MECH 225 Engineering Science 2

1. Fluids and fluid properties

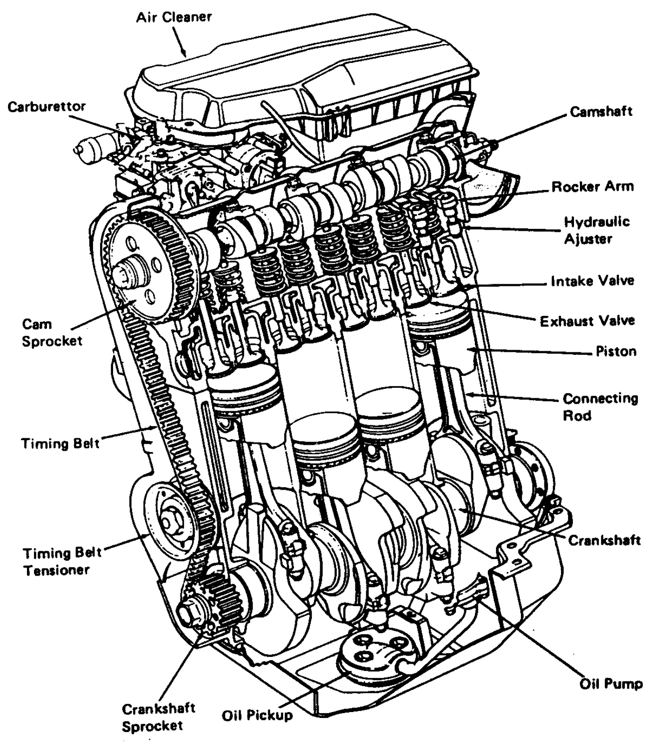
1.1. Introduction – why study fluids?

What did you do when you got up this morning? It is probable that you used water for some purpose.

Engineers design systems to collect and store water, to purify it, to distribute it, and to recycle it.

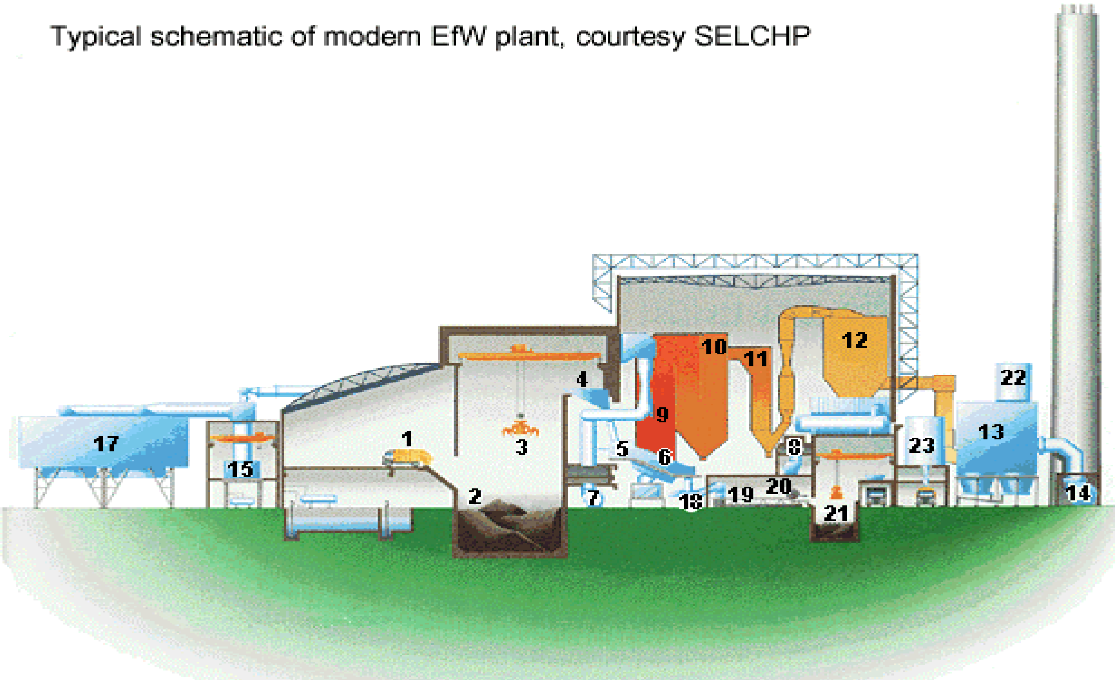
Fluids (which include liquids and gases) are the stuff of life. Here are a few examples of where technology has harnessed fluids to our advantage. *Can you think of others?*

The **internal combustion engine**, under the bonnet of almost every car, where the fluid, petroleum, is burned with air (another fluid) to produce hot gases, which do the work of turning the engine. Systems deal with the exhaust gases too.



Most forms of transport use fluids – trains, boats and ‘planes.

Electricity generation:



(*http://www.selchp.com*)

Electricity supply relies on fluids to transform energy in the form of heat from a variety of sources – fossil fuels, nuclear reactions, incineration of waste – into electrical energy. In most cases, the heat is used to boil water and generate steam, which is the working fluid in turbines that drive the electrical generators.

Many forms of **renewable energy** rely on fluids – wind turbines, tidal and wave devices.

(picture courtesy F.Johnson, at the University of Plymouth,ORECon)

Mechanical engineers need, therefore, to understand the behaviour of fluids.

1.2. What is a fluid?

We'll start this module by doing some simple "thought" experiments, and use the results to define a "fluid". Imagine you have in front of you an ordinary, empty, glass jar, with a screw top lid that is tightly closed.

Try and answer the following questions.

(1) What *is* in the jar?

(2) How much space does it occupy? What is its shape?

(3) What happens to the contents of the jar if you place the jar in a pan of boiling water?

(4) What might you need to do to keep the jar submerged in the water? Why?

Now, imagine that you open the jar, two-thirds fill it with water and close the lid tightly.

(5) What is in the jar now?

(6) How much space do the contents occupy? What is the shape?

(7) What happens to the contents if you lie the jar on its side?

(8) What happens to the contents of the jar if you place the jar in a pan of boiling water?

(9) What might you need to do to keep the jar submerged in the water? Why?

Answers overleaf.

Answers

(1) Air

(2) The **volume** of the jar. The same shape as the inside of the jar.

(3) The air will get warmer, and the lid might distort, if it were a thin one, because the **pressure** inside the jar will increase.

(4) You might have to hold the jar down, because otherwise it may float. This is because the overall **density** of the jar and air may be less than that of the water.

(5) Air and water

(6) The water occupies 2/3 the volume of the jar, the air 1/3 the volume of the jar. The water has the same shape as the bottom of the jar, but its surface will be horizontal. The air takes up the shape of the space above the water.

(7) The water will move until its shape becomes the same as the sides of the jar, and the surface again becomes horizontal. The shape of the air will change too.

(8) The water and air will become warmer, the pressure will increase.

(9) Probably nothing, because with water inside, the overall density of the jar and its contents will be greater than that of water, so the jar will sink.

So, now try and use the results of these "thought" experiments to answer the following questions:

(a) If the air and the water are both fluids, does a fluid have a shape of its own?

(b) Can you describe the difference between the nature of the volumes occupied by the air and the water?

(c) What property describes how warm the contents of the jar become when placed in the boiling water?

(d) How do you define density?

Answers overleaf.

Answers

(a) No. One characteristic of a fluid is that it has no shape of its own; it takes up the shape of its container.

(b) The air occupies the whole of the **volume** of the jar, and all the space available when there is water in the jar. This is characteristic of a **gas**. It will fill the space available. The water occupies 2/3 the volume of the jar, and this remains unchanged when the jar is turned over. A **liquid** has a fixed volume. Gases and liquids are both fluids.

(c) **Temperature**. This is a measure of how hot a body is.

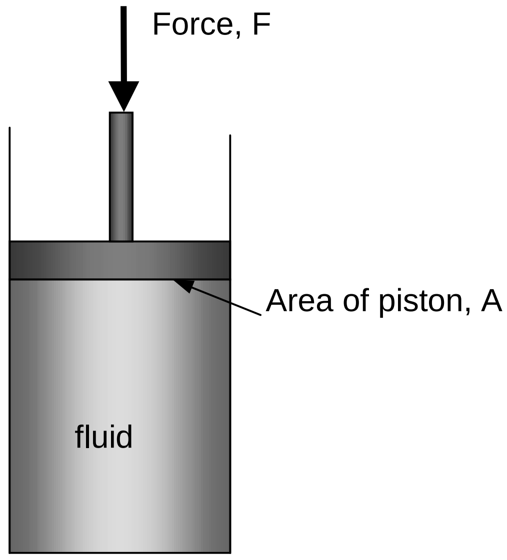
(d) **Density** is the mass per unit volume ($\rho = \frac{m}{V}$). For the closed jar full of air, the mass is the mass of the glass the jar is made from plus the mass of the lid. The mass of air is very small. The volume is the volume of the whole jar. For the jar 2/3 full of water, the volume is the same, the volume of the whole jar, but the mass has increased because the mass of the water is much bigger than the mass of the same volume of air – almost 1000 times bigger.

Further reading:

Bacon and Stephens, Fluid Mechanics for Technicians 3/4	Chapter 1
Massey, Mechanics of fluids	1.1-1.4
White, Fluid Mechanics	1.1-1.4

1.2. How does a fluid react to a force?

Imagine a cylinder and piston arrangement, such as shown below:

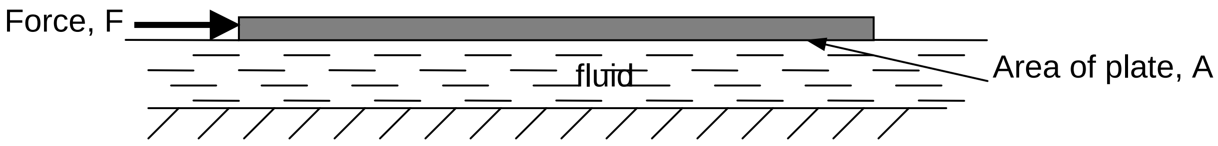


If the force F is applied as shown, the fluid will be compressed.

(1) How will the motion of the piston compare if the fluid were water or air?

(2) What will be the pressure of the fluid beneath the piston?

Now consider a fluid in a large flat container, with a flat plate floating on it, as illustrated below:



If a force F is applied as shown, a shear stress will be developed.

(3) In which direction will the fluid in contact with the plate move?

(4) In which direction will the fluid in contact with the container base move?

(5) How will the motion of the plate compare if the fluid were water or cold engine oil?

(6) What would be the shear stress in the fluid?

Answers overleaf.

(1) If the fluid were water the piston would move much less for the same force than if it were air. Water is relatively **incompressible**, compared with air.

Most liquids are modelled as **incompressible fluids**, which means that their volume (and density) does not change with an increase in pressure. Gases are usually considered to be **compressible fluids**, except where changes in density can be assumed to be negligible. Compressibility, β, is defined as:

$$\frac{1}{\beta} = K = -V\frac{dp}{dV}$$

where *K* is the bulk modulus of the fluid, *V* is the volume, and *p* the pressure. *dp/dV* is the rate of change of pressure with volume.

(2) The **pressure** will be F/A measured in Pascals (Pa) if F is in Newtons (N) and A is in metres squared (m^2).

(3) Towards the right. The fluid in contact with the plate moves with the plate.

(4) It will not move. The fluid in contact with the base has the same velocity as the base, which in this case is zero, since the container is stationary.

These two results are as a consequence of the **"no-slip" condition**.

(5) The plate will move more quickly if the fluid is water, than if it were cold engine oil. The water would offer less resistance to the shear stress applied, because its **viscosity** is lower. (Link?)

(6) The **shear stress** will be F/A measured in Nm^{-2}. A shear stress develops when a force is applied in a direction parallel to the plane in which it acts.

<u>*Some questions on units:*</u>

(a) What are the units of **K**? What is the significance of the minus sign?

(b) Pressure is F/A, and stress is F/A. What units is pressure normally measured in? What units is stress normally measured in? How are these units related?

Answers overleaf.

(a) The units of K are the same as pressure, Pa. The minus sign is there to make sure that K has a positive value. This is because an increase in pressure causes a decrease in volume. The opposite is also true, that a reduction in pressure will cause the volume to become bigger. This means that *dp/dv*, which represents the change in pressure divided by the corresponding change in volume, is always negative. The negative sign then means that K will be positive.

(b) Pressure is usually measured in Pascals (Pa) while stress is often described in terms of Newtons per metre squared (Nm^{-2}). But they are essentially the same, so that 1 Pa = 1 Nm^{-2}.

Now make a list of all the properties you might use to describe a fluid, in the light of the discussion so far.

Here is a possible list with, where relevant, the symbol normally used, and the units:

Property	**Symbol**	**Units**
Gas or liquid (or vapour)		
Mass	m	kg
Volume	V	m^3
Density	ρ (rho)	kgm^{-3}
Temperature	T	K (Kelvin) or C (Celsius)
Pressure	p	Pa (1 Pa = $1Nm^{-2}$)
Viscosity	μ (mu)	Pa s
Compressibility	β	Pa^{-1}
Bulk modulus	K	Pa
Specific volume	v	m^3kg^{-1}
Specific heat capacity	c	$Jkg^{-1}K^{-1}$

Included above are two other useful properties; the **specific volume, *v***, which is the volume per unit mass, and is the reciprocal of density, $1/\rho$; and the **specific heat capacity, *c***, (link to Pete's page) which is the energy required to raise the temperature of 1kg of a substance by 1K.