CHAPTER 3

FLUID-FLOW THEORY

Many raw materials for foods and many finished foods are in the form of fluids. These fluids have to be transported and processed in the factory. Food technologists must be familiar with the principles that govern the flow of fluids, and with the machinery and equipment that is used to handle fluids. In addition, there is an increasing tendency to handle powdered and granular materials in a form in which they behave as fluids. Fluidization, as this is called, has been developed because of the relative simplicity of fluid handling compared with the handling of solids.

The engineering concept of a fluid is a wider one than that in general use, and it covers gases as well as liquids and fluidized solids. This is because liquids and gases obey many of the same laws so that it is convenient to group them together under the general heading of fluids.

The study of fluids can be divided into the study of fluids at rest - fluid statics, and the study of fluids in motion - fluid dynamics. For some purposes, further subdivision into compressible fluids such as gases, and incompressible fluids such as liquids, is necessary. Fluids in the food industry vary considerably in their properties. They include such materials as:

Thin liquids - milk, water, fruit juices,
Thick liquids - syrups, honey, oil, jam,
Gases - air, nitrogen, carbon dioxide,
Fluidized solids - grains, flour, peas.

FLUID STATICS

A very important property of a fluid at rest is the pressure exerted by that fluid on its surroundings.

Pressure is defined as force exerted on an area. Under the influence of gravity, a mass of any material exerts a force on whatever supports it. The magnitude of this force is equal to the mass of the material multiplied by the acceleration due to gravity. The mass of a fluid can be calculated by multiplying its volume by its density, which is defined as its mass per unit volume. Thus the equation can be written:

$$F = mg = V\rho g$$

where F is the force exerted, m is the mass, g the acceleration due to gravity, V the volume and ρ (the Greek letter rho) the density. The units of force are Newtons, or kg m s^{-2}, and of pressure Pascals, one Pascal being one Newton m^{-2} and so one Pascal is also one kg m^{-1} s^{-2}.

For a mass to remain in equilibrium, the force it exerts due to gravity must be resisted by some supporting medium. For a weight resting on a table, the table provides the supporting reaction; for a multi-storey building, the upper floors must be supported by the lower ones so that as you descend the building the burden on the floors increases until the foundations support the whole building. In a fluid, the same situation applies. Lower levels of the fluid must provide the support for the fluid that lies above them. The fluid at any point must support the fluid above. Also, since fluids at rest are not able to sustain shearing forces, which are forces tending to move adjacent layers in the fluid relative to one another, it can be shown that the forces at any point in a fluid at rest are equal in all directions. The force per unit area in a fluid is called the fluid pressure. It is exerted equally in all directions.

Consider a horizontal plane in a fluid at a depth Z below the surface, as illustrated in Fig. 3.1.

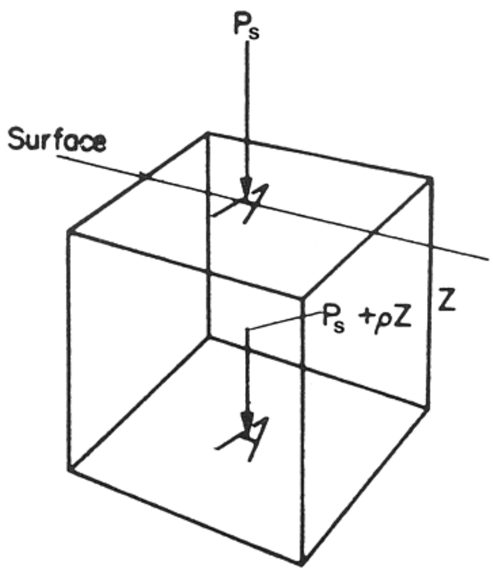

Figure 3.1 Pressure in a fluid

If the density of the fluid is ρ, then the volume of fluid lying above an area A on the plane is ZA and the weight of this volume of fluid, which creates a force exerted by it on the area A which supports it, is $Z\rho Ag$. But the total force on the area A must also include any additional force on the surface of the liquid. If the force on the surface is P_s per unit area,

$$F = AP_s + Z\rho Ag \tag{3.1}$$

where F is the total force exerted on the area A and P_s is the pressure above the surface of the fluid (e.g. it might be atmospheric pressure). Further, since total pressure P is the total force per unit area:

$$P = F/A = P_s + Z\rho g \tag{3.2}$$

In general, we are interested in pressures above or below atmospheric. If referred to zero pressure as datum, the pressure of the atmosphere must be taken into account. Otherwise the atmospheric pressure represents a datum or reference level from which pressures are measured. In these circumstances we can write

$$P = Z\rho g \tag{3.3}$$

This may be considered as the fundamental equation of fluid pressure. It states that the product of the density of the fluid, acceleration due to gravity and the depth gives the pressure at any depth in a fluid.

EXAMPLE 3.1. Total pressure in a tank of peanut oil
Calculate the greatest pressure in a spherical tank, of 2m diameter, filled with peanut oil of specific gravity 0.92, if the pressure measured at the highest point in the tank is 70 kPa.

Density of water = $1000 kgm^{-3}$
Density of oil = 0.92 x $l000 kgm^{-3}$ = $920 kgm^{-3}$
Z = greatest depth = 2 m
and g = $9.81 ms^{-2}$

Now $P = Z\rho g$
= 2 x 920 x 9.81 $kgm^{-1}s^{-2}$
= 18,050Pa
= 18.1kPa.

To this must be added the pressure at the surface of 70kPa.

Total pressure = <u>70 + 18.1 = 88.1 kPa</u>.

Note in Example 3.1, the pressure depends upon the pressure at the top of the tank added to the pressure due to the depth of the liquid; the fact that the tank is spherical (or any other shape) makes no difference to the pressure at the bottom of the tank.

In the previous paragraph, we established that the pressure at a point in a liquid of a given density is solely dependent on the density of the liquid and on the height of the liquid above the point, plus any pressure which may exist at the surface of the liquid. When the depths of the fluid are substantial, fluid pressures can be considerable. For example, the pressure on a plate 1 m^2 lying at a depth of 30 m will be the weight of 1 m^3 of water multiplied by the depth of 30 m and this will amount to 30 x 1000 x 9.81 = 294.3 kPa. As 1 tonne exerts a force on $1m^2$ of 1000 x 9.81 = 9810Pa = 9.81 kPa the pressure on the plate is equal to that of a weight of 294.3 / 9.81 = 30 tonnes of water.

Pressures are sometimes quoted as **absolute pressures** and this means the total pressure including atmospheric pressure. More usually, pressures are given as **gauge pressures**, which implies the pressure above atmospheric pressure as datum. For example, if the absolute pressure is given as 350 kPa, the gauge pressure is (350 - 100) = 250 kPa assuming that the atmospheric pressure is 100 kPa. These pressure conversions are illustrated in Fig. 3.2.

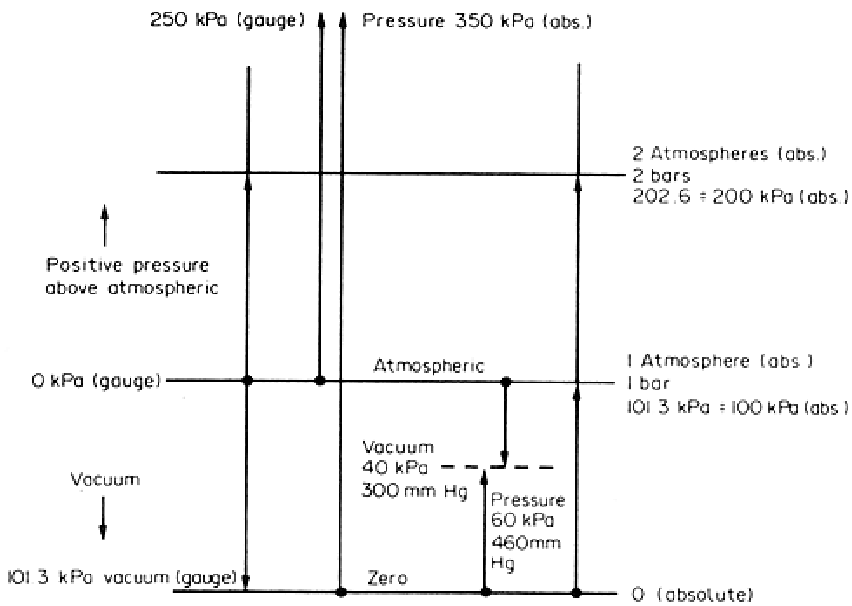

Figure 3.2 Pressure conversions

Standard atmospheric pressure is actually 101.3kPa but for our practical purposes l00kPa is sufficiently close and most convenient to use. Any necessary adjustment can easily be made.

Another commonly used method of expressing pressures is in terms of "head" of a particular fluid. From eqn. (3.3) it can be seen that there is a definite relationship between pressure and depth in a fluid of given density. Thus pressures can be expressed in terms of depths, or heads as they are usually called, of a given fluid. The two fluids most commonly used, when expressing pressures in this way, are water and mercury. The main reason for this method of expressing pressures is that the pressures themselves are often measured by observing the height of the column of liquid that the pressure can support. It is straightforward to convert pressures expressed in terms of liquid heads to equivalent values in kPa by the use of eqn. (3.3.).

EXAMPLE 3.2. Head of Water

Calculate the head of water equivalent to standard atmospheric pressure of 100 kPa.

Density of water $= 1000 \text{ kg m}^{-3}$

g $= 9.81\text{ms}^{-2}$

and pressure $= 100 \text{ kPa}$

$= 100 \times 10^3\text{Pa}$

$= 100 \times 10^3 \text{ kgm}^{-1}\text{s}^{-2}$

but from eqn. (3.3) Z $= P/\rho g$

$= (100 \times 10^3)/ (1000 \times 9.81)$

$\underline{= 10.5\text{m}}$

EXAMPLE 3.3. Head of mercury

Calculate the head of mercury equivalent to a pressure of two atmospheres.