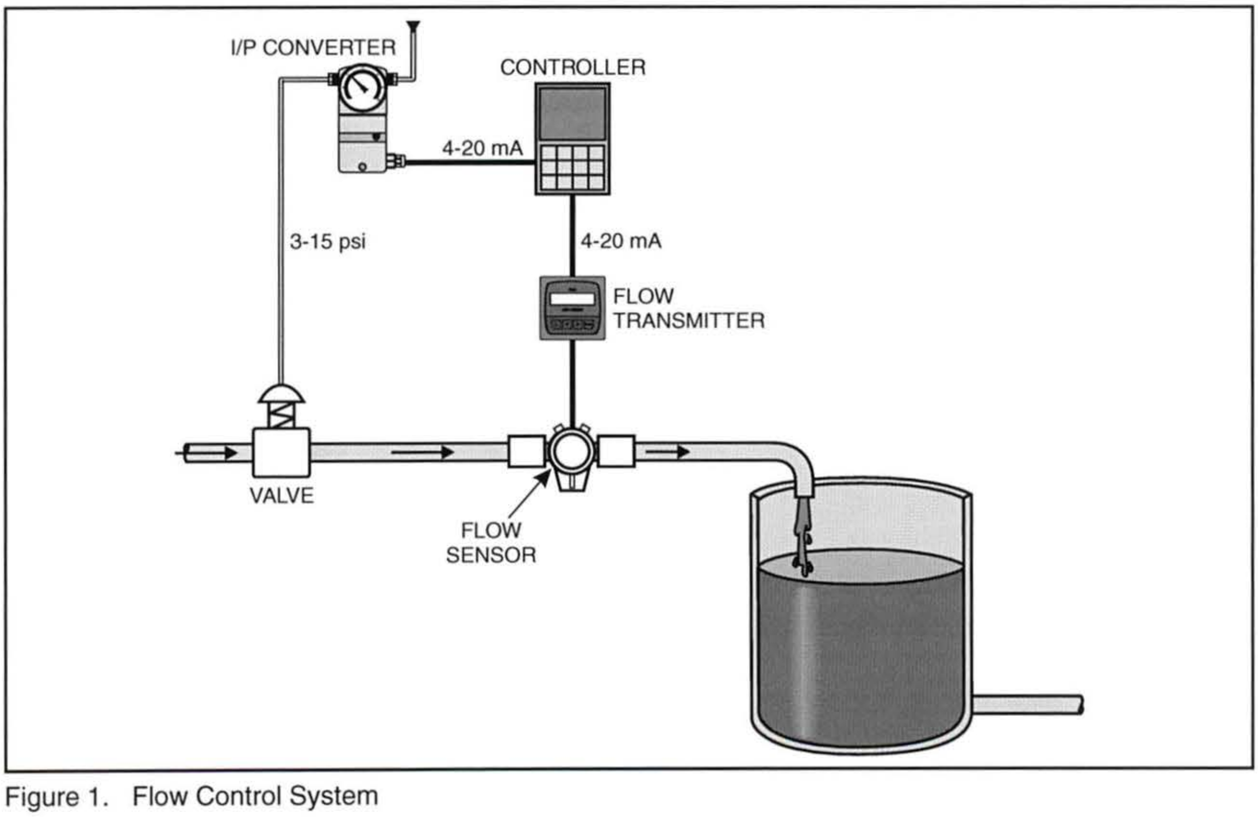

Figure 1. Flow Control System

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OBJECTIVE 2 DEFINE THREE FLOW MEASUREMENT UNITS

Read This

Process control systems measure flow using one of three types of units: velocity, volume, and mass. The units used typically depends on the application.

Velocity

Velocity refers to the time it takes a fluid to travel a given distance. The velocity of a fluid is typically specified in feet per second (ft/sec) or meters per second (m/sec), as shown in figure 2.

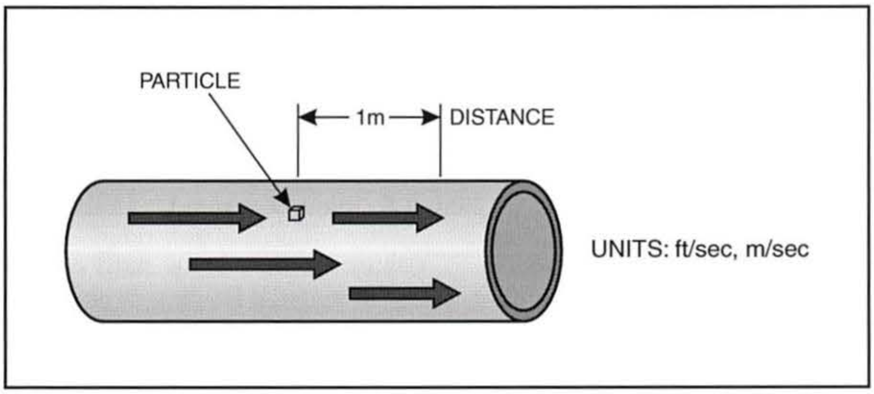

Figure 2. Flow Measured in Units of Velocity

Velocity measurement is common in applications where fluid velocity is directly related to the process performance. An example is in a heat exchanger where fluid velocity affects the heat transfer rate.

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Volumetric Flow

Volumetric flow rate describes the volume of fluid that flows past a given point in a period of time. The volumetric flow rate combines the velocity of the fluid and the area of the pipe or container. Volumetric flow is typically expressed in cubic feet per minute (ft^3/min), gallons per minute (gpm), or liters per minute (lpm), as shown in figure 3.

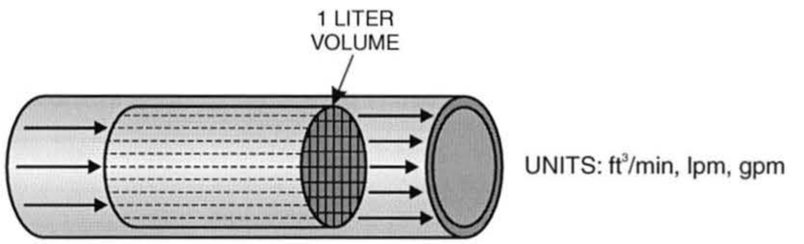

Figure 3. Flow Measured in Units of Volume

Volumetric flow is the most common method of measuring how the quantity of material flowing through the system directly relates to process performance in many applications. An example is a mixing application where two fluid streams are mixed together in a specific ratio.

Mass Flow

The mass flow rate describes the mass of fluid that flows past a given point in a period of time. Mass flow rate combines the density of the fluid and the volumetric flow rate. The mass flow rate is often expressed in pounds per min (lbs/min, ppm) or kilograms per min (kg/min), as shown in figure 4.

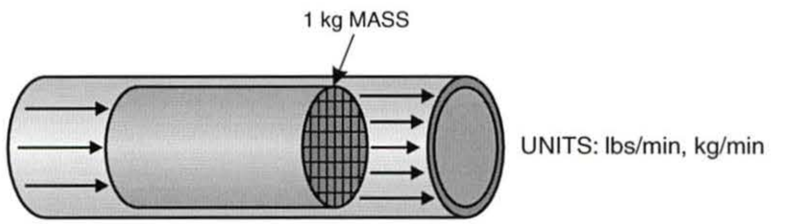

Figure 4. Flow Measured in Units of Mass

Mass flow measurement is the most accurate method of measurement of the quantities of material flowing through the system because density variations do not cause a reading error. Many applications that control the flow of compressed air or other gases use mass flow measurement.

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OBJECTIVE 3 DESCRIBE HOW TO CONVERT BETWEEN VELOCITY AND VOLUMETRIC FLOW RATE UNITS

Many flow sensors actually measure the velocity of the liquid flow and convert it to a volumetric flow rate. The following formula shows the conversion from velocity units to volumetric flow rate units given the inside diameter (ID) of the pipe:

FORMULA: VELOCITY UNITS TO VOLUMETRIC UNITS

S.I. Units:

$$Q_v = 0.0471189 \times ID^2 \times V$$

Where:

Q_v = *Volumetric flow rate in liters per minute (lpm)*
ID = *Inside diameter of pipe in millimeters (mm)*
0.0471189 = *Constant*
V = *Velocity in meters per second (m / sec)*

U.S. Customary Units:

$$Q_v = \frac{ID^2 \times V}{0.4084967}$$

Where:

Q_v = *Volumetric flow rate in gallons per minute (gpm)*
ID = *Inside diameter of pipe in inches (in.)*
0.4084967 = *Constant*
V = *Velocity in feet per second (ft / sec)*

The constants given are based on the relationship between the ID of the pipe (in inches or millimeters) and its cross-sectional area (πr^2), where r is the radius. They also provide the required conversions from ft/sec or m/sec (for the velocity) to gpm or lpm for the volumetric flow rate.

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Pipes come in standard sizes of both English and metric units. To determine the inside diameter (ID) of a pipe, it is looked up in a table like the one shown in figure 5. The nominal pipe size (NPS) is an approximation of the actual ID and is used for convenience in naming the pipe size. For example, Schedule 40 pipe with a nominal size of 1 inch has an ID of 1.049. Diametre Nominal (DN) is the metric equivalent of the NPS.

STANDARD PIPE SIZES					
SCHEDULE 40 PIPE SIZES			METRIC PIPE SIZES		
NOMINAL SIZE (in)	OUTSIDE DIAMETER (in)	INSIDE DIAMETER (in)	DN (mm)	OUTSIDE DIAMETER (mm)	INSIDE DIAMETER (mm)
1/2	.840	.622	15	20	15
3/4	1.050	.824	20	25	20
1	1.315	1.049	25	32	25
1-1/2	1.900	1.610	40	50	40
2	2.375	2.067	50	63	50
2-1/2	2.875	2.469	65	75	65
3	3.500	3.068	80	90	80
4	4.500	4.026	100	110	100
5	5.563	5.047	125	140	125
6	6.625	6.065	150	160	150
8	8.625	7.981	200	225	200
10	10.750	10.020	250	280	250

Figure 5. Standard Pipe Size Table

Some flow measurement applications require conversion from flow velocity to volumetric flow rate or vice versa. For example, designers use velocity to size pipes and volumetric flow rate to size components. Another example would be an operation where a velocity-type flow sensor is the only type available, but the system needs volumetric flow units.

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Example – Calculate the volumetric flow rate of the liquid in liters per minute (lpm) flowing through the pipe shown in figure 6 using the following information:

Liquid Velocity = 4.5 m/sec

Nominal Pipe Size = 25 mm

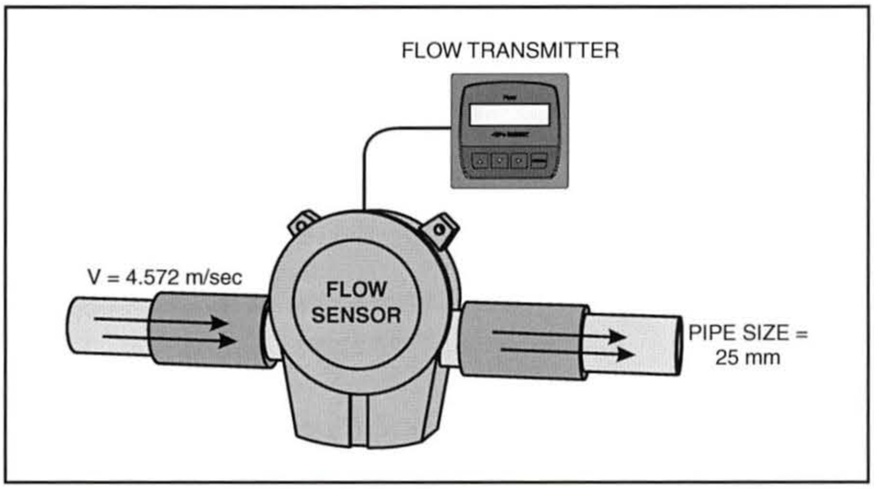

Figure 6. Velocity Flow Rate Through a Pipe

The solution is as follows:

First, determine the ID for the pipe using the pipe size table in figure 5. In this case, the ID of the pipe is 25 mm.

Next, calculate the volumetric flow rate using the formula.

$Q_v = 0.0471189 \times ID^2 \times V$

$Q_v = 0.0471189 \times (25)^2 \times 4.5$

$Q_v = 0.0471189 \times 625 \times 4.5$

$Q_v = 132.52\ lpm$

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Rearranging the formulas allows the velocity of the fluid to be found given the volumetric flow.

FORMULA: VOLUMETRIC FLOW UNITS TO VELOCITY UNITS

S.I. Units:

$$V = \frac{Q_v \times 21.22291}{ID^2}$$

Where:

V = *Velocity in meters per second (m / sec)*

Q_v = *Volumetric flow rate in liters per minute (lpm)*

ID = *Inside diameter of pipe in millimeters (mm)*

21.22291 = *Constant*

U.S. Customary Units:

$$V = \frac{Q_v \times 0.4084967}{ID^2}$$

Where:

V = *Velocity in feet per second (ft / sec)*

Q_v = *Volumetric flow rate in gallons per minute (gpm)*

ID = *Inside diameter of pipe in inches (in.)*

0.4084967 = *Constant*

The constant 21.22291 is the reciprocal of the constant 0.0471189 ($\frac{1}{0.0471189}$ = 21.22291).

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Example – Calculate the velocity in feet per second (ft/sec) of the liquid flowing through the pipe shown in figure 7 using the following information.

Volumetric Flow Rate = 25 gpm

Nominal Pipe Size = 1-1/2 in.

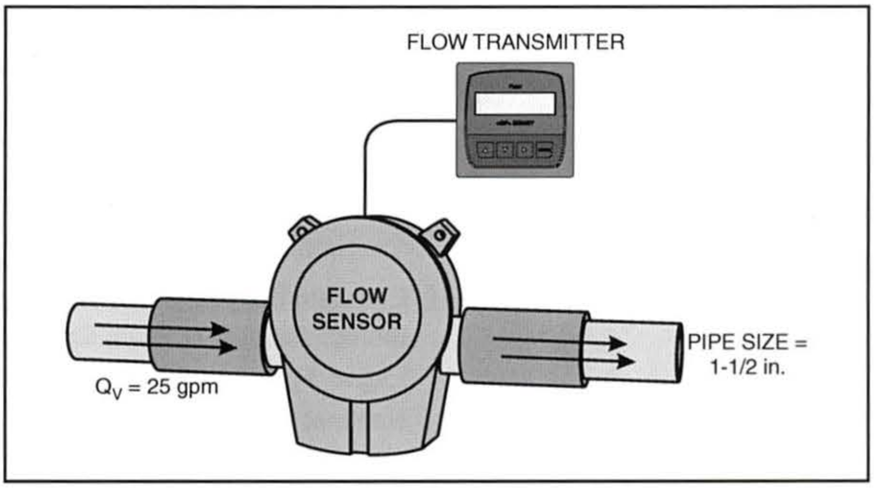

Figure 7. Volumetric Flow Rate through a Pipe

The solution is as follows:

First, determine the ID for the 1-1/2 inch pipe from the table in figure 5. In this case, the ID is 1.610.

Next, calculate the velocity using the formula.

$$V = \frac{Q_v \times 0.4084967}{ID^2}$$

$$V = \frac{25 \times 0.4084967}{(1.610)^2}$$

$$V = \frac{10.2124}{2.5921}$$

$$V = 3.94\ ft/sec$$

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SKILL 1 CONVERT BETWEEN VELOCITY AND VOLUMETRIC FLOW RATES

Procedure Overview

In this procedure, you will calculate the volumetric flow rate given the size of the pipe and the liquid velocity. You will also calculate the liquid velocity given the volumetric flow rate and the size of the pipe.

Use the Standard Pipe Size table in Appendix A to determine the ID of the pipes.

❑ 1. Calculate the volumetric flow rate (in gpm) of the liquid flowing through the pipe in figure 8 using the following information:

Liquid Velocity = 4 ft/sec

Nominal Pipe Size = 2 inches

Volumetric Flow Rate ______________________________ (gpm)

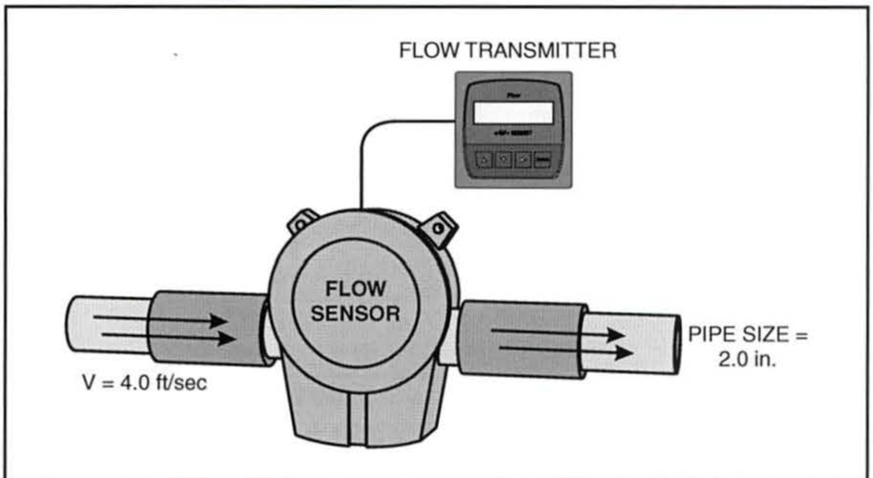

Figure 8. Liquid Velocity through a Pipe

You should find that the volumetric flow rate is 41.84 gpm.

❑ 2. Calculate the volumetric flow rate of liquid flowing through a pipe using the following information:

Liquid Velocity = 1.5 m/sec

Nominal Pipe Size = 20 mm

Volumetric Flow Rate ______________________________ (lpm)

You should find that the volumetric flow rate is 28.27 lpm.

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❑ 3. Calculate the velocity (in ft/sec) of the liquid flowing through the pipe in figure 9 using the following information:

Volumetric Flow Rate = 18 gpm

Nominal Pipe Size = 1 inch

Liquid Velocity ________________________________ (ft/sec)

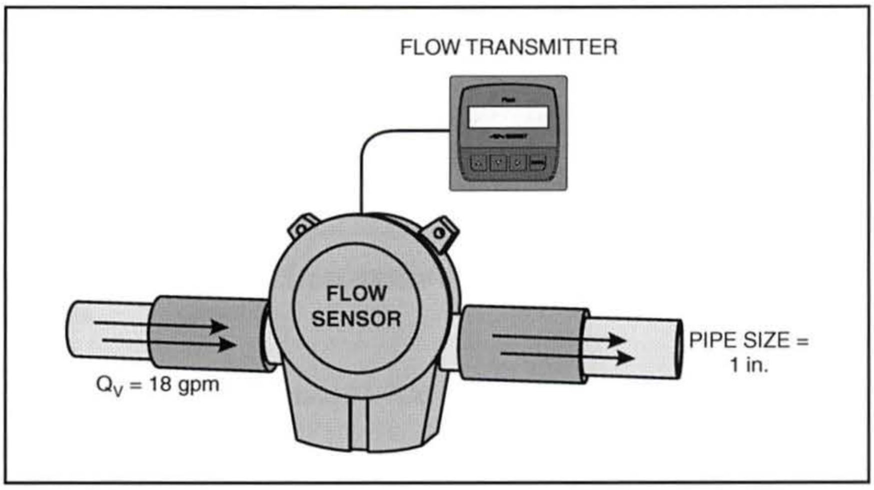

Figure 9. Volumetric Flow through a Pipe

You should find that the liquid velocity is 6.68 ft/sec

❑ 4. Calculate the velocity (in m/sec) of liquid flowing through a pipe using the following information:

Volumetric Flow Rate = 35 lpm

Nominal Pipe Size = 40 mm

Volumetric Flow Rate ___________________________ (m/sec)

You should find that the liquid velocity is 0.464 m/sec.

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OBJECTIVE 4 DESCRIBE HOW TO CONVERT BETWEEN VOLUMETRIC AND MASS FLOW RATE UNITS

In some processes (e.g. processing of ethylene), it is more desirable to measure the mass flow rate rather than the volumetric flow rate. Mass flow can be measured by a mass flow meter or it can be calculated from volumetric flow. This calculation is useful because the mass flow rate does not change as the temperature or pressure changes. Therefore, sensors that measure mass flow are more accurate than sensors that measure volumetric flow.

Use the following formula to convert volumetric flow units to mass flow units:

FORMULA: VOLUMETRIC FLOW UNITS TO MASS FLOW UNITS

S.I. Units:

$$Q_m = Q_v \times 0.001 \times \rho$$

Where:

Q_m = *Mass flow rate in kilograms per minute (kg / min)*

Q_v = *Volumetric flow rate in liters per minute (lpm)*

ρ = *Density of fluid in kilograms per cubic meter (kg / m^3)*

0.001 = *Conversion factor (lpm to m^3 / min)*

U.S. Customary Units:

$$Q_m = Q_v \times 0.1336 \times \rho$$

Where:

Q_m = *Mass flow rate in pounds per minute (lbs / min or ppm)*

Q_v = *Volumetric flow rate in gallons per minute (gpm)*

ρ = *Density of fluid in pounds per cubic foot (lbs / ft^3)*

0.1336 = *Conversion factor (gpm to ft^3 / min)*

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The table in figure 10 lists the density of some common fluids.

LIQUID	DENSITY (lbs/ft^3)	DENSITY (kg/m^3)
Water (20°C)	62.336	998.230
Water (0°C)	62.455	1000.433
Water (4°C)	62.463	1000.561
Water (100°C)	59.864	958.929
Gasoline	41.23 - 43.10	660.44-690.40
Ethyl Alcohol	49.409	791.456
Turpentine	53.09	850.420
Olive Oil	56.2	900.237
Castor Oil	60.528	969.565
Seawater	64.34	1030.628
Milk	62.214 - 64.651	996.57-1035.61
Glycerin	78.705	1260.733
Mercury	846.39	13557.864

Figure 10. Density of Common Fluids

Gasoline comes in three different grades, each of which has a different density. Also, the density of milk differs based on the percentage of milk fat. For example, 2% milk has less density than whole milk.

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Example - Calculate the mass flow rate in kilograms per minute (kg/min) through the pipe shown in figure 11 using the following information:

Fluid = Water at 4°C

Volumetric Flow Rate = 75 lpm

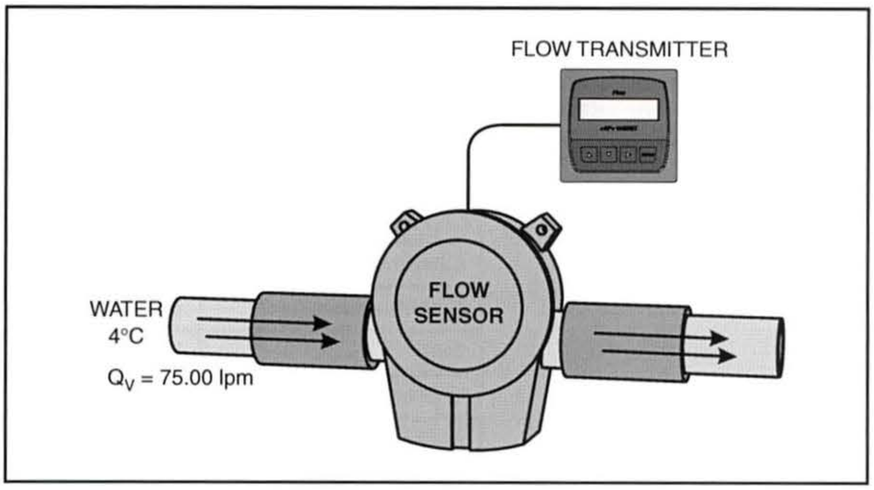

Figure 11. Volumetric Flow Through a Pipe

The solution is as follows:

First, determine the density of the water. At 4°C, the density of water is 1000.561 kg/m^3.

Next, calculate the mass flow rate using the formula.

$$Q_m = Q_v \times 0.001 \times \rho$$

$$Q_m = 75 \times 0.001 \times 1000.561$$

$$Q_m = 75.042\ kg/min$$

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Rearranging the formula allows the volumetric flow rate to be found if given the mass flow rate.

FORMULA: MASS FLOW UNITS TO VOLUMETRIC FLOW UNITS

S.I. Units:

$$Q_v = \frac{Q_m}{0.001 \times \rho}$$

Where:

Q_v = *Volumetric flow rate in liters per minute (lpm)*

Q_m = *Mass flow rate in kilograms per minute (kg/min)*

ρ = *Density of fluid in kilograms per cubic meter (kg/m^3)*

0.001 = *Conversion factor (lpm to m^3/min)*

U.S. Customary Units:

$$Q_v = \frac{Q_m}{0.1336 \times \rho}$$

Where:

Q_v = *Volumetric flow rate in gallons per minute (gpm)*

Q_m = *Mass flow rate in pounds per minute (lbs/min or ppm)*

ρ = *Density of fluid in pounds per cubic foot (lbs/ft^3)*

0.1336 = *Conversion factor (gpm to ft^3/min)*

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Example – Calculate the volumetric flow rate in gallons per minute (gpm) through the pipe shown in figure 12 using the following information:

Fluid = Water at 20°C

Mass Flow Rate = 85 lbs/min

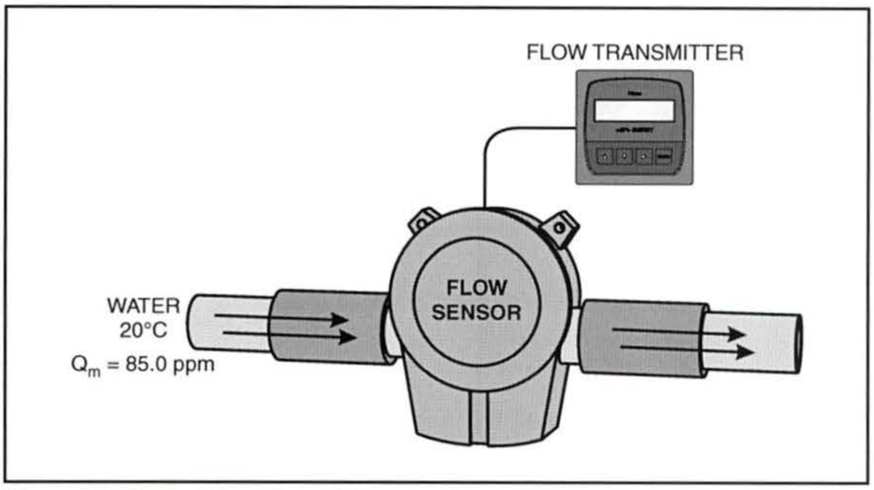

Figure 12. Mass Flow Rate through a Pipe

The solution is as follows:

Using the fluid density table, you should find that the density of water at 20°C is 62.336 lbs/ft³.

Using the formula, calculate the volumetric flow rate.

$$Q_v = \frac{Q_m}{0.1336 \times \rho}$$

$$Q_v = \frac{85}{0.1336 \times 62.336}$$

$$Q_v = 10.21 \; gpm$$

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SKILL 2 CONVERT BETWEEN MASS AND VOLUMETRIC FLOW RATES

Procedure Overview

In this procedure, you will convert between mass and volumetric flow rates. Refer to Appendix B for the density of common fluids table. All fluids are at 20°C unless otherwise noted.

❑ 1. Calculate the mass flow rate of water at 4°C flowing through the pipe shown in figure 13. The volumetric flow rate is 567 lpm.

Mass Flow Rate ________________________________ (kg/min)

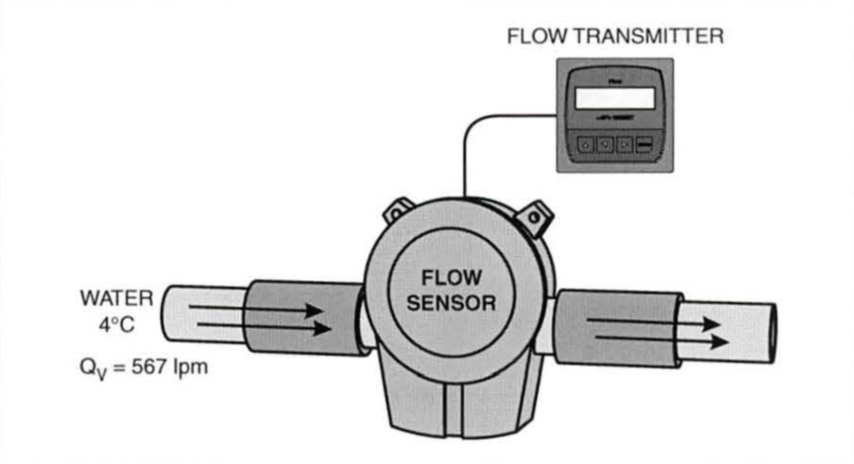

Figure 13. Volumetric Flow through a Pipe

You should find that the mass flow rate is 567.25 kg/min.

❑ 2. Calculate the mass flow rate of turpentine that has a volumetric flow rate of 20 gpm.

Mass Flow Rate ________________________________ (lbs/min)

You should find that the mass flow rate is 141.86 lbs/min.

❑ 3. Calculate the mass flow rate of ethyl alcohol that has a volumetric flow rate of 91 lpm.

Mass Flow Rate ________________________________ (kg/min)

You should find that the mass flow rate is 72.02 kg/min.

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❑ 4. Calculate the mass flow rate of milk that has a volumetric flow rate of 8 gpm.

Mass Flow Rate ______________________________ (lbs/min)

You should find that the mass flow rate is between 66.49 – 69.10 lbs/min depending on the chosen value for the density.

❑ 5. Calculate the volumetric flow rate of castor oil in the pipe shown in figure 14. The mass flow rate is 39.455 kg/min.

Volumetric Flow Rate ____________________________ (lpm)

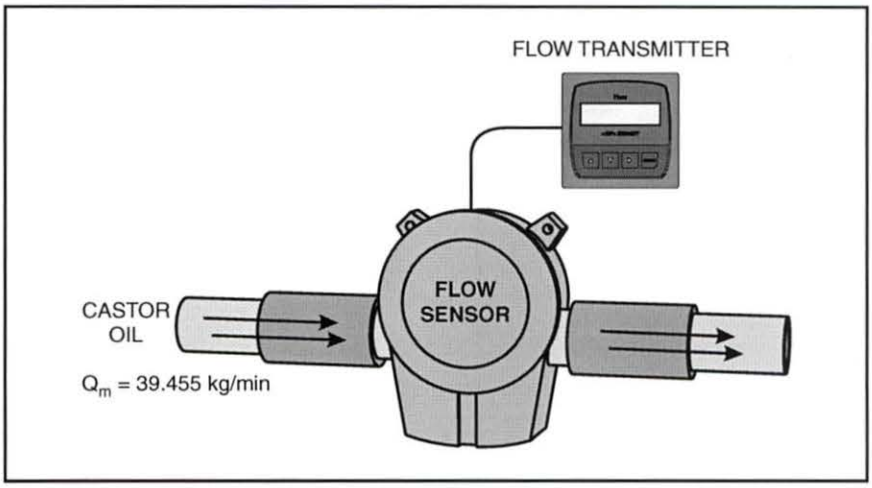

Figure 14. Mass Flow through a Pipe

You should find that the volumetric flow rate is 40.69 lpm.

❑ 6. Calculate the volumetric flow rate of mercury that has a mass flow rate of 275 lbs/min.

Volumetric Flow Rate ____________________________ (gpm)

You should find that the volumetric flow rate is 2.43 gpm.

❑ 7. Calculate the volumetric flow rate of seawater that has a mass flow rate of 61.224 kg/min.

Volumetric Flow Rate ____________________________ (lpm)

You should find that the volumetric flow rate is 59.40 lpm.

❑ 8. Calculate the volumetric flow rate of olive oil that has a mass flow rate of 104 lbs/min.

Volumetric Flow Rate ____________________________ (gpm)

You should find that the volumetric flow rate is 13.85 gpm.

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SELF REVIEW

1. __________ measurement is the measurement of the volume or mass of material that passes a given point per a specified time period.

2. Volumetric and mass flow rates are the most frequently used units because they describe the ____________ of material that is flowing through the system.

3. The three types of units process control systems use to measure flow are __________, volume, and mass.

4. When ________ is used to express flow, the velocity of the fluid and the area of the pipe or container are considered.

5. To convert from volumetric flow rate to mass flow, you need to know the volumetric flow rate and the ___________ of the fluid.

6. ___________ flow rate does not change as the temperature or pressure changes.

7. To convert velocity to volumetric flow, you need to know the velocity of the fluid and the _______.

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SEGMENT 2

FLOW SENSORS

OBJECTIVE 5 DESCRIBE FOUR CATEGORIES OF FLOW SENSORS AND GIVE AN APPLICATION OF EACH

Read This

Flow sensors can be grouped into the following four categories according to the way in which they measure flow:

- Differential Pressure
- Velocity
- Volumetric
- Mass

Differential Pressure Flow Sensors

Differential pressure flow sensors measure flow by measuring the pressure difference across a restriction. They require a differential pressure transmitter to convert the pressure reading to a flow rate. Differential pressure flow sensors include orifice plates, pitot tubes, venturi tubes, and flow nozzles.

Figure 15 shows an orifice plate flow sensor, which creates a pressure difference as the fluid flows through its small opening. The pressure before the restriction (upstream pressure) is 20 psi and 15 psi after the restriction (downstream pressure). This indicates a pressure difference of 5 psi (20 - 15 = 5), which the transmitter converts to a 4-20 mA signal that is proportional to flow rate.

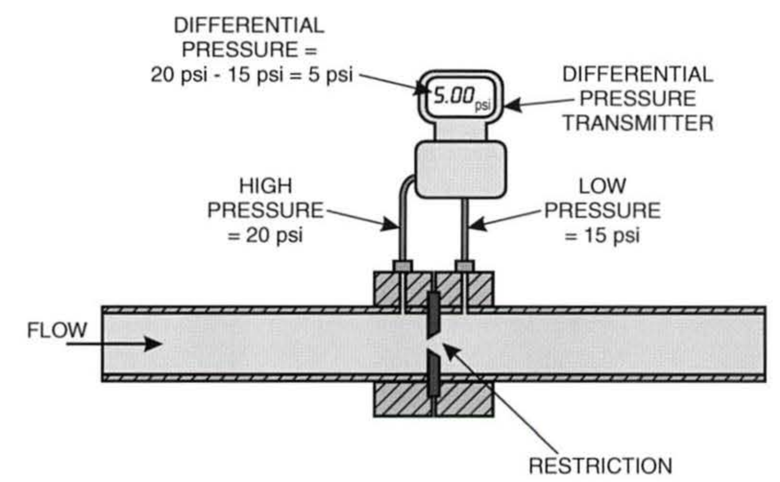

Figure 15. Differential Pressure Across a Restriction

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A differential pressure transmitter has internal circuitry and a microprocessor that uses the mathematical relationship between the differential pressure and flow rate to calculate the flow rate. The flow rate is equal to the square root of the differential pressure.

Velocity Flow Sensors

Velocity flow sensors determine volumetric flow rate based on the velocity of the process fluid. Velocity flow sensors include magnetic, turbine, ultrasonic, and vortex shedding flow sensors.

Magnetic flowmeters, like the one shown in figure 16, use electrical coils (field coils) to create a magnetic field around the process pipe. Magnetic flowmeters only work with fluids that are conductive. Most fluids conduct electricity to some extent. However, fluids that are more conductive, sodium chloride for example, work better with a magnetic flowmeter.

As the conductive fluid flows through the magnetic field, it induces a voltage at the electrodes that is proportional to the velocity of the fluid. The electrodes carry the voltage signal to a transmitter, which converts the signal to the volumetric flow rate.

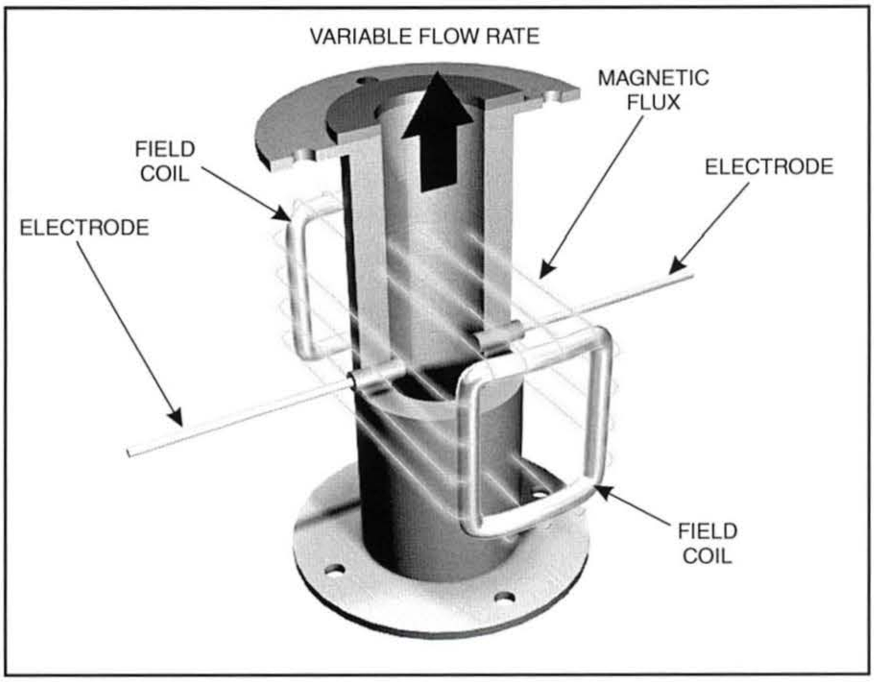

Figure 16. Magnetic Flowmeter

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A turbine flow sensor measures flow by measuring the speed of its rotor blades as they rotate. Each time a blade rotates past the magnetic pickup, the sensor creates a pulse. The frequency of the pulses, which is proportional to the flow rate, is read by another instrument (transmitter) that converts the frequency rate into a flow rate measurement.

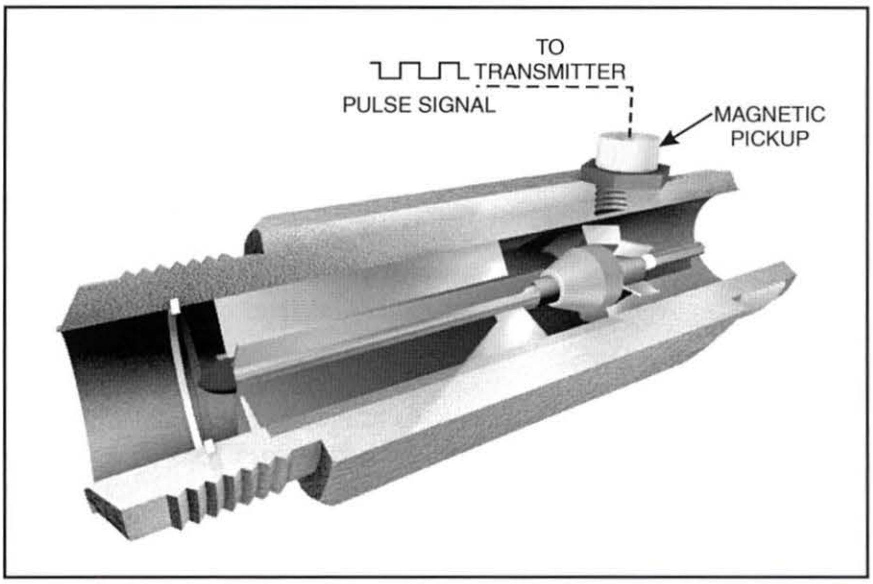

Figure 17. Turbine Flowmeter

Velocity flow sensors are used to measure the flow of gases and liquids in many applications including low-density gases, water distribution, and crude oils.

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Volumetric Flow Sensors

Volumetric flow sensors, also called positive displacement (PD) sensors, typically contain one or more rotating gears or rotors that measure flow by trapping a known amount of process fluid in the sensor. Therefore, the volume of fluid that passes through the sensor is proportional to flow rate. PD sensors include oval gear, helical gear, and nutating disc sensors.

Figure 18 shows an example of an oval gear PD flow sensor. As the two oval gears rotate, they trap a known volume of fluid between the gear and the sensor body. A magnetic pickup senses the rotation of the oval gears, which generate a pulse each time fluid becomes entrapped. A transmitter calculates flow rate based on the frequency of pulses.

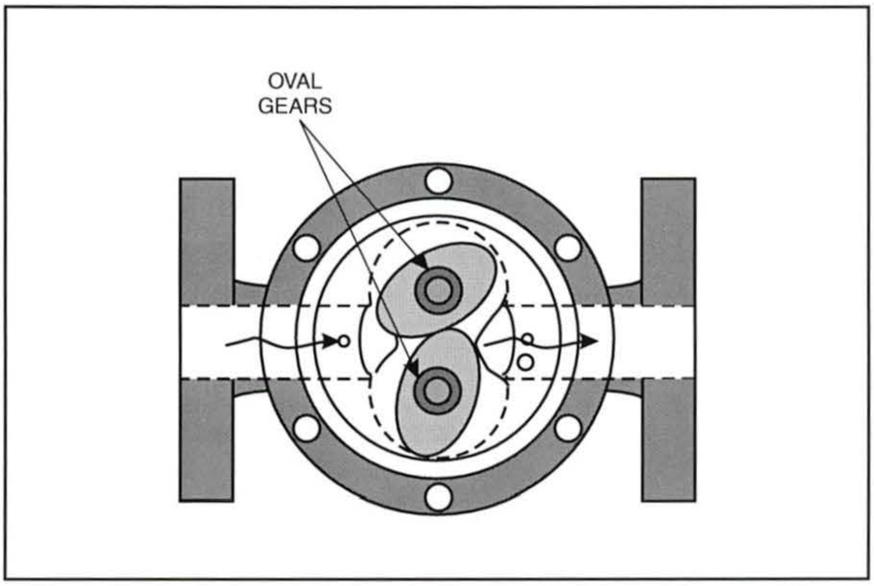

Figure 18. Oval Gear PD Sensor

Volumetric flow sensors are used to measure the flow of gases and liquids with applications in natural gas, crude oils, cryogenic liquids and steam heated liquids.

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Mass Flow Sensors

Mass flow sensors measure the mass flow rate of both liquids and gases. Mass flow sensors include Coriolis and thermal flow sensors. Some sensors are able to measure the mass flow directly, independent of any physical properties of the fluid.

Figure 19 shows an example of a Coriolis mass flow sensor, which has this capability. It measures the vibration of the tubes as fluid flows through them. Displacement sensors placed at the inlet and outlet of the tubes measure the vibrations and send the measurement to a transmitter. This measurement is proportional to the mass flow rate.

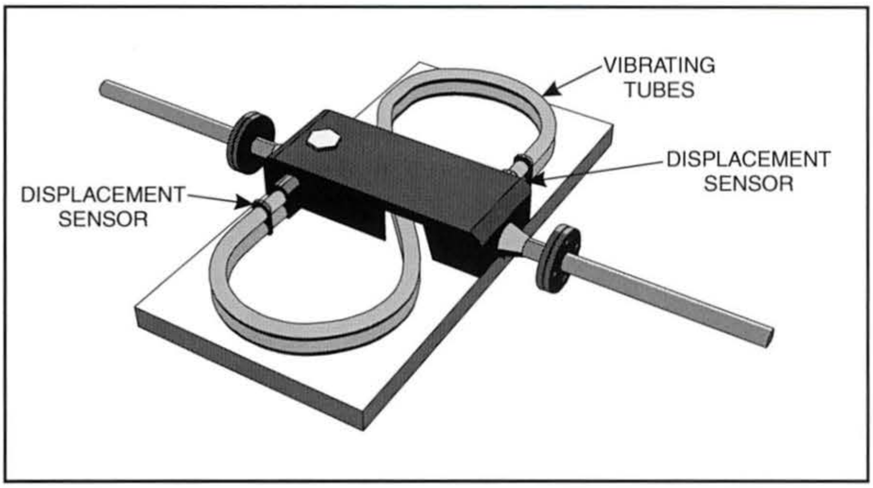

Figure 19. Coriolis Mass Flow Sensor

Mass flow sensors are finding increasing applications in industry. They are often used to determine the flow rate of low velocity gases and all liquids.

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OBJECTIVE 6 DESCRIBE THE OPERATION OF A TURBINE FLOW SENSOR

Read This

A turbine flow sensor uses a rotor and a magnetic pickup to create a pulse frequency that is proportional to flow. The rotor is located inside the sensor body, while a magnetic pickup, which detects the rotation of the rotor blades, extends outside the sensor body, as figure 20 shows. The flow of liquid past the blades causes the rotor to rotate. The magnetic pickup creates a pulse each time a blade passes by.

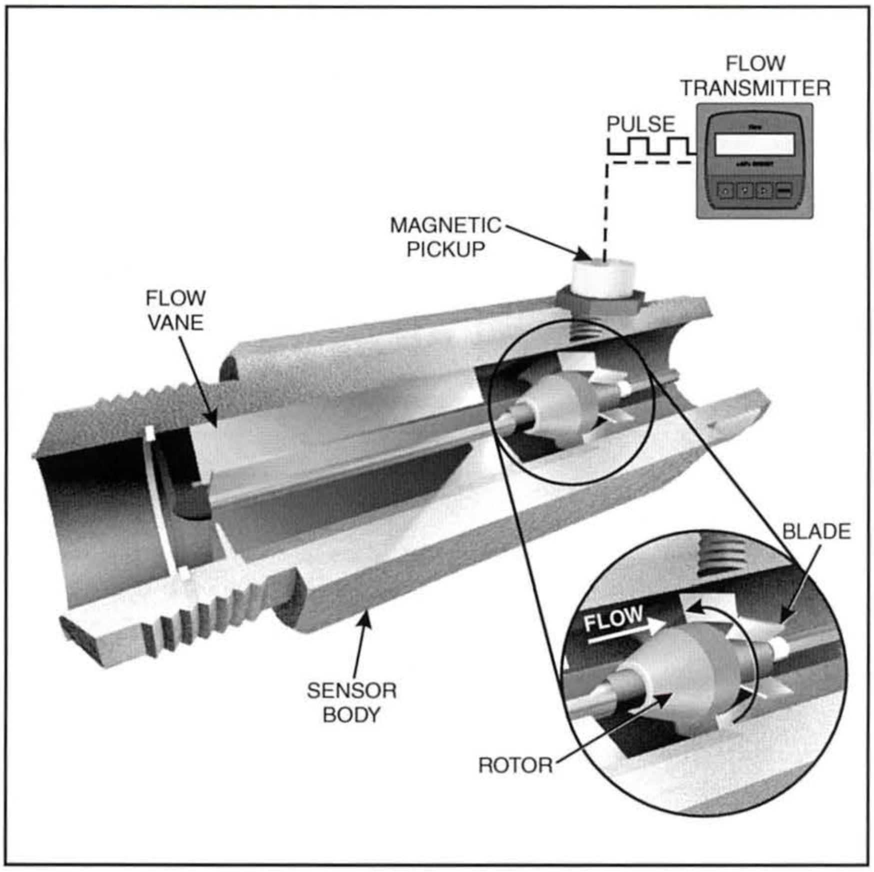

Figure 20. Operation of a Turbine Flow Sensor

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The magnetic pickup includes a coil and a permanent magnet, as figure 21 shows. The rotor blades are either made of a material that attracts magnets, have been permanently magnetized, or have small magnets embedded in the tips. Therefore, each time a blade rotates past the pickup, it generates an electrical pulse. A transmitter receives the electrical pulses and converts the frequency to a proportional 4-20 mA signal.

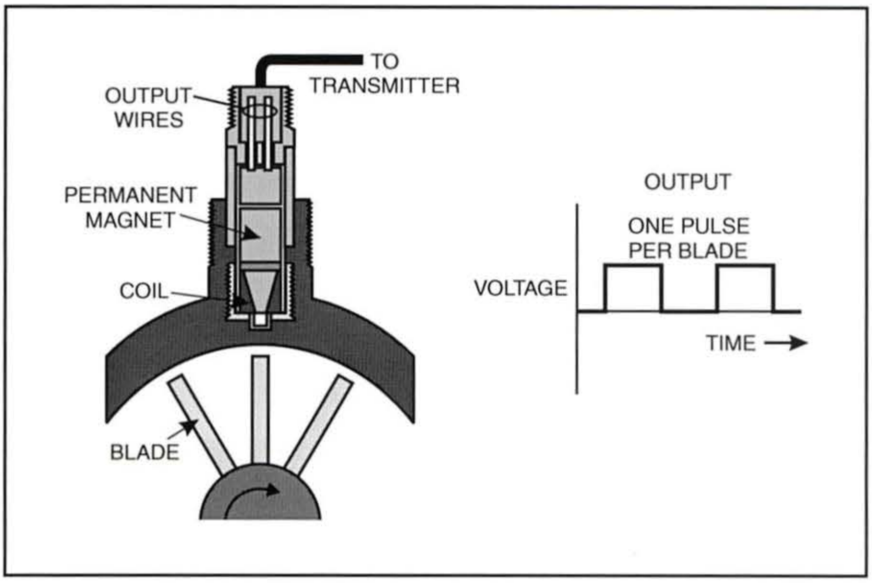

Figure 21. Pulse Generation in a Turbine Flow Sensor

In addition to a rotor, the sensor contains stationary flow vanes. These vanes are located at the inlet to the rotor, as shown in figure 22. The flow vanes smooth the flow to the rotor (i.e. create flow that does not have vortices or directional changes) to increase the accuracy of the sensor.

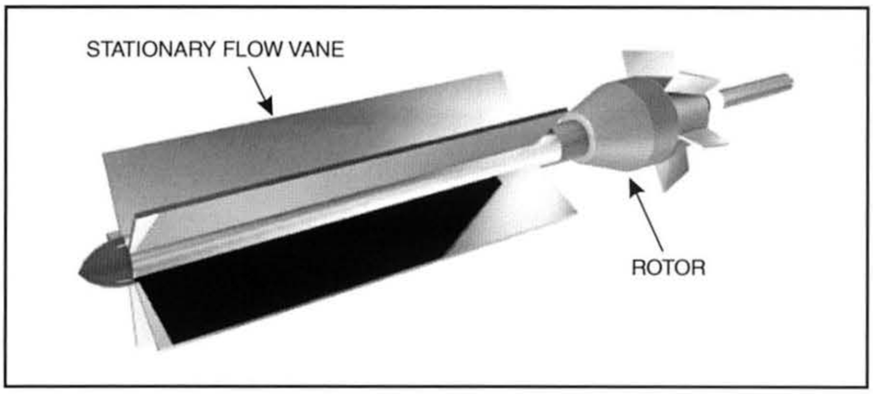

Figure 22. Turbine Rotor and Flow Vanes

Turbine flow sensors are often used to measure the flow of viscous fluids. They can also maintain high accuracy when the flow rate is high, making them a popular choice for flow measurement.

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Sensor Installation

Devices and restrictions upstream of turbine flow sensors can have negative effects on sensor accuracy. Therefore, most turbine flow sensors require a certain length of straight pipe upstream and downstream of the sensor to ensure proper operation. For example, the turbine sensor shown in figure 23 requires a straight length of pipe equal to 10 diameters (i.e. 10 times the inner diameter of the piping) upstream of the sensor and a length of 5 diameters downstream of the sensor.

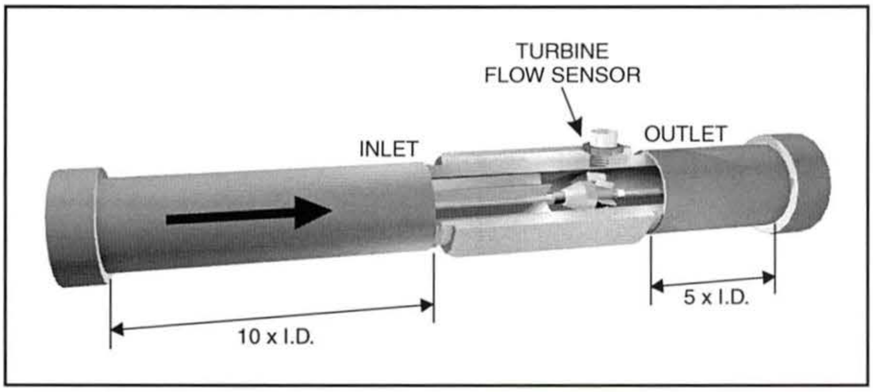

Figure 23. Example of Straight Pipe Requirements for a Turbine Flow Sensor

These requirements can increase depending on the type of device or restriction. For example, if two elbows in different planes are placed in the piping (forcing the flow to twist or corkscrew), a turbine flow sensor can require as many as 40 pipe diameters of straight pipe upstream.

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OBJECTIVE 7 DESCRIBE THE OPERATION OF A PADDLEWHEEL FLOW SENSOR

Read This

A paddlewheel flow sensor, also called a tangential turbine sensor, is a type of flow sensor that uses a rotating paddlewheel to determine the volumetric flow rate, as shown in figure 24. The paddlewheel flow sensor generates electrical pulses based on the rotation of the rotor just like a standard turbine flow sensor. However, the paddlewheel blades are perpendicular to the flow, as figure 24 shows. The pickup device senses the pulses and sends them to the transmitter.

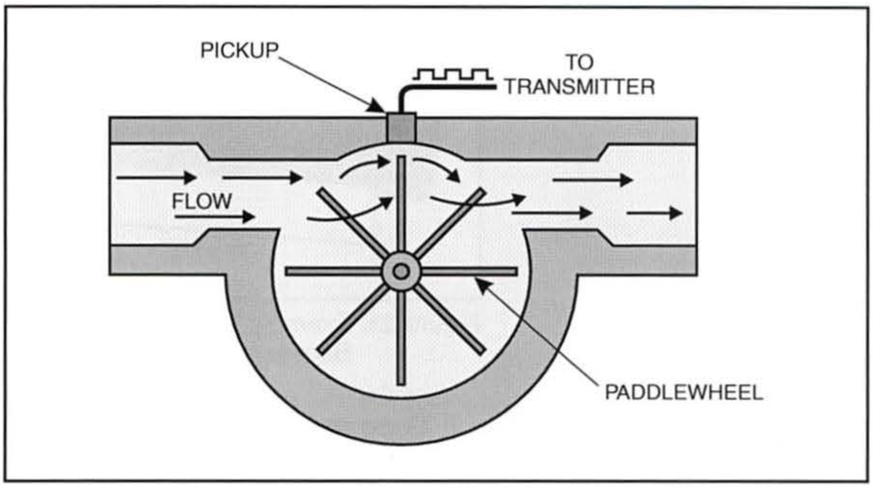

Figure 24. Paddlewheel Flow Sensor

Paddlewheel flow sensors are constructed of plastic instead of metal like most other turbine flow sensors. Therefore, they are generally used for low flow rate applications, typically less than 5 gpm. However, advances in paddlewheel, rotor, and shaft design are making them more rugged. These advances now make them a popular choice for some high flow rate applications.

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OBJECTIVE 9	DESCRIBE THE CALIBRATION PARAMETERS OF A DIGITAL FLOW TRANSMITTER

Digital flow transmitters must be calibrated to properly display the flow rate. This involves setting parameters in the transmitter, usually with a keypad. Although calibration parameters vary from one manufacturer to another, there are some standard parameters, which include:

- Flow Units
- Flow K-Factor
- Loop Range
- Low Loop Adjust
- High Loop Adjust
- Total K-Factor

Flow Units

The flow units parameter sets the measurement units for the flow rate (e.g. GPM or FPS). This parameter typically only affects the display of the transmitter. Figure 32 shows a digital flow transmitter displaying flow units.

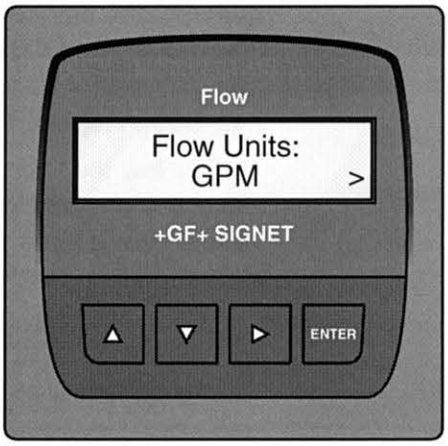

Figure 32. Flow Units Displayed on a Digital Flow Transmitter

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Flow K-Factor

The flow K-factor represents the number of pulses per volumetric unit (e.g. gallons, liters, etc.) that the flow sensor generates. It provides the processor with the conversion factor needed to convert the pulse frequency to the desired flow rate. Each brand and model of digital flow sensor has a unique flow K-factor. Therefore, the manufacturer of the sensor must provide the K-factor. For example, figure 33 shows the K-factors for different sensor models from a particular manufacturer (+GF+ SIGNET).

K-FACTORS			
SENSOR MODEL	PULSES PER U.S. GAL	PULSES PER LITER	PULSES PER mL
3-2000-11	9950	2629	2.629
3-2000-12	9950	2629	2.629
3-2000-21	3160	834.9	0.835
3-2000-22	3160	834.9	0.835

Figure 33. K-Factors for Digital Flow Sensors

Loop Range

The loop range parameter allows you to set the minimum and maximum flow rates. The minimum flow rate results in an output of 4 mA. The maximum flow rate results in an output of 20 mA. Setting these values allows the processor to determine the appropriate output for any flow rate between the minimum and maximum (scaling).

Low Loop Adjust

The low loop adjust parameter allows you to set the desired current output that corresponds to the minimum flow rate. Typically, this will be set to 4 mA. This is similar to setting the zero adjustment on a device such as an I/P converter.

High Loop Adjust

The high loop adjust parameter allows you to set the desired current output that corresponds to the maximum flow rate. Typically, this will be set to 20 mA. This is similar to setting the span adjustment on a device.

Total K-Factor

The total K-factor provides the processor with the conversion factor needed to convert the pulse frequency to a volumetric total. This allows the transmitter to determine the total volume of material that flows through the system for a specific span of time. For example, you can use it to determine how much material has been processed in a day. The total K-factor is typically the same value as the flow K-factor.

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Most digital flow transmitters include more parameters for controlling the display and the output of the transmitter. For example, figure 34 lists additional parameters for the +GF+ SIGNET 8550-1 digital flow transmitter.

PARAMETER	FUNCTION
Total Units	Identifies the units for the Totalizer (i.e. the display that tracks the total volume counted)
Output Mode	Output mode (i.e. Hi, Low, Pulse, Frequency) of optional open collector output
Contrast	Adjust LCD contrast
Flow Decimal	Adjust decimal place of flow rate
Total Decimal	Adjust decimal place of totalizer
Averaging	Averages input signal over time to provide a more stable response
Total Reset	Allows totalizer to be reset
Output Active	Determines if the output turns on a device (HIGH) at the setpoint or turns off a device (LOW)

Figure 34. Additional Programmable Parameters in the +GF+ SIGNET 8550-1

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OBJECTIVE 10 DESCRIBE HOW TO CONFIGURE A +GF+ SIGNET 8550-1 DIGITAL FLOW TRANSMITTER

A +GF+ SIGNET 8550-1 digital flow transmitter has three menus: VIEW, CALIBRATE, and OPTIONS. The transmitter displays the VIEW menu during normal operation. This menu displays the current flow rate and total volume measured. The CALIBRATE and OPTIONS menus contain the configuration parameters for the transmitter.

Figure 35 shows the VIEW menu in the LCD display and the programming keys for the transmitter. The figure also shows a right arrow next to the totalizer on the readout. This indicates that the parameter can be edited.

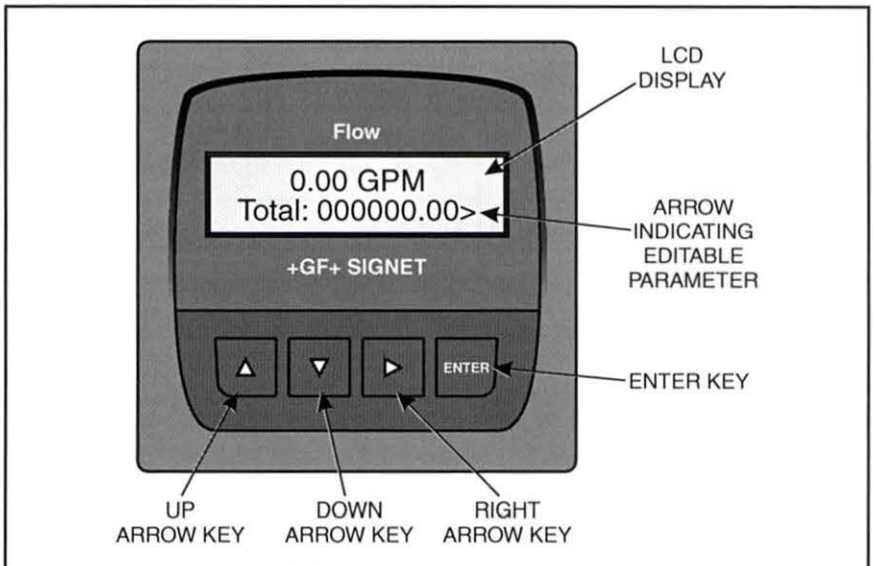

Figure 35. Programming Keys and Right Arrow Indicating an Editable Parameter

The +GF+ SIGNET 8550-1 is equipped with four programming keys to enable the user to navigate the memory and edit parameters. The up ▲ and down ▼ arrow keys are used to scroll through the parameters or change parameter settings. The right arrow ▶ key is used to move from left to right and the ENTER key to save the parameter setting.

Pressing the up arrow ▲ and down arrow ▼ keys at the same time always returns the transmitter to the VIEW menu.

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The following steps describe how to configure a +GF+ SIGNET 8550-1:

Step 1: Enter the CALIBRATE Menu and Set the Desired Parameters

Enter the calibration menu by pressing and holding the ENTER key for 2 seconds. The display then prompts for the key code, as figure 36 shows. The key code for the +GF+ SIGNET 8550-1 flow transmitter is UP ▲, UP ▲, UP ▲, DOWN ▼. Once the key code is entered, the parameters can be set as desired.

Parameters in the CALIBRATE menu include:

- Flow Units
- Flow K-Factor
- Total Units
- Total K-Factor
- Loop Range
- Output Mode

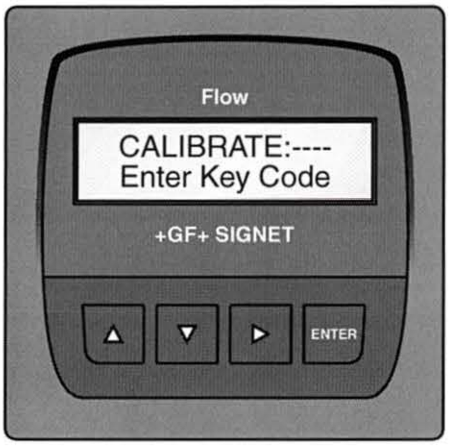

Figure 36. CALIBRATE Menu on the +GF+ SIGNET 8550-1

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Step 2: Enter the OPTIONS Menu and Set the Desired Parameters

Enter the OPTIONS menu by pressing and holding the ENTER key for 5 seconds. The display then prompts for the key code, as figure 37 shows. After entering the key code, the parameters can be set as desired. The same key code is used for the OPTIONS menu as for the CALIBRATE menu.

Parameters in the OPTIONS menu include:

- Contrast
- Flow Decimal
- Total Decimal
- Averaging
- Total Reset
- Low Loop Adjust
- High Loop Adjust
- Output Active

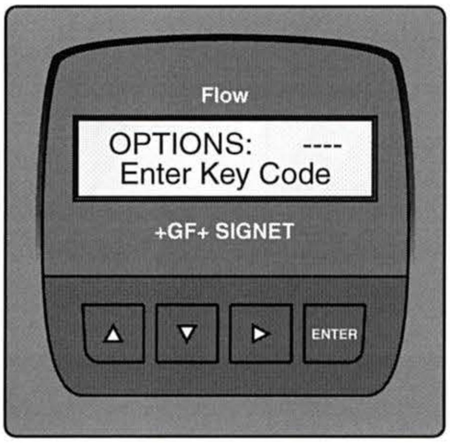

Figure 37. +GF+ SIGNET 8550-1 Displaying OPTIONS Menu Group

Step 3: Return to the VIEW Menu and Run the Process

Pressing the UP ▲ and DOWN ▼ keys at the same time displays the VIEW menu.

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SKILL 3 CONFIGURE A +GF+ SIGNET 8850-1 DIGITAL FLOW TRANSMITTER

Procedure Overview

In this procedure, you will configure the digital flow transmitter on the T5552. This involves setting the required parameters to match the flow sensor used on the system.

- ❑ 1. Perform a lockout/tagout.
- ❑ 2. Perform the following substeps to set up the T5552, as shown in figure 38.

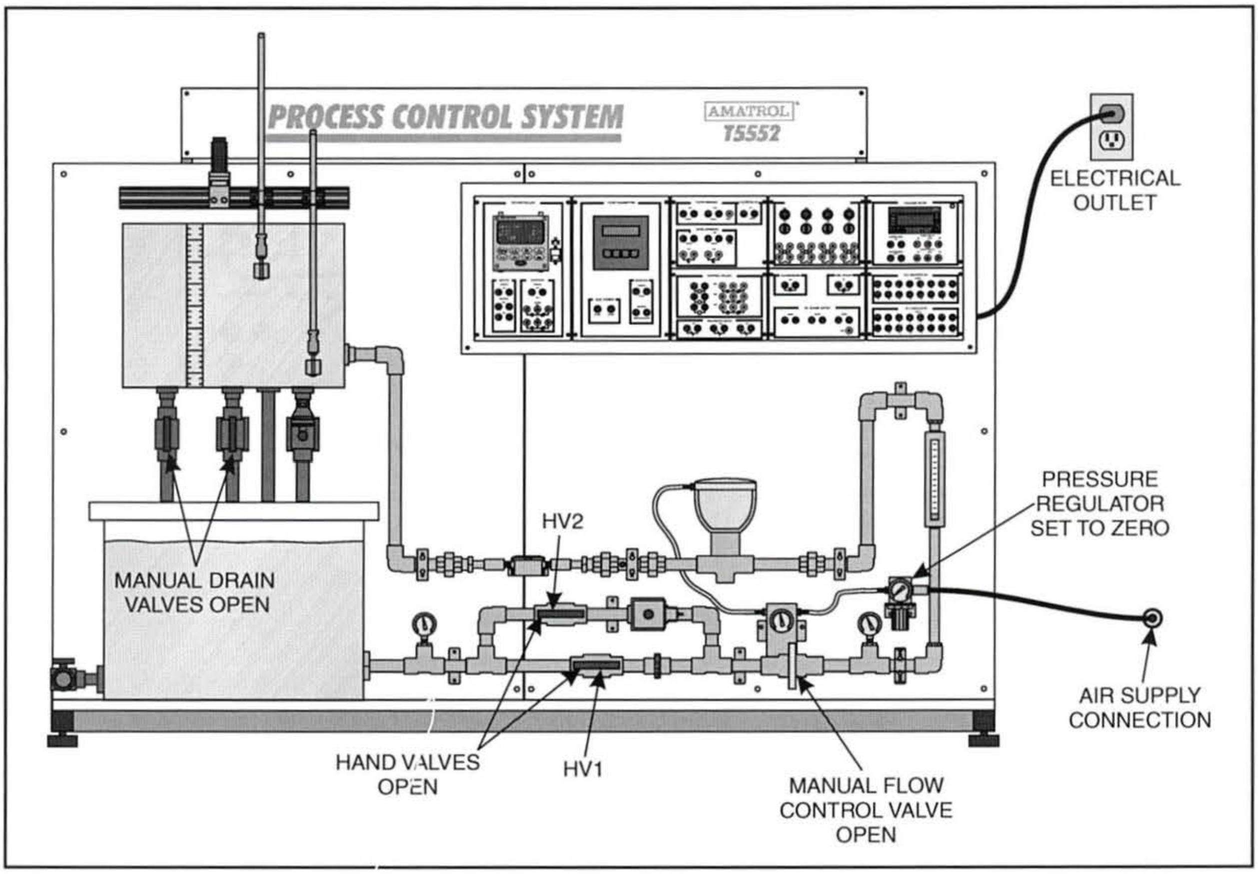

Figure 38. T5552 Setup

A. Connect the power cord to an electrical outlet.

B. Connect the T5552 to the air supply line.

C. Set the pressure regulator to 0 psi.

D. Fill the reservoir tank with water.

E. Open the process tank manual drain valves.

F. Open the manual flow control valve.

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❑ 3. Connect the circuit shown in figure 39.

You need to connect a loop calibrator (set to the READ mode) or a multimeter (set to read DC mA) in the circuit, as figure 39 shows.

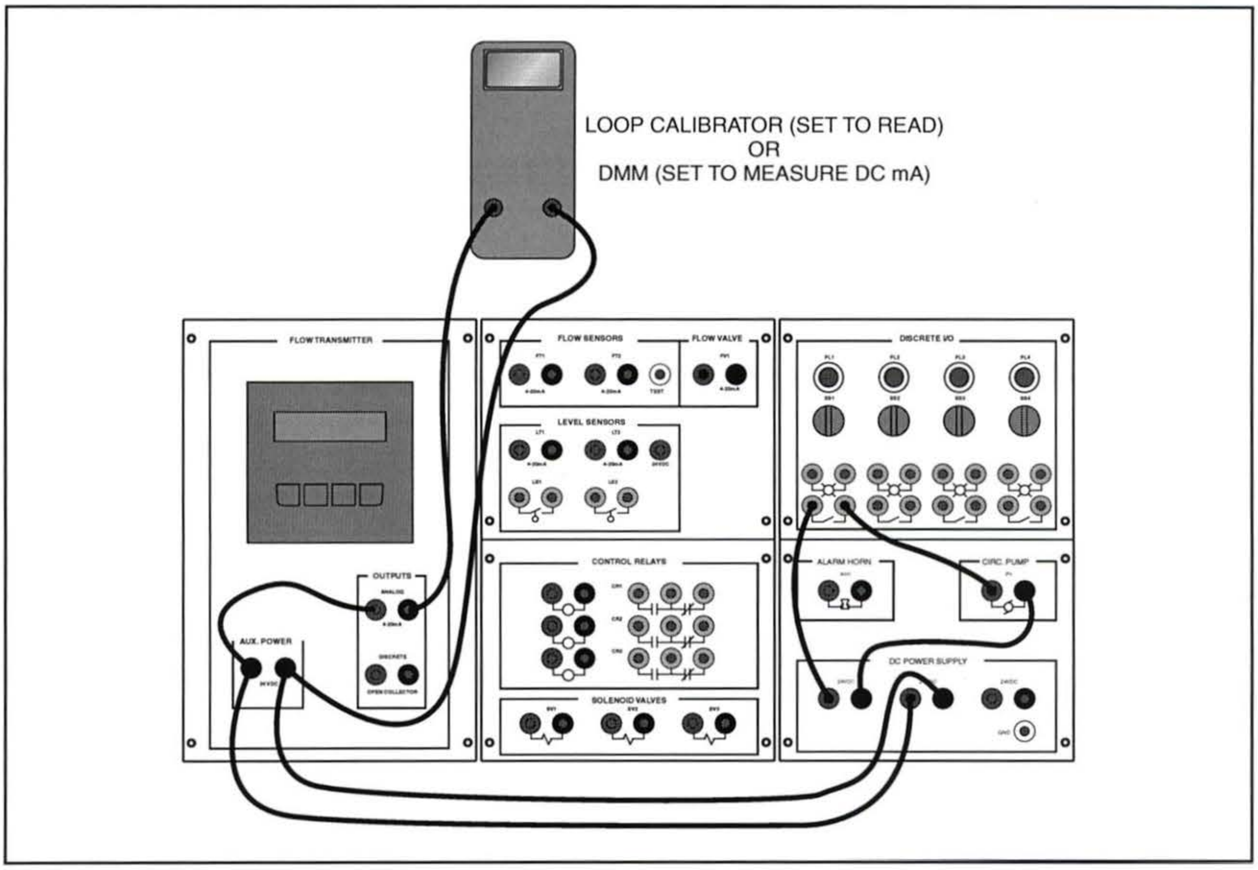

Figure 39. Circuit to Configure and Test the Digital Flow Transmitter

❑ 4. Remove the lockout/tagout.

❑ 5. Turn on the main circuit breaker.

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❑ 6. Perform the following substeps to set the CALIBRATE menu parameters for the flow transmitter.

A. Press and hold the **ENTER** key for 2 seconds.

This selects the CALIBRATE menu. The display prompts you to enter the key code, as figure 40 shows.

> **NOTE**
>
> Pressing and holding the ENTER key for 2 seconds selects the CALIBRATE menu. Pressing and holding the ENTER key for 5 seconds selects the OPTIONS menu.

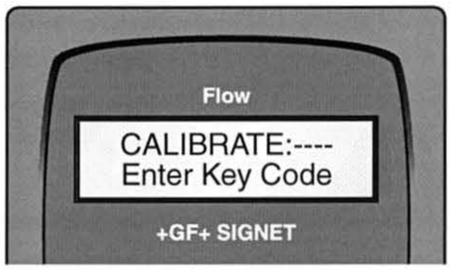

Figure 40. Enter Key Code Prompt Displayed

B. Press the keys in the following sequence to enter the key code: **up ▲, up ▲, up ▲, down ▼**.

After you enter the Key Code, the display shows the first menu item in the CALIBRATE menu. The first item is Flow Units, as figure 41 shows.

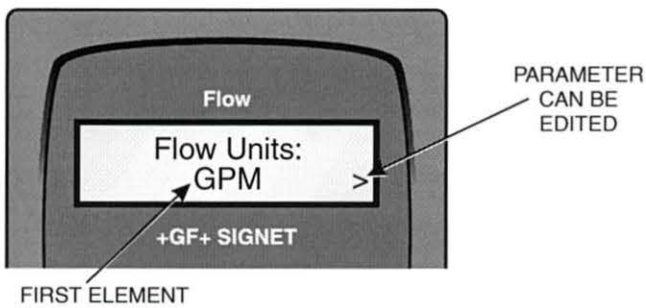

Figure 41. Flow Units Displayed

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C. Press the **right arrow** ▶ key to select the Flow Units item for editing.

When a menu item is selected, the first (far left) element will flash. Also, a right arrow symbol appears in the lower right corner to indicate the parameter can be edited.

D. Press the **up arrow** ▲ and **down arrow** ▼ keys as needed to set the first element to **G** for gallons.

E. Press the **right arrow** ▶ key to advance to the next element.

The next element should now be flashing.

F. Press the **up arrow** ▲ and **down arrow** ▼ keys as needed to set the second element to **P** (per).

G. Press the **right arrow** ▶ key to advance to the next element.

H. Press the **up arrow** ▲ and **down arrow** ▼ keys as needed to set the third element to **M** (minute).

This makes the flow units GPM (gallons per minute).

I. Press the **ENTER** key to save this setting.

J. Press the **down arrow** ▼ key to advance to the next menu item.

The next menu item is the Flow K-Factor, as figure 42 shows. The K-factor is supplied by the manufacturer of the flow sensor. The K-factor for the paddlewheel flow sensor on the T5552 is 3160.

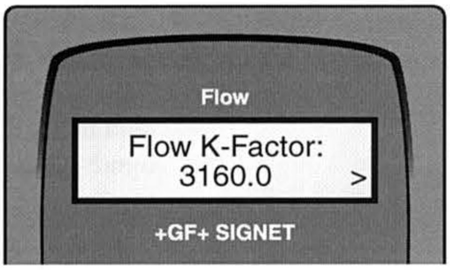

Figure 42. Flow K-Factor Displayed

K. Press the **right arrow** ▶ key to select the Flow K-Factor item for editing.

L. Use the **up arrow** ▲ and **down arrow** ▼ keys as needed and the **right arrow** ▶ key to set the K-factor to **3160**.

Remember, use the right arrow ▶ key to select a menu element and the up and down arrow ▲▼ keys to change the selected element.

M. Once the K-factor is set to **3160**, press the **ENTER** key to save the setting.

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N. Set the remaining CALIBRATE menu items listed below as indicated.

MENU ITEM	SETTING
Total Units	Gallons
Total K-Factor	3160
Loop Range: GPM	0 → 1.5
Last CAL	Today's Date (e.g. 6-30-02)

NOTE

You will not change all of the menu items in the CALIBRATE menu. For those items that are not listed, you can press the down arrow ▼ key to scroll past those items without changing them.

O. Press the **up ▲** and **down ▼** arrow keys simultaneously to exit the CALIBRATE menu and return to the VIEW menu.

❑ 7. Perform the following substeps to set the OPTIONS menu items for the flow meter/transmitter.

A. Press and hold the **ENTER** key for 5 seconds.

The display prompts you to enter the key code.

B. Press the keys in the following sequence: **up ▲, up ▲, up ▲, down ▼**.

After you enter the Key Code, the display shows the first menu item in the OPTIONS menu. The first item is Contrast, as figure 43 shows.

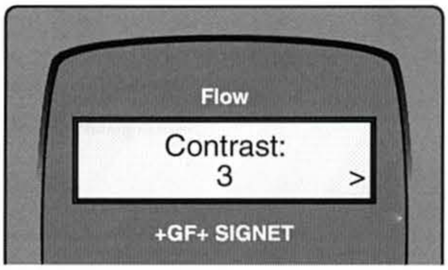

Figure 43. Contrast Setting Displayed

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C. Set the OPTIONS menu items listed below as indicated.

MENU ITEM	SETTING
Contrast	3
Flow Decimal	***.**
Total Decimal	******.**
Averaging	Off
Total Reset	Lock Off
Loop Adjust	4.00mA
Loop Adjust	20.00mA
Output Active	Low

❑ 8. Press the **up** ▲ and **down** ▼ arrow keys simultaneously to exit the edit mode.

The display should return to the VIEW menu and indicate a flow rate of 0.00 GPM, as figure 44 shows.

Figure 44. Display Indicates Flow Rate of 0.00 GPM

❑ 9. Leave the system set up and proceed to Skill 4. You will use this configuration in Skill 4.

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SKILL 4 MEASURE FLOW USING A PADDLEWHEEL FLOW SENSOR

Procedure Overview

In this procedure, you will measure the flow of liquid into a tank using a paddlewheel flow sensor that feeds a digital transmitter. You will notice the effect on the flow rate as the demand on the process changes.

❑ 1. Make sure the circuit is still connected from the previous skill, as shown in figure 45.

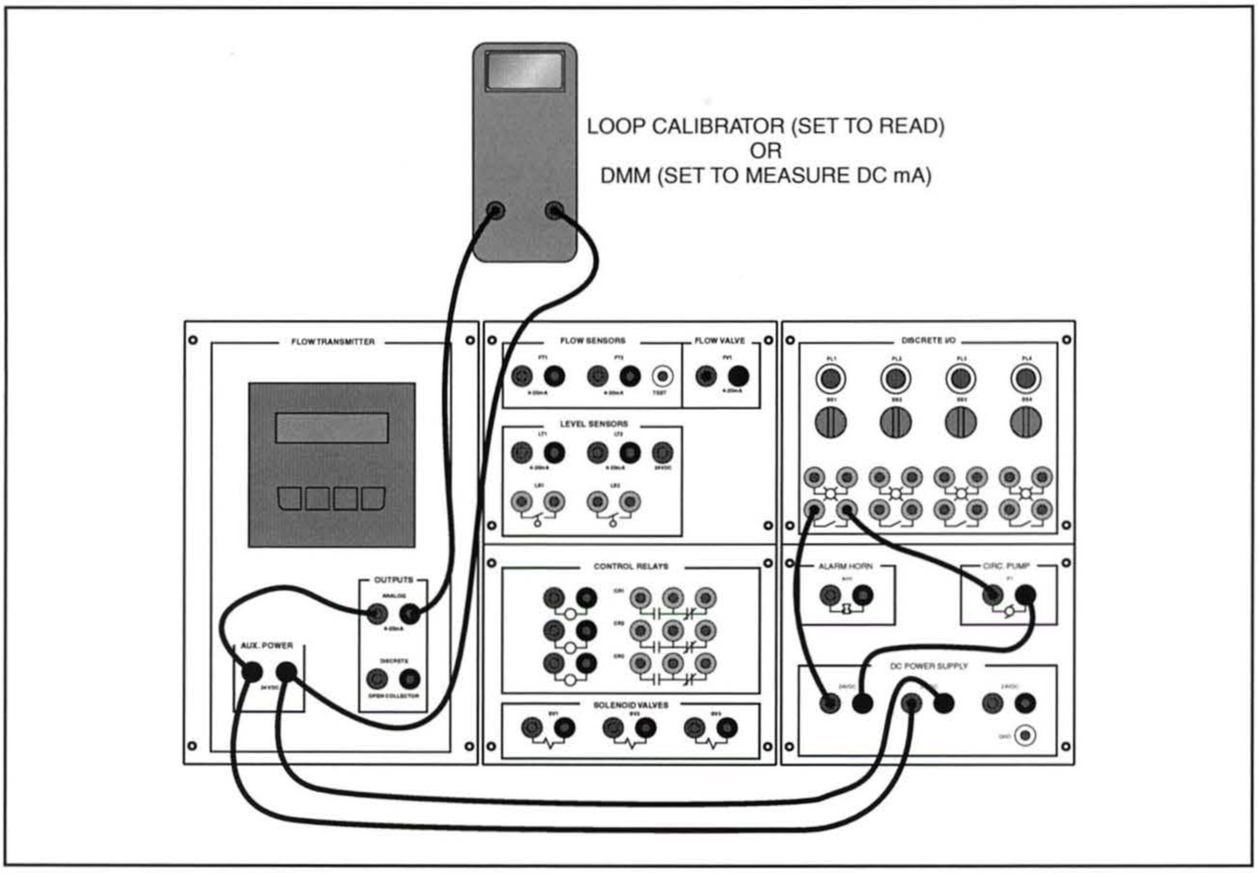

Figure 45. Circuit to Measure Flow with Paddlewheel Flow Sensor

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❑ 2. Locate the paddlewheel flow sensor on the T5552, as shown in figure 46.

As you can see, the outside of the sensor is plastic (a non-conductive material). The housing of the sensor must not be made of a conductive material. Otherwise, the magnetic pickup coil would not be able to sense the turbine blades.

The pickup coil has wires that connect it to the transmitter unit.

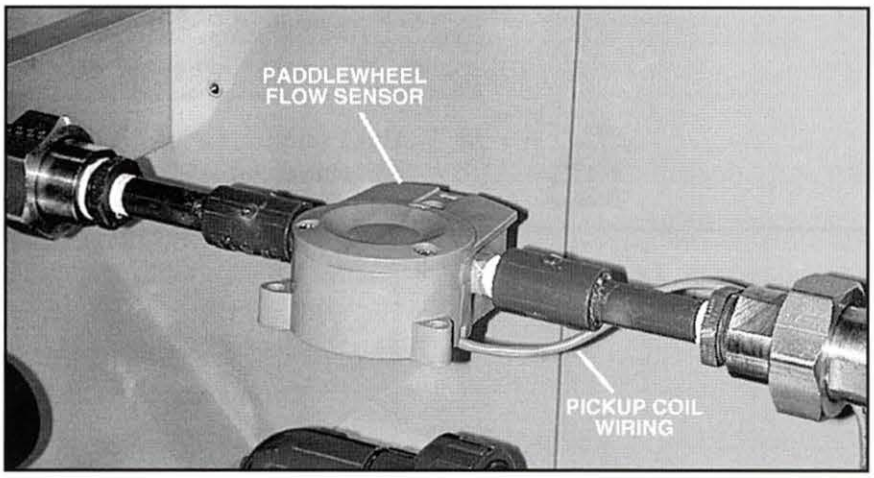

Figure 46. Paddlewheel Flow Sensor on the T5552

The blades of a paddlewheel rotor are placed perpendicular to the fluid flow, as figure 47 shows. A magnetic pickup senses the blades as they pass.

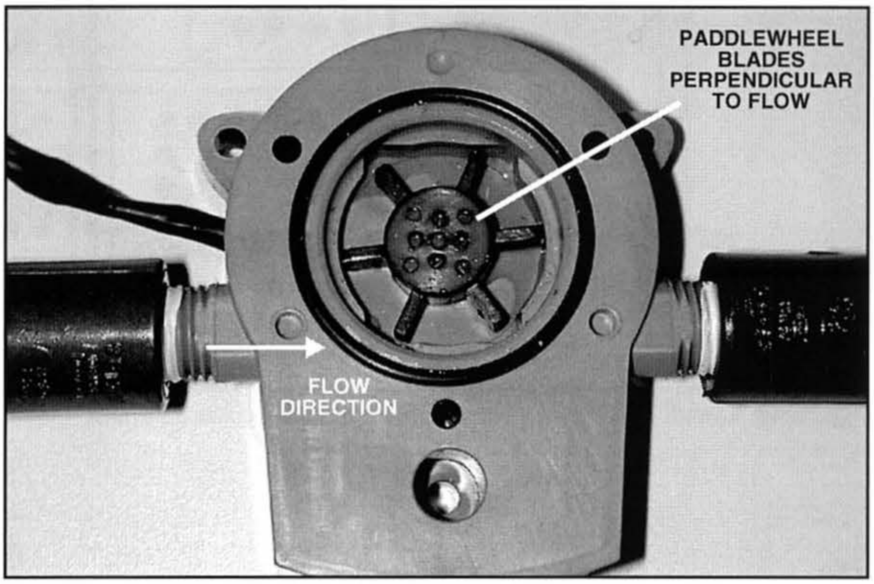

Figure 47. Paddlewheel Flow Sensor Construction

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❑ 3. Perform the following substeps to manually control the flow into the process tank and measure the flow.

A. Start the circulation pump by turning on **SS1**.

There should be no flow because the manual flow control valve is closed. The loop calibrator or multimeter should read 4mA with no flow.

B. Open the manual flow control valve until the rotameter indicates a flow rate of 0.5 gpm.

C. Observe the display of the digital flow transmitter and record the flow rate indicated on the display.

Flow Rate ______________________________(gpm)

The flow transmitter should indicate a flow rate of approximately 0.5 gpm as well.

D. Record the current reading on the loop calibrator or multimeter.

Current ______________________________(mA)

The flow transmitter should output a current of approximately 9.3 mA for a flow rate of 0.5 gpm.

E. Open the manual control valve until the rotameter indicates a flow rate of 1.0 gpm.

F. Observe the display of the digital flow transmitter, as shown in figure 48, and record the flow rate indicated on the display.

Flow Rate ______________________________(gpm)

Figure 48. Transmitter Indicating a Flow of 1.0 GPM

The flow transmitter should indicate a flow rate of approximately 1.0 gpm.

G. Record the current reading on the loop calibrator or multimeter.

Current ______________________________(mA)

The flow transmitter should output a current of approximately 14.70 mA for a flow rate of 1.0 gpm.

H. Open the manual control valve until the rotameter indicates a flow rate of 1.3 gpm.

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I. Observe the display of the digital flow meter/transmitter and record the flow rate indicated on the display.

Flow Rate ________________________________(gpm)

The flow transmitter should indicate a flow rate of 1.3 gpm.

J. Record the current reading on the loop calibrator or multimeter.

Current ________________________________(mA)

The flow transmitter should output a current of approximately 17.80 mA for a flow rate of 1.3 gpm.

If the readings and current output do not match (within ± 0.02 mA), repeat the previous skill to re-calibrate the digital flow transmitter. Then, repeat step 3 to test the settings.

❑ 4. Turn off selector switch **SS1** to stop the pump.

❑ 5. Close the manual flow control valve.

❑ 6. Enter the CALIBRATE menu and set the following parameters:

- Flow Units: LPM
- Loop Range: LPM 0→ 5.68
- K-Factor: 834.9
- Total Units: Liters
- Total K-Factor: 834.9

This changes the flow units to liters per minute (lpm) with an equivalent scale to the GPM scale you set previously. The K-factor represents the number of pulses per volumetric unit. Therefore, its value must also be changed to represent pulses/liter instead of pulses/gallon.

❑ 7. Turn on selector switch **SS1** to start the pump.

❑ 8. Open the manual flow control valve until the display on the flow transmitter reads 2.5 lpm.

❑ 9. Determine if the reading on the transmitter equals (within ± 0.1) the reading on the rotameter.

Equal Readings ________________________________ (Yes/No)

You should find that the measurements do not appear to be equal because the transmitter is measuring in units of liters per minute and the rotameter is measuring in units of gallons per minute. However, the rotameter should indicate a flow rate of approximately 0.65 gpm, which equals 2.5 lpm.

You can verify that the transmitter and rotameter flow rates are equal using the conversion factor 1 Gal = 3.7864 Ltrs.

❑ 10. Increase or decrease the flow rate using the manual flow control valve and compare the displayed flow rate with the flow indicated by the rotameter.

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❑ 11. Perform the following substeps to shut down the T5552.

A. Turn off the circulation pump (SS1 off).

B. Close the manual flow control valve.

C. Open both manual drain valves to drain the process tank. When the tank is completely drained, close the valves.

D. Turn off the main circuit breaker.

E. Disconnect the circuit.

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SEGMENT 3

SELF REVIEW

1. Most digital flow transmitters have a digital readout display and _______.

2. The __________ units parameter sets the measurement units for the flow rate.

3. The flow _____________ provides the processor with the conversion factor for converting the pulse frequency to the desired flow rate.

4. The ________ loop adjust allows you to set current output that corresponds to the minimum flow rate.

5. The ___________ loop adjust allows you to set the current output that corresponds to the maximum flow rate.

6. The loop __________ parameter allows you to set the minimum and maximum flow rates for the 4-20 mA signal.

7. Turbine-type flow sensors use a digital transmitter to convert the digital pulses to a(n) ____________ signal.

8. A +GF+ SIGNET 8550-1 digital flow transmitter has three menus: VIEW, _______, and OPTIONS.

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SEGMENT 4

BASIC FLOW CONTROL

OBJECTIVE 11 DESCRIBE THE OPERATION OF A CLOSED LOOP FLOW CONTROL SYSTEM

Read This

A flow control loop contains the same elements as a level control loop except the sensor measures flow instead of level. A flow sensor provides a feedback signal to a controller, which determines the necessary output to send to a final control element such as a valve. The final control element responds to the signal from the controller to make the process variable equal to or near the setpoint. Figure 49 shows an example of a flow control system.

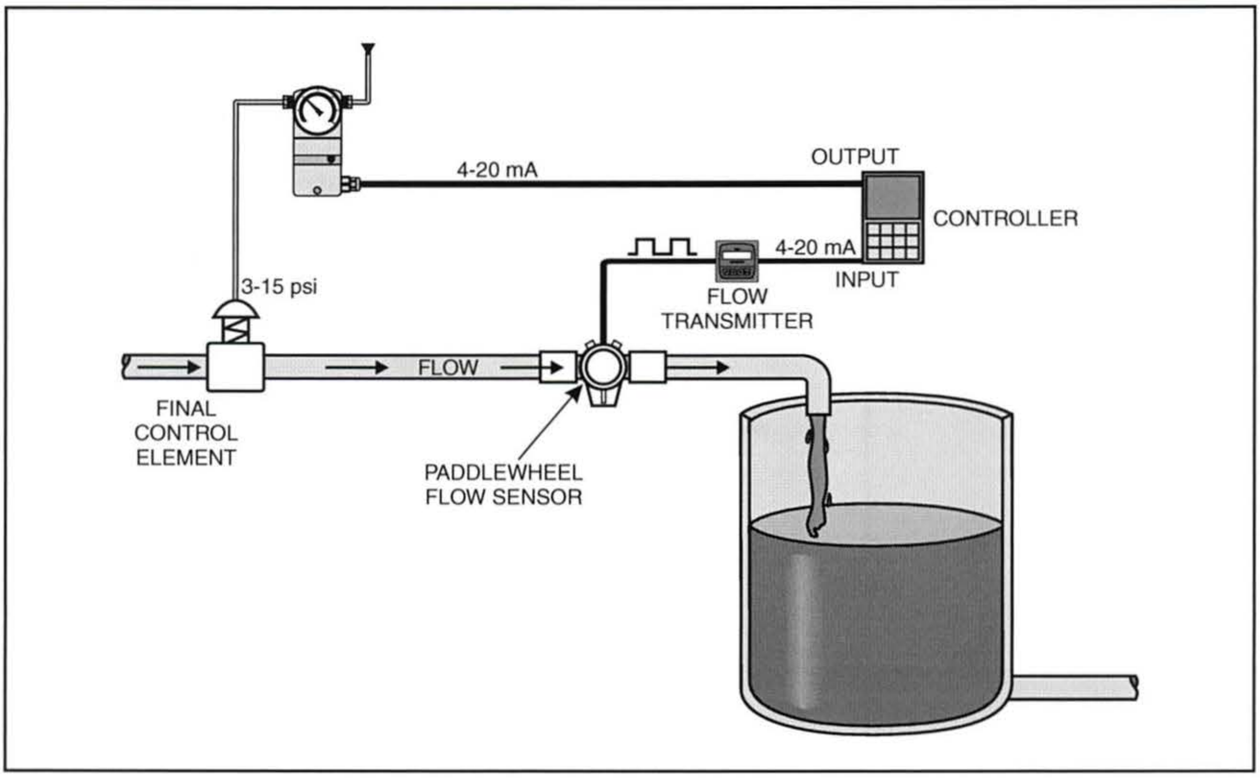

Figure 49. Flow Control Loop

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Although flow control systems are similar to level control systems in many ways, flow systems have different performance characteristics. Flow systems respond faster to controller output changes than level systems because flow is both the manipulated and the controlled variable.

The control method used most often in flow systems is the proportional plus integral (PI) mode. Flow control systems are subject to frequent load disturbances, so PI control allows these systems to react quickly to these disturbances. Proportional control provides an immediate response to the error and the integral control maintains the flow rate at the SP. Figure 50 shows the response of a system using PI control.

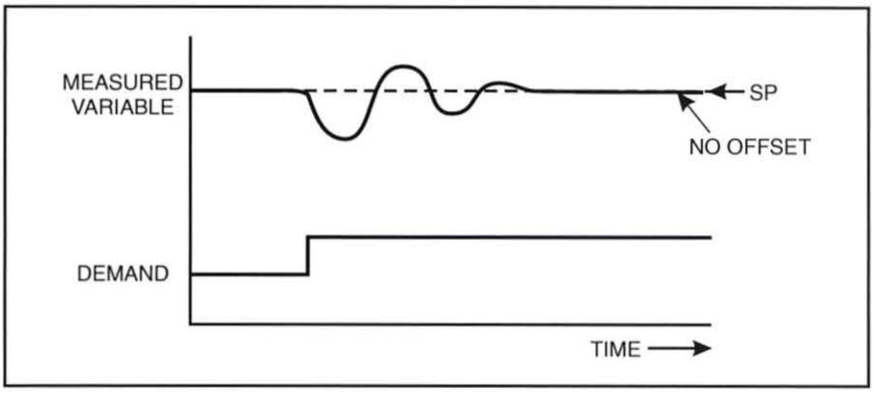

Figure 50. System Response Using PI Control

If the load disturbances are rapid enough and large enough to cause the system to oscillate, the derivative mode is sometimes added to provide an immediate response to the load changes and helps to prevent oscillation, as figure 51 shows.

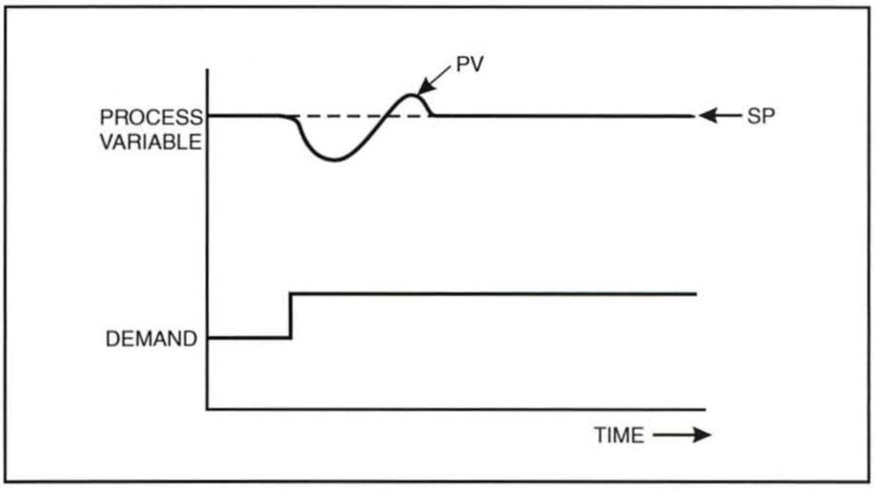

Figure 51. System Response Using PID Control

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SKILL 5 OPERATE A FLOW CONTROL LOOP USING A PADDLEWHEEL FLOW SENSOR

Procedure Overview

In this procedure, you will control the rate of flow measured by a paddlewheel sensor using a PID controller.

❑ 1. Perform a lockout/tagout.

❑ 2. Perform the following substeps to set up the T5552, as shown in figure 52.

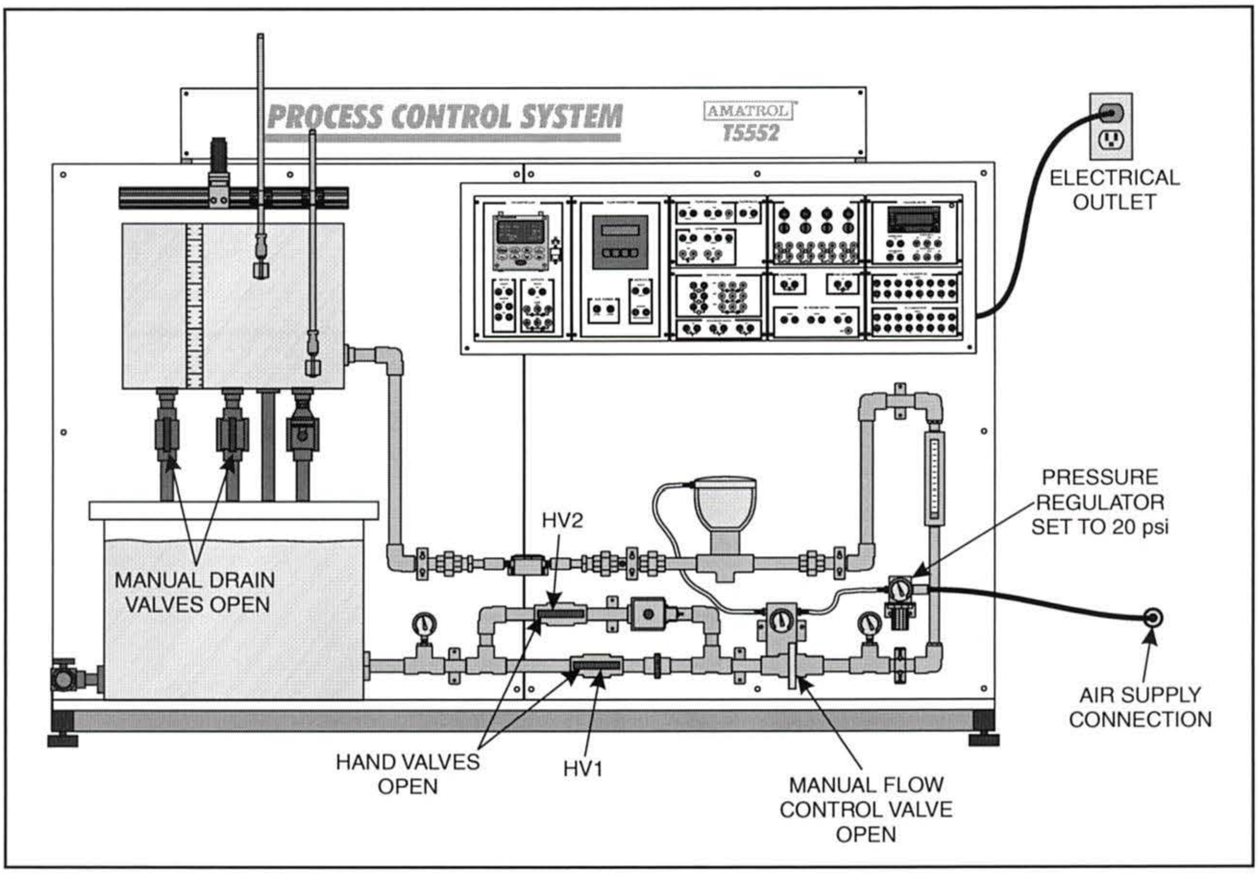

Figure 52. T5552 Setup

A. Connect the air supply line to the T5552.

B. Set the pressure regulator to 20 psi.

C. Fill the reservoir tank with water.

D. Open (fully counterclockwise) the two manual process tank drain valves.

E. Open (fully counterclockwise) the manual flow control valve.

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F. Connect the circuit shown in figure 53.

This circuit allows you to measure, display, and control the flow through the process lines.

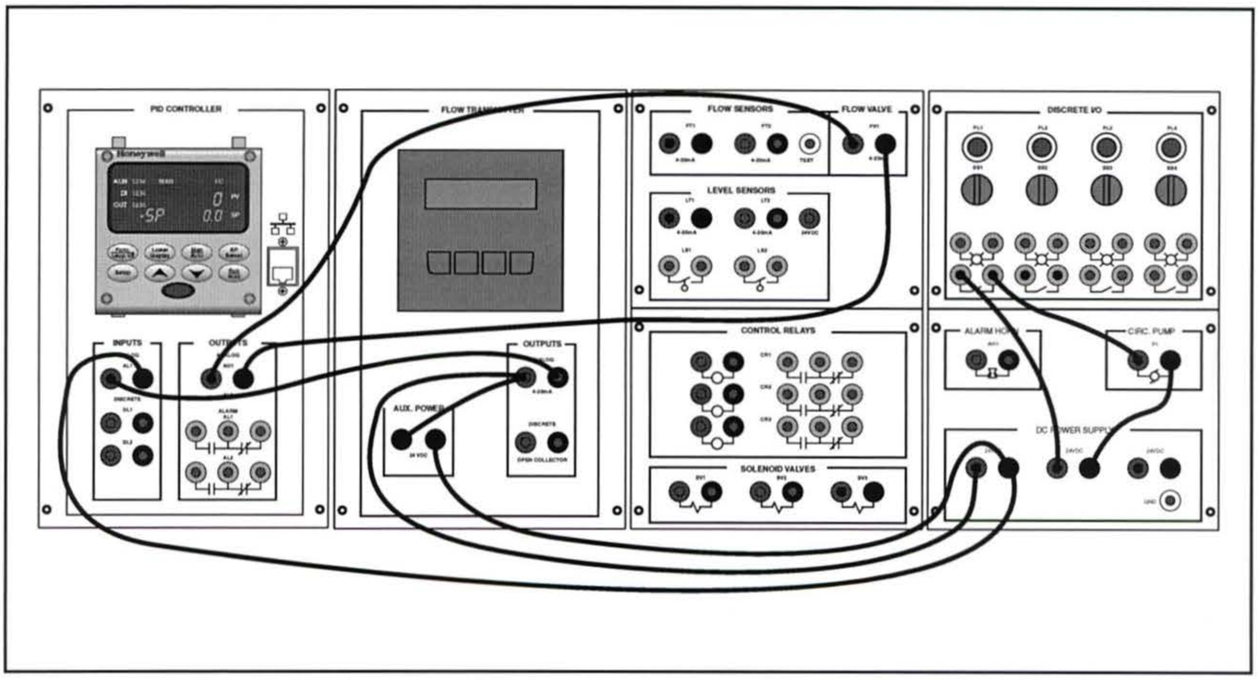

Figure 53. Flow Control Circuit

Figure 54 shows the wiring diagram for the circuit.

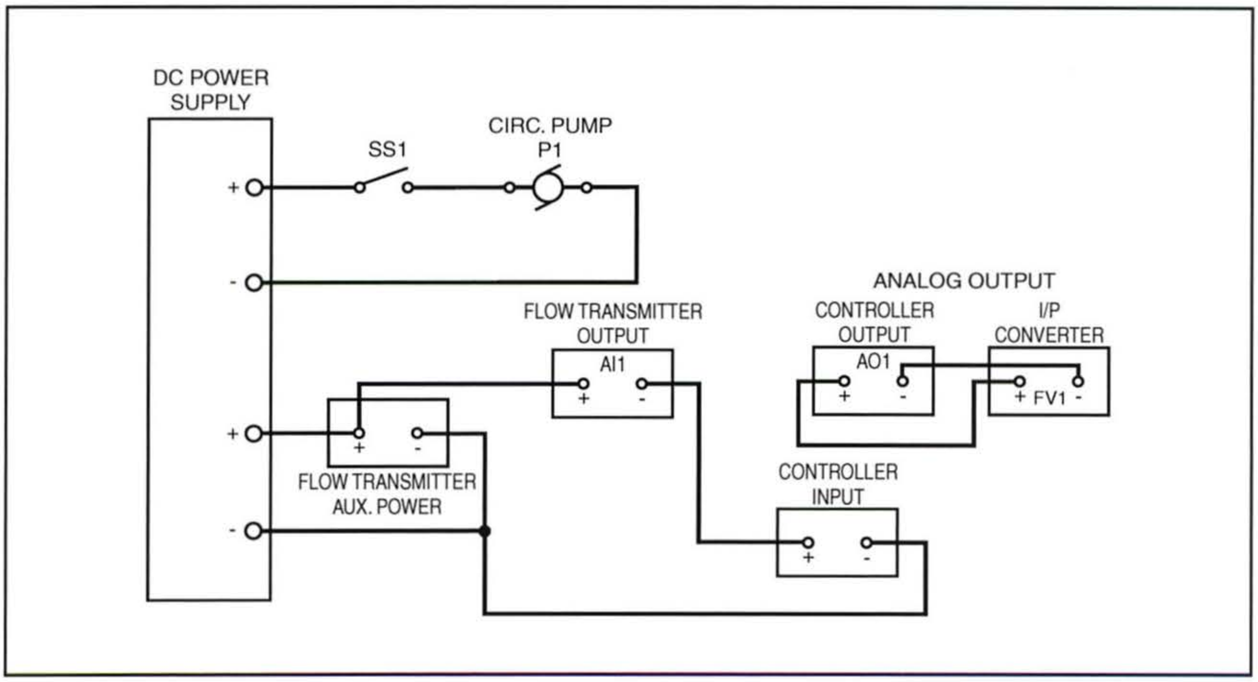

Figure 54. Measuring Circuit Wiring Diagram for Flow

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Figure 55 shows the P&ID for the T5552. The active components and wiring are highlighted.

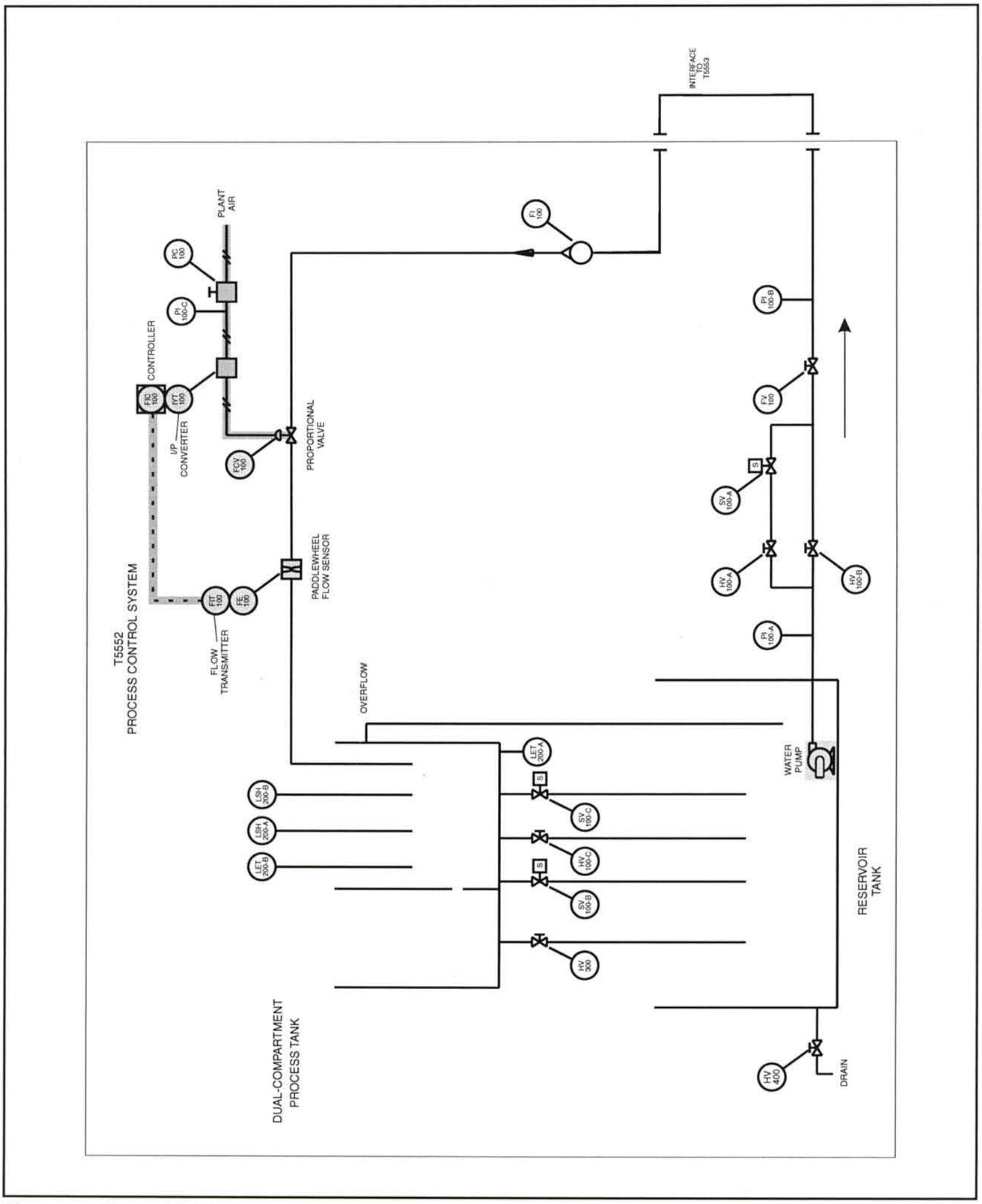

Figure 55. T5552 P&ID

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NOTE

The paddlewheel flow sensor is pre-wired to the flow transmitter. The circuit is complete when the flow sensor is attached to the T5552 system.

❑ 3. Remove the lockout/tagout.

❑ 4. Turn on the main circuit breaker.

❑ 5. Turn the **SS1** and adjust the manual flow control valve until the flow rate indicated on the rotameter is approximately **1.2** gpm. Then, turn off **SS1**.

❑ 6. Perform the following substeps to program the +GF+ SIGNET 8550-1 flow transmitter.

A. Press and hold the **ENTER** key for approximately 2 seconds to enter the CALIBRATE menu.

B. When prompted, enter the key code: **up ▲**, **up ▲**, **up ▲**, **down ▼** to view the CALIBRATE menu parameters.

C. In the CALIBRATE menu, program the following parameters:

MENU ITEM	SETTING
Flow Units	GPM
Flow K-Factor	3160.0
Total Units	Gallons
Total K-Factor	3160.0
Loop Range: GPM	0 → 1.5
Last CAL	Today's Date (e.g. 6-30-04)

D. Press the **up ▲** and **down ▼** keys simultaneously to exit the edit mode.

E. Press and hold the **ENTER** key for approximately 5 seconds to enter the OPTIONS menu.

F. When prompted, enter the key code.

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G. Set the OPTIONS menu items listed below as indicated.

MENU ITEM	SETTING
Contrast	3
Flow Decimal	***.**
Total Decimal	******.**
Averaging	Off
Total Reset	Lock Off
Loop Adjust	4.00mA
Loop Adjust	20.00mA
Output Active	Low

H. Press the **up** ▲ and **down** ▼ keys simultaneously to exit the edit mode.

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❑ 13. Perform the following substeps to control the flow using only proportional control.

This allows you to see the effects of no integral control on the system's performance.

A. Turn off **SS1** and place the controller in manual mode.

B. Enter the SETUP menu.

C. Scroll to the ALGORITHM function group and adjust the CONT ALG parameter setting to **PD + MR**.

D. Scroll to the TUNING function group and adjust the MAN RES parameter to **50**.

This places the valve in the middle of its range when the error is zero, which helps to ensure use of the valve's entire range during operation.

E. Exit the SETUP menu.

F. Adjust the controller's setpoint to **0.8** gpm.

G. Turn on selector switch **SS1** to start the circulation pump.

H. Place the controller in automatic mode.

I. Record the value at which the controller reaches a steady state, the output at this value, and the offset (controller deviation value) at this value. Consider the controller in steady state if the process variable remains constant for at least 2 minutes.

Steady State Value ______________________ (gpm)

Controller Output ______________________ (%)

Offset ______________________ (gpm)

You should find that the controller reaches a steady state near 0.69 gpm. It is not able to achieve control at the SP because there is no integral control. The controller output is approximately 38%, and the offset is 0.11 gpm.

❑ 14. Perform the following substeps to observe the proportional response of the system at a new SP.

A. Place the controller in manual mode and adjust the controller's setpoint value to 1.2 gpm.

B. Place the controller in automatic mode.

C. Record the value at which the controller reaches a steady state, the output at this value, and the offset (controller deviation value) at this value.

Steady State Value ______________________ (gpm)

Controller Output ______________________ (%)

Offset ______________________ (gpm)

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You should find that the controller reaches a steady state near 1.05 gpm. Again, it is not able to achieve control at the SP because there is no integral control. The controller output is approximately 23% and the offset is 0.15 gpm.

D. Turn off selector switch **SS1** to stop the circulation pump.

E. Place the controller in manual mode.

❑ 15. Perform the following substeps to observe how changes in gain affect a proportional flow control system.

A. Turn on selector switch **SS1** to start the circulation pump.

B. Adjust the controller's setpoint to **0.8** gpm and place the controller in automatic mode.

You should notice that the system immediately reaches a steady state at approximately 0.69 gpm.

C. Turn off **SS1** and place the controller in manual mode.

D. Enter the SETUP menu and adjust the GAIN setting to **2.7**.

E. Exit the SETUP menu and place the controller in automatic mode.

You should find that the system oscillates one or more times and then reaches a steady state value of approximately 0.73 gpm after 5 seconds.

F. Turn off **SS1** and place the controller in manual mode.

G. Enter the SETUP menu and adjust the GAIN setting to **3.2**.

H. Exit the SETUP menu and place the controller in automatic mode.

You should find that the new gain setting causes the system to become unstable. The valve repeatedly opens and closes.

I. Turn off **SS1** and place the controller in manual mode.

J. Enter the SETUP menu and adjust the GAIN setting back to **2.5**.

K. Exit the SETUP menu and place the controller in automatic mode.

You should find that the system immediately reaches a steady at approximately 0.69 gpm.

As you can see, increasing the proportional gain allows the system to react faster. However, there is a point where increasing the gain causes the system to become unstable. In addition, without integral control, there is an offset present.

❑ 16. Perform the following substeps to shut down the T5552.

A. Turn off selector switch **SS1** to turn off the circulation pump.

B. Close the manual flow control valve.

C. Close both manual tank drain valves.

D. Turn off the main circuit breaker.

E. Disconnect the circuit.

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SEGMENT 4

SELF REVIEW

1. The proportional control action provides a response that is proportional to the ________.

2. If the disturbances in flow control systems are rapid enough to cause the system to oscillate, adding the ___________ mode provides an immediate response to the load changes.

3. In flow control systems, flow is both the _____________ and the controlled variable.

4. The most commonly used method for controlling flow is _______________ control.

5. Flow control systems generally respond ___________ than systems that control other process variables.

6. In a flow control loop, a _______ sensor provides a feedback signal to the controller.

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APPENDIX

STANDARD PIPE SIZES					
SCHEDULE 40 PIPE SIZES			METRIC PIPE SIZES		
NOMINAL SIZE (in)	OUTSIDE DIAMETER (in)	INSIDE DIAMETER (in)	DN (mm)	OUTSIDE DIAMETER (mm)	INSIDE DIAMETER (mm)
1/2	.840	.622	15	20	15
3/4	1.050	.824	20	25	20
1	1.315	1.049	25	32	25
1-1/2	1.900	1.610	40	50	40
2	2.375	2.067	50	63	50
2-1/2	2.875	2.469	65	75	65
3	3.500	3.068	80	90	80
4	4.500	4.026	100	110	100
5	5.563	5.047	125	140	125
6	6.625	6.065	150	160	150
8	8.625	7.981	200	225	200
10	10.750	10.020	250	280	250

Appendix A. Standard Pipe Size Table

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LIQUID	DENSITY (lbs/ft^3)	DENSITY (kg/m^3)
Water (20°C)	62.336	998.230
Water (0°C)	62.455	1000.433
Water (4°C)	62.463	1000.561
Water (100°C)	59.864	958.929
Gasoline	41.23 - 43.10	660.44-690.40
Ethyl Alcohol	49.409	791.456
Turpentine	53.09	850.420
Olive Oil	56.2	900.237
Castor Oil	60.528	969.565
Seawater	64.34	1030.628
Milk	62.214 - 64.651	996.57-1035.61
Glycerin	78.705	1260.733
Mercury	846.39	13557.864

Appendix B. Density of Common Fluids

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