UNIT 2

Hydraulic Fundamentals - Hydraulic Principles

Upon completion of this unit, the student will be able to:

Demonstrate an understanding of the basic hydraulic principles..

Introduction

Hydraulic systems are extremely important to the operation of heavy equipment. Basic hydraulic principles are used when designing hydraulic implement systems, steering systems, brake systems and power train systems. An understanding of the basic hydraulic principles must be accomplished before continuing into machine systems.

NOTES

Lesson 1: Hydraulic Principles

BASIC HYDRAULIC SYSTEMS

HYDRAULIC PRINCIPLES

Introduction

We all know that hydraulic principles are demonstrated when using a liquid under controlled pressure to do work. There are laws that state the action of liquids under conditions of changing flows and increasing and decreasing pressures. The student must be able to state and understand these laws to become successful as a heavy equipment technician..

Objectives

Upon completion of this lesson, the student will be able to:

1. State why liquid is used in hydraulic systems.
2. Identify Pascal's Law as applied to hydraulic principles.
3. State the characteristics of oil flow through an orifice.
4. Demonstrate an understanding of the basic hydraulic principles.

Using a Liquid

There are several advantages for using a liquid.

1. Liquids conforms to the shape of the container.
2. Liquids are practically incompressible.
3. Liquids apply pressure in all directions.

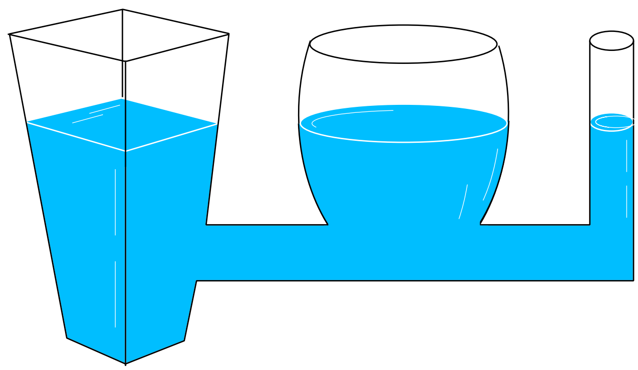

Fig. 2.1.1 Liquid Containers

Liquids Conform to Shape

Liquids will conform to the shape of any container. Liquids will also flow in any direction through lines and hoses of various sizes and shapes.

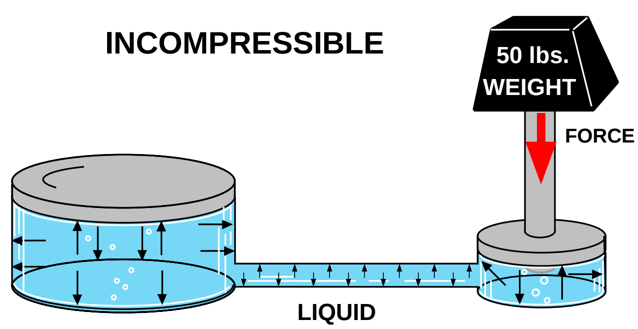

Fig. 2.1.2 Liquid Under Pressure

Practically Incompressible

A liquid is practically incompressible. When a substance is compressed, it takes up less space. A liquid occupies the same amount of space or volume even when under pressure. The space or volume that any substance occupies is called "displacement."

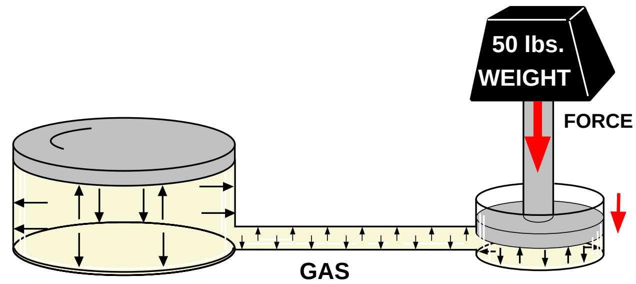

Fig. 2.1.3 Gas is Compressible

Gas is compressible

Gas is compressible. When gas is compressed, it takes up less space and it's displacement becomes less. The space previously occupied by the gas may be occupied by another object. Therefore, a liquid is best suited for the hydraulic system because it continually occupies the same volume or displacement.

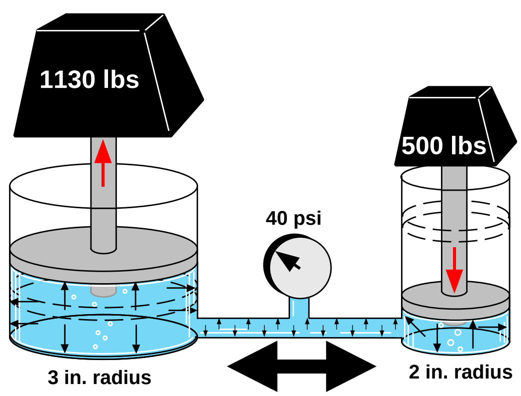

Fig. 2.1.4 Hydraulics Doing Work

Hydraulics Doing Work

According to Pascal's Law, "Pressure exerted on a confined liquid is transmitted undiminished in all directions and acts with equal force on all equal areas." Therefore, a force exerted on any part of an enclosed hydraulic oil system transmits equal pressure in all directions throughout the system.

In the above example, a 500 pound force acting upon a piston with a 2 in. radius creates a pressure of approximately 40 pounds per square inch (psi) in a confined liquid. The same 40 psi acting upon a piston with a 3 in. radius supports a 1130 pound weight.

Force = Pressure x Area

Pressure = Force ÷ Area

Area = Force ÷ Pressure

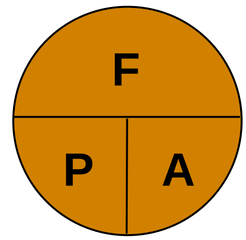

Fig. 2.1.5 Pascal's Law

A simple formula allows us to determine the Force, the Pressure, and the Area when two of the three are known. Understanding these terms is necessary to understand the fundamentals of hydraulics.

Force is the push or pull acting upon a body. Force is usually expressed in pounds (lbs.). Force is equal to the pressure times the area (F = P x A).

Pressure is the force of a fluid per unit area, usually expressed in pounds per square inch (psi).

Area is a measurement of surface space. The area is calculated in square inches. Sometime the surface area is referred to as effective area. The effective area is the total surface that is used to create a force in the desired direction.

The surface area of a circle is calculated with the formula:

Area = Pi (3.14) times radius-squared
If the radius of the circle is 2 inches, Figure 2.1.4,
A = Pi x r square
A = 3.14 x (2" x 2")
A = 12.5 sq. in.

With the knowledge of the surface area, it is possible to determine how much system pressure it will take to lift a given weight. Pressure is the force per unit and is expressed in pounds per square inch (psi).

If a force of 500 pounds was acting upon an area of 12.5 sq. in., the pressure created would be 40 psi.

The pressure is calculated with the formula:

Pressure = Force divided by Area
P = 500 lbs./12.5 sq. in.
P = 40 psi

Solving for the large piston we find:

Pressure x Area = Force
40 x (3x3) x 3.14 = Force.
40 x 28.26 = 1130 lbs.

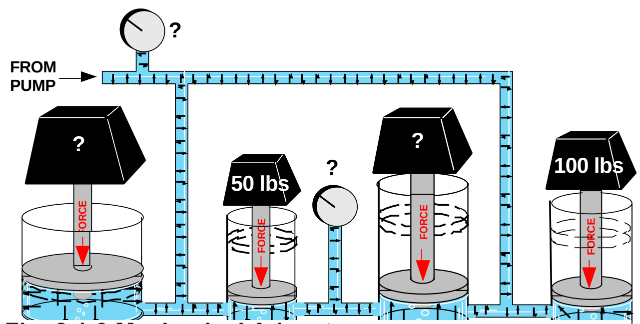

Fig. 2.1.6 Mechanical Advantage

Mechanical Advantage

Figure 2.1.6 demonstrates how liquid in a hydraulic system provides a mechanical advantage.

Since all cylinders are connected, all areas must be filled before the system pressurizes.

Use the hydraulic formula and calculate the items in question. Cylinders are counted from left to right.

When calculating the pressure in the system, we use the two known values of the second cylinder from the left. The formula used is "pressure equals force divided by area."

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \qquad \text{Pressure} = \frac{50 \text{ lbs}}{1 \text{ sq. in.}} \qquad \text{Pressure} = 50 \text{ psi}$$

Now that we know the pressure in the system, we can calculate the force of the load for cylinders one and three and the piston area for container four.

Calculate cylinders one and three loads using the formula, force equals pressure times area (Force = Pressure x Area).

Calculate cylinder four piston area using the formula, area equals force divided by pressure (Area = Force / Pressure).

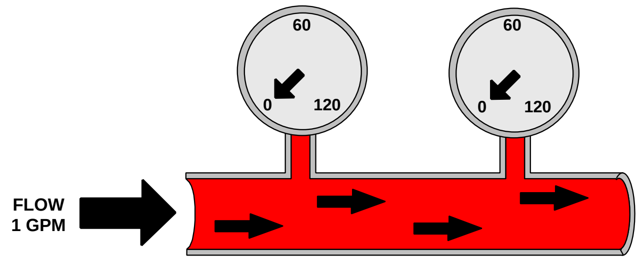

Fig. 2.1.7 No Restriction

ORIFICE EFFECT

When discussing hydraulics, it is a common practice to use the term "pump pressure." However, the pump does not produce pressure. The pump produces flow. When flow is restricted, pressure is produced.

In Figures 2.1.7 and 2.1.8, the pump flow through the pipe is 1 gpm.

In Figure 2.1.7, there is no restriction to the flow through the pipe. Therefore, the pressure reading is zero for both gauges.

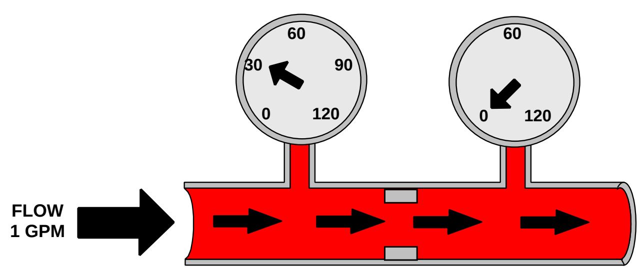

Fig. 2.1.8 Orifice Offers Restriction

Orifice Offers Restriction

An orifice offers a restriction to the pump flow. When oil flows through an orifice, pressure is produced on the upstream side of the orifice.

In figure 2.1.8, there is an orifice in the pipe between the two gauges. The gauge up stream of the orifice shows that a pressure of 207 kPa (30 psi) is needed to send a flow of 1 gpm through the orifice. There is no restriction to flow after the orifice. The gauge down stream of the orifice shows 0 pressure.

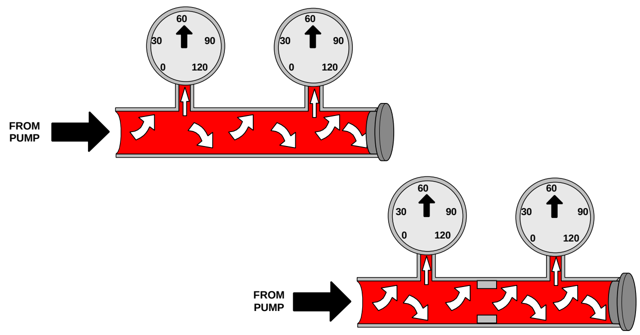

Fig. 2.1.9 Blocked Flow

Oil Flow to Tank Blocked

When the end of either pipe is plugged, oil flow to the tank is blocked.

The positive displacement pump continues pumping at 1 gpm and fills the pipe. When the pipe is filled, the resistance to any additional flow into the pipe produces pressure. The pressure reaction is the same as Pascal's Law which states that "pressure exerted on a confined liquid is transmitted undiminished in all directions and acts with equal force on all equal areas." The two gauge readings are the same.

The pressure will increase until the pump flow is diverted from the pipe to another circuit or to the tank. This is usually done with a relief valve.

If total pump flow was not diverted from the pipe, pressure in the pipe would continue to rise and cause an eruption of the circuit.

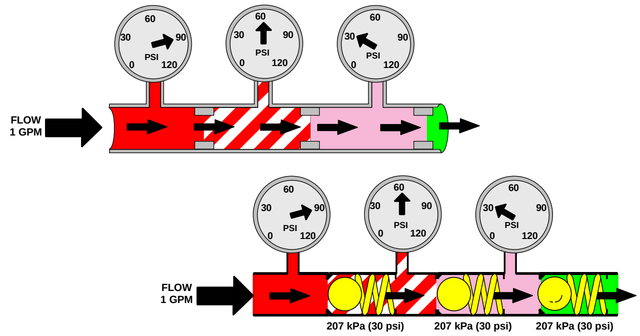

Fig. 2.1.10 Restrictions in Series

Restrictions In Series

There are two basic types of circuits, series and parallel.

In Figure 2.1.10, a pressure of 620 kPa (90 psi) is required to send 1 gpm through either circuit.

Orifices or relief valves in series in a hydraulic circuit offer a resistance that is similar to resistors in series in an electrical circuit in that the oil must flow through each resistance. The total resistance equals to the sum of each individual resistance.

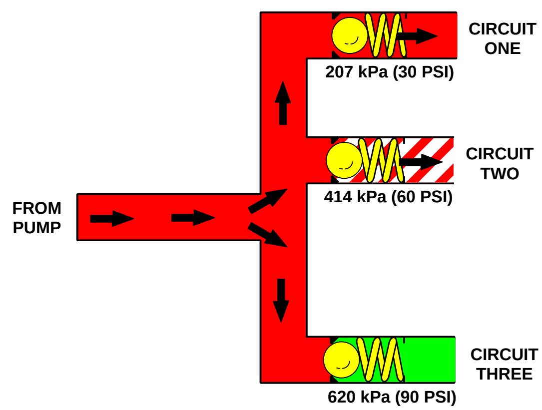

Fig. 2.1.11 Restrictions In Parallel

Restrictions In Parallel

In a system with parallel circuits, pump oil follows the path of least resistance. In figure 2.1.11, the pump supplies oil to three parallel circuits. Circuit three has the lowest priority and circuit one has the highest priority.

When the pump oil flow fills the passage to the left of the three valves, pump oil pressure increases to 207 kPa (30 psi). The pump oil pressure opens the valve to circuit one and oil flows into the circuit. When circuit one is filled, the pump oil pressure begins to increase. The pump oil pressure increases to 414 kPa (60 psi) and opens the valve to circuit two. The pump oil pressure can not continue to increase until circuit two is filled. The pump oil pressure must exceed 620 kPa (90 psi) to open the valve to circuit three.

There must be a system relief valve in one of the circuits or at the pump to limit the maximum pressure in the system.

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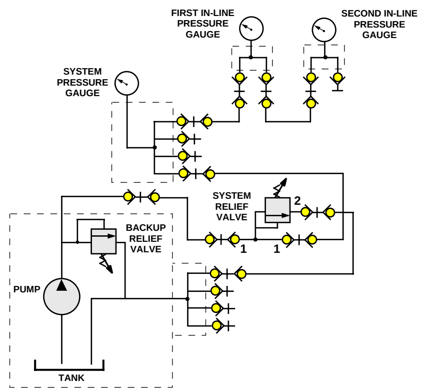

Fig. 2.1.12

LAB 2.1.1: PASCAL'S LAW

Purpose

The purpose is to demonstrate Pascal's law. When lines are connected and filled with blocked oil, the pressure is the same throughout the circuit

Materials Needed

1. Basic Hydraulic Training Unit

Procedure:

1. Use the shortest hose possible when making hose connections.
2. Connect a hose from the pump output to the No. 1 port on the system relief valve.
3. Connect a hose from the opposite No. 1 port on the system relief valve to the pressure manifold.
4. Connect a hose from the No. 2 port on the system relief valve to the return manifold.
5. Connect a hose from the pressure manifold to the left side first in-line pressure gauge port.
6. Connect a hose from the right side first in-line pressure gauge port to the left side second in-line pressure gauge port.
7. Turn the system pressure relief valve adjustment screw counter-clockwise until it stops. Then turn the adjustment screw clockwise two turns.
8. Turn ON the training unit and wait 10 seconds.
9. Read the pressures on the system pressure gauge and the two in-line gauges. Record each pressures in the appropriate space below.

   System pressure gauge _____________ Second in-line pressure gauge _______

   First in-line pressure gauge _________
10. Turn OFF the training unit and disconnect the hoses.

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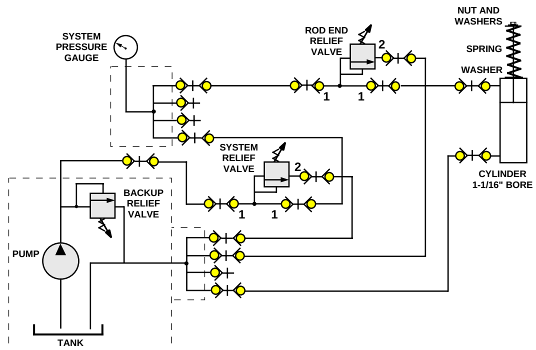

Fig. 2.1.13

LAB 2.1.2: BASIC HYDRAULIC PRINCIPLES

Purpose

The purpose is to demonstrate a basic hydraulic principle, force = pressure x area.

Materials Needed

1. Basic Hydraulic Training Unit

Procedure

In this lab, a compression spring will be used to simulate a load on a cylinder. When the cylinder rod is retracted, the rod compresses the spring and produces a load on the cylinder.

Before starting the lab, try compressing the spring with your fingers. This will give you some idea of the amount of force that can be generated by a small cylinder.

1. Use the shortest hose possible when making hose connections.
2. Connect a hose from the pump output to the No. 1 port on the system relief valve.
3. Connect a hose from the the No. 2 port on the system relief valve to the return manifold.
4. Connect a hose from the opposite No. 1 port on the system relief valve tee to the pressure manifold.
5. Turn ON the training unit.
6. Adjust the system pressure relief valve until the pressure gauge reads 5856 kPa (850 psi).
7. Turn OFF the training unit.
8. Connect a hose from the pressure manifold to the No. 1 port on the rod end relief valve.
9. Connect a hose from the opposite No. 1 port on the rod end relief valve to the rod end port on the 1-1/16" bore cylinder.
10. Connect a hose from the No. 2 port on the rod end relief valve to the return manifold.
11. Connect a hose from the head end of the 1-1/16" bore cylinder to the return manifold.

LAB 2.1.2: BASIC HYDRAULIC PRINCIPLES (continued)

12. Extend the rod on the cylinder with the 1-1/16" bore. (To extend the rod, disconnect both hoses from the cylinder, switch the hoses by connecting the supply hose to the head end port (bottom) and connecting the return hose to the rod end port (top). Turn ON the training unit and allow the cylinder rod to become fully extended. Turn OFF the training unit.) Reconnect hoses as in Steps 9 and 11.
13. Attach the load spring assembly to the rod of the hydraulic cylinder as shown in Figure 2.1.13.
14. Turn the rod end pressure relief valve clockwise until it stops.
15. Turn ON the training unit.
16. Turn the rod end pressure relief valve counter-clockwise until it stops.
17. Measure the length of the spring.
18. Record the spring measurement and the gauge pressure in the chart below.
19. Turn the rod end pressure relief valve clockwise until the gauge pressure reads 1380 kPa (200 psi).
20. Measure the length of the spring.
21. Record the spring measurement and the gauge pressure in the chart below.
22. Turn the rod end pressure relief valve clockwise until the gauge pressure reads 2756 kPa (400 psi). Repeat Steps 17 and 18.
23. Turn the rod end pressure relief valve clockwise until the gauge pressure reads 4134 kPa (600 psi). Repeat Steps 17 and 18.
24. Turn the rod end pressure relief valve clockwise until the gauge pressure reads 5510 kPa (800 psi). Repeat Steps 17 and 18.

Pressure kPa (psi)	Spring Length cm (inches)	Change In Spring Length cm (inches)
689 kpa (100 psi)		
1378 kPa (200 psi)		
2756 kPa (400 psi)		
4134 kPa (600 psi)		
5512 kPa (800 psi)		

The above chart readings may differ slightly from the readings on your training unit. The changes in the spring length should be constant.

25. Turn OFF the training unit and disconnect the hoses.

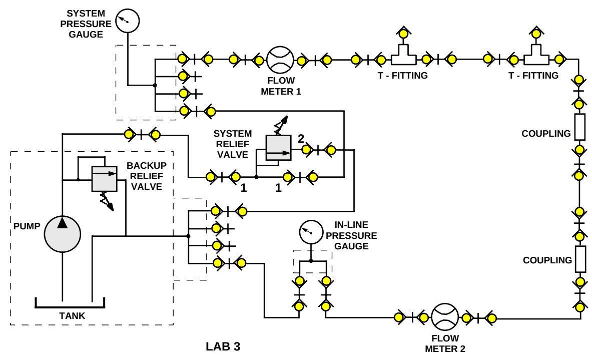

Fig. 2.1.15

LAB 2.1.3: SYSTEM PRESSURE INCREASE

Purpose

The purpose of this lab is to demonstrate how friction and restrictions in the hoses and fittings causes the system pressure to increase.

Materials Needed

1. Basic Hydraulic Training Unit

Procedure

1. Construct the circuit in Figure 2.1.15.
2. Adjust system pressure to 5860 kPa (850 psi). (To adjust the system pressure, disconnect the hose from the system relief valve to the pressure manifold. Turn ON the training unit and adjust the system pressure relief valve. Turn OFF the training unit and reconnect the hose from the system relief valve to the pressure manifold.)
3. Turn ON the training unit.
4. Read the pressure gauges and flow meters. Record the data in the space provided below Step 6.
5. Turn OFF the training unit.
6. Subtract the in-line pressure reading from the system pressure reading. Record this value in the line labeled "Pressure drop." The amount of pressure drop will depend on the hoses used and the oil temperature.

   System pressure gauge reading ___________________

   Flow rate on flow meter 1 ________________________

   Flow rate on flow meter 2 ________________________

   In-line pressure gauge reading ____________________

   Pressure required to send oil flow through hoses and fittings _________________.

8. What caused the difference in pressure between the system pressure gauge and the in-line pressure gauge? ____

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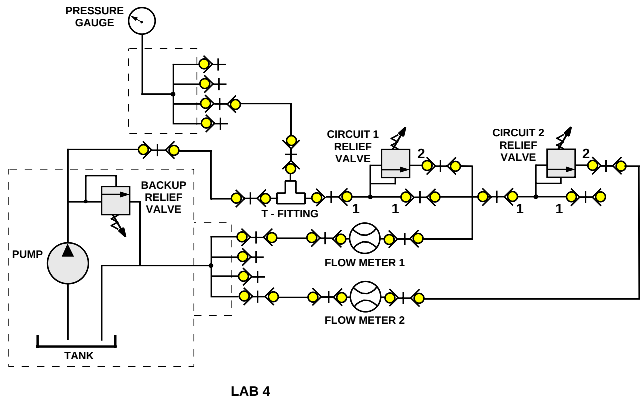

Fig. 2.1.16

LAB 2.1.4: RESISTANCE IN PARALLEL

Purpose

The purpose is to demonstrate resistance in a parallel circuit.

Materials Needed

1. Basic Hydraulic Training Unit

Procedure

1. Construct the circuit in Figure 2.1.16.
2. Turn the adjustment on both relief valves fully counter-clockwise.
3. Disconnect the hose between flow meter 2 and the drain port.
4. Turn ON the training unit.
5. Turn the adjustment on circuit 1 relief valve clockwise until the pressure gauge reads 1378 kPa (200 psi).
6. Turn OFF the training unit.
7. Connect the hose between flow meter 2 and the drain port and disconnect the hose between flow meter 1 and the drain port.
8. Turn ON the training unit.
9. Turn the adjustment on circuit 2 relief valve clockwise until the pressure gauge reads 2756 kPa (400 psi).
10. Turn OFF the training unit.
11. Connect the hose between flow meter 1 and the drain port.
12. Turn ON the training unit.
13. Read the pressure gauge and flow meters. Record the readings in the spaces below.

    Pressure ________ Flow Meter 1 _________ Flow Meter 2 ________

LAB 2.1.4: RESISTANCE IN PARALLEL (continued)

14. Turn the adjustment on circuit 1 relief valve clockwise until the pressure gauge reads approximately 2756 kPa (400 psi).
15. Read the pressure gauge and flow meters. Record the readings in the spaces below.

    Pressure ________ Flow Meter 1 ________ Flow Meter 2 ________

16. Turn the adjustment on circuit 1 relief valve clockwise one turn.
17. Read the pressure gauge and flow meters. Record the readings in the spaces below.

    Pressure ________ Flow Meter 1 ________ Flow Meter 2 _________

Explain the gauge and flow meter readings in 13 above.

____

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Explain the gauge and flow meter readings in 15 above.

____

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Explain the gauge and flow meter readings in 17 above.

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