Pearson BTEC Level 4 Higher Nationals in Engineering (RQF)

Unit 30: Operations and Plant Management

Unit Workbook 3

in a series of 4 for this unit

Learning Outcome 1

Static & Dynamic Fluid Systems

Contents

This document is prepared to break the unit material down into bite size chunks. You will see the learning outcomes above treated in their own sections. Therein you will encounter the following structures;

Purpose

Explains *why* you need to study the current section of material. Quite often learners are put off by material which does not initially seem to be relevant to a topic or profession. Once you understand the importance of new learning or theory you will embrace the concepts more readily.

Theory

Conveys new material to you in a straightforward fashion. To support the treatments in this section you are strongly advised to follow the given hyperlinks, which may be useful documents or applications on the web.

Example

The examples/worked examples are presented in a knowledge-building order. Make sure you follow them all through. If you are feeling confident then you might like to treat an example as a question, in which case cover it up and have a go yourself. Many of the examples given resemble assignment questions which will come your way, so follow them through diligently.

Question

Questions should not be avoided if you are determined to learn. Please do take the time to tackle each of the given questions, in the order in which they are presented. The order is important, as further knowledge and confidence is built upon previous knowledge and confidence. As an Online Learner it is important that the answers to questions are immediately available to you. Contact your Unit Tutor if you need help.

Challenge

You can really cement your new knowledge by undertaking the challenges. A challenge could be to download software and perform an exercise. An alternative challenge might involve a practical activity or other form of research.

Video

Videos on the web can be very useful supplements to your distance learning efforts. Wherever an online video(s) will help you then it will be hyperlinked at the appropriate point.

1.1 Pressure and Force

1.1.1 Defining Fluid

Before beginning the unit, it is important to know exactly what a fluid is. Fluids are commonly mistaken as a liquid, and while this is technically correct, fluids are defined as something that flows, which means that fluids actually encompass both liquids ***and*** gases. Fluids do not have a fixed shape and will yield easily to external pressure.

1.1.2 Pascal's Law

Pascal's law is an important consideration in fluid mechanics that was first coined by the French scientist Blaise Pascal. Pascal's Law states:

"A pressure change in one part of a fluid at rest in a closed container will transmit to every portion of the fluid and the walls of the container without any losses"

This is an important principle when considering hydraulic systems. Pressure P can be defined by Eq.1.1, where F is the force and A is the area.

$$\mathrm{P} = \frac{\mathrm{F}}{\mathrm{A}} \quad (1.1)$$

This explains why being stood on by a high heel is more painful than being stood on by a flat shoe. The force applied will still be the same, but the pressure on the concentrated heel will be much greater than a flat shoe.

1.1.3 Hydraulics

Pascal's principle is applied to hydraulic systems. A force applied to a given area can be used to exert a force elsewhere through fluid transmission.

Hydraulics operate with two classes of piston, the "Master" and the "Slave" piston. The master piston is the dictator in the system and controlled by the operator, while the slave piston is the one that will move as a result. One of the most common hydraulic systems in day-to-day life are the brakes in cars. Fig.1.1 shows a basic schematic of a hydraulic system in place, the master piston is shown as the one receiving the operator's "effort force" F_1, and the slave piston is applying the "load force" F_2.

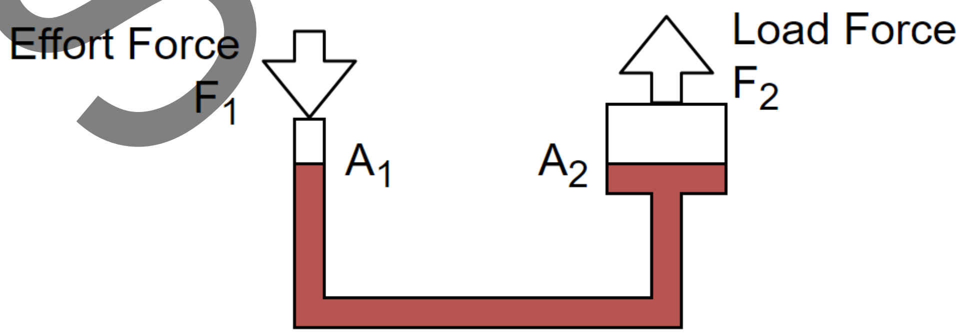


Figure 1.1: Hydraulic diagram

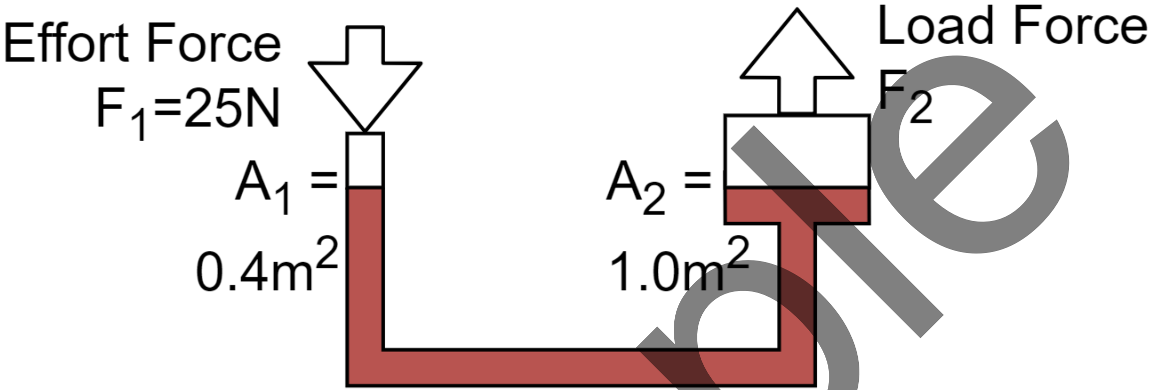
Since hydraulics are closed systems, the energy and work transmitted out of the system is zero, which means that the pressure on each piston is the same. The load force generated can be calculated using Eq.1.2.

$$F_2 = F_1 \cdot \frac{A_2}{A_1} \quad (1.2)$$

Example 1

A master piston, which has a cross sectional area of 0.4m^2 receives an effort force of 25N to push a slave piston with a cross-sectional area of 1.0m^2. Calculate:

1. The pressure created on the fluid by the effort force.
2. The load force exerted.



1. The pressure is given as:

$$P = \frac{F_1}{A_1} = \frac{25}{0.4} = 62.5\ \text{Nm}^{-2}$$

2. Since this is a closed system, the resultant load force can be calculated as:

$$F_2 = P \cdot A_2 = 62.5 \cdot 1.0 = 62.5\ \text{N}$$

Hydraulics can be found in a lot of heavy equipment, such as cranes, diggers, etc. However, one of the most common uses is found in the brakes of a car. As the driver pushes the pedal, the small master cylinder pushes down on the hydraulic fluid, which will then push the slave pistons and clamp down on the brake discs, which will slow the turning speed of the wheels. A basic schematic of a car's brakes can be seen in Fig.1.2.

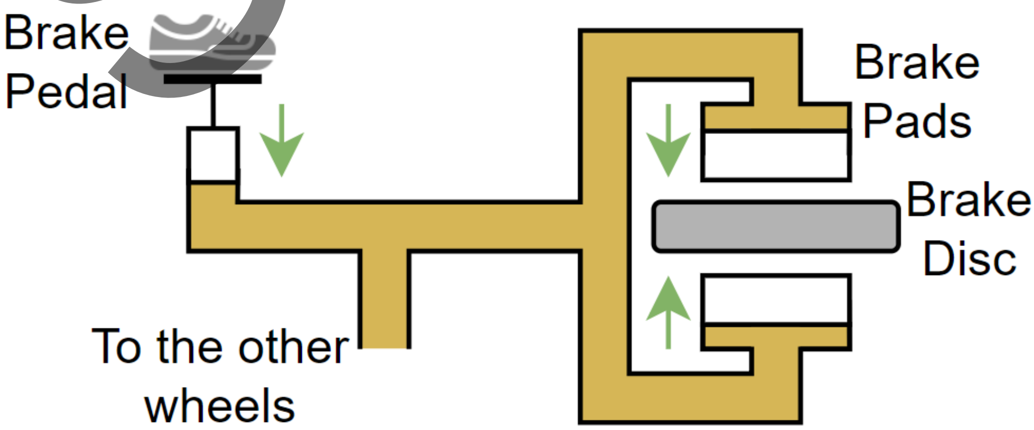


Figure 1.2: A schematic of a vehicle's braking system

This is a basic system and is very unlikely to be found in any modern vehicle. This configuration is prone to "locking", in which the brake disc does not rotate, and the wheel will slip. The solution for this is anti-lock brakes, which will incorporate a tachometer and several "bleed" valves in the hydraulics. Once the system detects that the brakes are locking (the tachometer will sense zero rotation in the wheel), the bleed valves will open and reduce the pressure on the brake pads, releasing the disc and allow it to rotate once again. With the disc rotating once again, the valves close and the brake pads are again pushed against the brake disc, essentially creating a rapid clapping motion to optimise braking performance.

1.1.4 Measuring Pressure

Pressures will be defined as a measure of *absolute* or *gauge* pressure:

- *Absolute Pressure* is the pressure relative to a vacuum (0Pa), absolute gauges are preferred when the measured pressure is below the atmospheric pressure.
- *Gauge Pressure* is the pressure measurement relative to atmospheric pressure ($1\text{bar} = 101.3\ \text{kPa}$).

Pressure can be measured by a manometer, which is a U-shaped system partially filled with liquid, typically this working liquid is mercury due to its high density relative to other liquids ($13{,}560\ \text{kg/m}^3$). One side of the u-bend is sealed by the gas being measured, while the other side can be sealed off as a vacuum (absolute measurement), or left open to the atmosphere (gauge measurement).

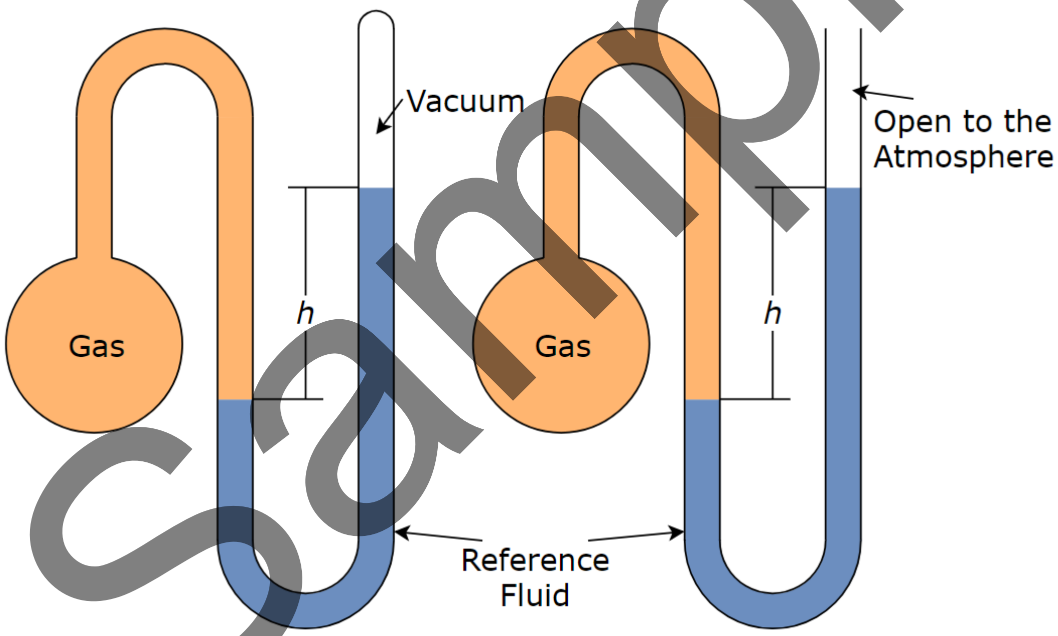


Figure 1.3: An absolute pressure manometer (left) and a gauge pressure manometer (right)

The pressure reading for the absolute pressure manometer is given as Eq.1.3, where ρ is the density of the reference fluid, g is acceleration due to gravity and h is the height difference in the reference fluid:

$$P = \rho g h \quad (1.3)$$

The pressure reading for the gauge will be the same as Eq.1.3, however to find the absolute pressure of a gauge manometer, Eq.1.4 is required:

$$P_{abs} = P_{atm} + P = P_{atm} + \rho g h \quad (1.4)$$

Example 2

A manometer is showing a height difference of $+3\ \text{cm}$, the working fluid is mercury ($13{,}560\ \text{kg/m}^3$). Calculate the absolute pressure of the system if:

a) The manometer is sealed off to a vacuum
b) The manometer is open to atmospheric pressure ($101.3\ \text{kPa}$)

You are to assume that acceleration due to gravity is $9.81\ \text{m/s}^2$

Answer:

a) If the manometer is sealed off to a vacuum, then the absolute pressure is given as:

$$P_{abs} = \rho gh = 13560 \times 9.81 \times 0.03 = 3990.7\ \text{Pa}$$

b) The manometer is open to atmospheric pressure, so absolute pressure can be given as:

$$P_{abs} = P_{atm} + \rho gh = 101.3 \times 10^3 + 3990.7\text{Pa} = 105291\ \text{Pa}$$

1.2 Submerged Surfaces

The human body is constantly under pressure from the atmosphere, however, since the body is so accustomed to it, there is no feeling, no problem with breathing. However, once the human body is submerged in water there is a noticeable difference, the force on the body is greater from the increased hydrostatic pressure of the water, meaning it becomes harder to move, and harder to breathe.

A similar situation can be seen when a car falls into a deep body of water. The people in the car are left with two options, they can get out immediately, or they can wait until the hydrostatic pressure balances on the inside and outside of the car, and open the door with little to no problem; this does mean, however, that the inside of the car has to be completely full of water before trying to open the door.

Hydrostatic pressure increases almost linearly as depth increases. Every 10 metres submerged increase the pressure by 1bar.

1.2.1 Submarines

Submarines are incredible engineering systems; the hull of a submarine is under an incredible pressure imbalance. The inside of a submarine is required to be at atmospheric pressure, as increasing the air pressure will result in a toxic amount of oxygen for the passengers.

Submarines are typically given four classifications as a measure for their hull strength:

- Design depth: This is the depth set by the design specification and is the depth that is used in calculations for the hull's depth, size and other design considerations.
- Test Depth: This is the depth that submarines are tested to in order to test hull integrity. This is also the deepest permissible depth allowed during peacetime.
- Operating depth: The maximum allowable depth in any conditions during war time.
- Collapse depth: This is the depth that the submarine will begin to crumble under the hydrostatic pressure. Nuclear submarines are predicted to have a collapse depth of roughly 700 metres, which will be a pressure of 71 bar.

The deepest recorded depth of a manned submersible is currently held by the Bathyscaphe Trieste, that reached 10,911 metres below sea level to view the Challenger Deep, the deepest known point in the ocean in the Mariana Trench, Atlantic Ocean. The deepest solo journey was by Director James Cameron, who followed the same journey and reached 10,898 metres in the more advanced Deepsea Challenger. The pressures at this depth are 1092 bar, or 110.6 MPa. The only living things at this depth are microorganisms.

1.2.2 Thrust on Immersed Surfaces

The thrust (or force) on a horizontal surface submerged in a fluid is calculated as:

$$F = P_a A = \rho g h A \quad (1.5)$$

Where:

- P_a is the average pressure acting on the surface (Pa)
- A is the submerged area (m^2)
- ρ is the fluid density
- h is the depth
- g is the acceleration due to gravity

As discussed, the change in pressure is linear, therefore the pressure profile can be described as Fig.1.4.

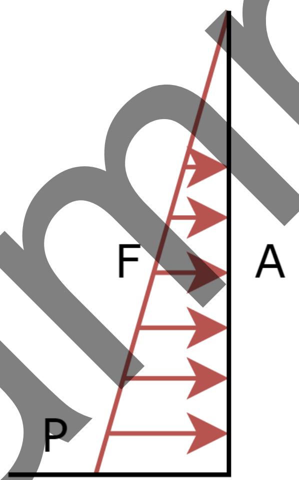


Figure 1.4: The effect of varying pressure on the force

Thus, the average force on a vertical surface F_a can be considered as Eq.1.6:

$$F_a = \frac{P_t + P_b}{2} A = \rho g A \frac{h_t + h_b}{2} \quad (1.6)$$

Where:

- P_t and P_b are the pressures at the top and bottom of the surface, respectively.
- h_t and h_b are the height of the top and bottom of the surface, respectively.