Lecture One

1.1 Introduction

Transport phenomena are one of the cornerstones *Engineering* is built upon. The three components that comes under transport phenomena are:

1. Heat transfer

2. Mass transfer

3. Momentum transfer

Other than conduction and diffusion in solid materials, both heat and mass transfer are influenced by the motion of the medium. In most chemical engineering applications the heat and mass transfer involve fluids. For example, reactors are continuously stirred to induce flow to improve heat transfer as well as mixing. In a heat exchanger, two fluids flow on either side of tubes transferring heat from the process fluid to a service fluid (in cooling). In most cases, they are to ensure process fluids be transported from the storage tanks through the process equipment to the product storage in a controlled manner. For these tasks and many other, engineers *must* have an understanding of Fluid Mechanics.

Fluids, like any other substance, are made of molecules. Weak cohesive forces keep molecules attracted to each other. However, the molecules are in constant motion.

The **density**, **viscosity**, **compressibility**, and **surface tension** of crude oil are all crucial properties that affect its **extraction**, **transportation**, and **refining**. Each property plays a role in determining how crude oil behaves under various conditions, influencing its economic value and how it is processed.

In this section, we briefly discuss the nature of fluids. Basic concepts such as density, viscosity, surface tension and pressure are introduced and discussed in detail.

1.2 Properties of fluids

A bottle would weigh more when filled with water than olive oil. Again, you might have observed that honey flows slower than water. Fluids differ from one another due to the differences of the inherent properties. Important properties to consider when learning mechanics of fluids are

1. Density

2. Viscosity and

3. Surface tension

There are other properties such as boiling point, freezing point that are not considered here.

1.2.1 Density

Density of any substance (i.e. fluids and solids) is defined as the mass of a unit volume of that substance. It is often expressed in kg/m3 and usually designated by the Greek symbol ρ (rho). Therefore, the density,

$$\rho = \frac{m}{V}$$

where m and V represent the mass and the volume respectively. On the other hand, the specific volume is the volume per unit mass. It is given by the reciprocal of the density –that is

$$V = \frac{1}{\rho}$$

Units of specific volume are m^3/kg.

Density varies widely between different fluids. Densities of some common fluids are given in Table 1.1. Usually, density varies with temperature and pressure. Figure 1.2 (a) shows the variation of density of water with temperature at atmospheric pressure. It shows that the density of water decreases with increasing temperature. It should be noted that for water at 1 atm, density increases to a maximum 1000 kg/m3 at 4 °C before starting to decrease. Figure 1.2 (b) shows the influence of pressure on density at 20 °C. The density increases with increasing pressure. Since the compressibility (a concept discussed in section 1.2.4) of water is very small, the density variation is small for a wide range of pressures. It can be seen from Figure 1.2 (b) that the density increased only by 1% over 200 fold increase in pressure. Therefore variation of density with press is often assumed negligible for liquids. For gases however, this variation is considerably large as the compressibility of gasses is rather high.

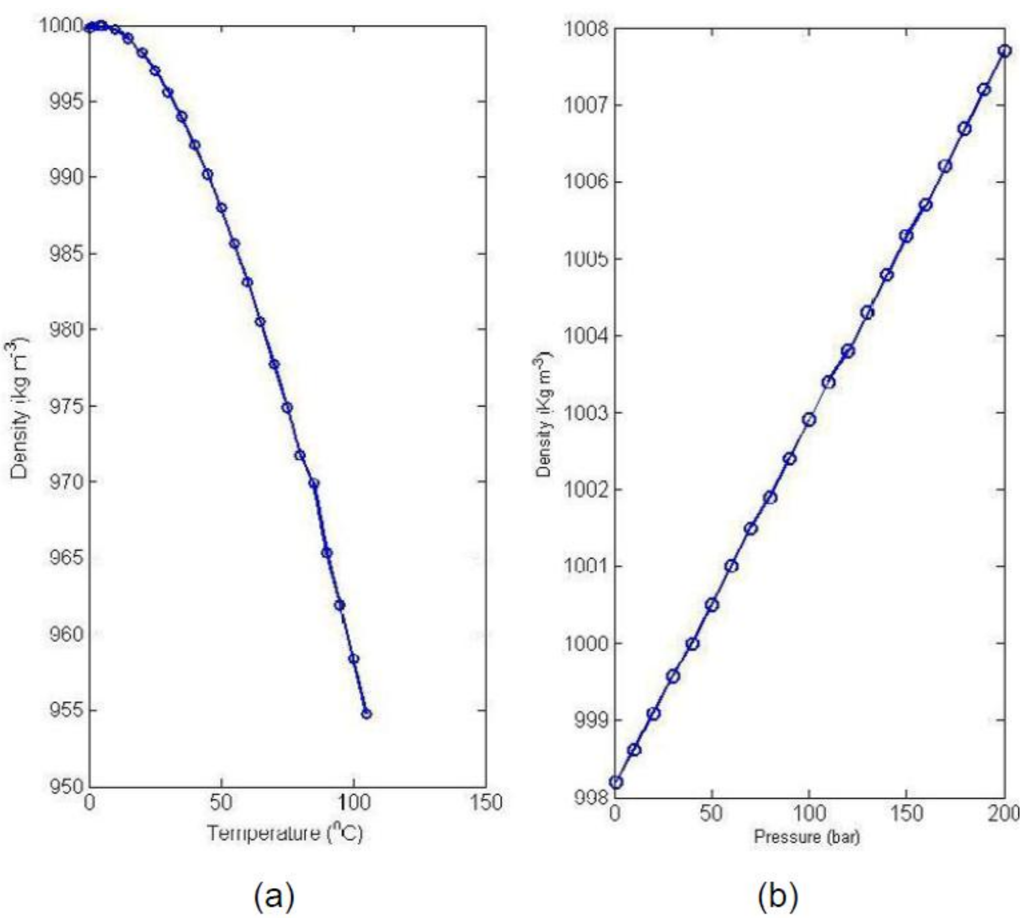


Figure 1.2. Variation of density with temperature at various pressures

The reason for increase of the density with increasing pressure is the compressibility of fluids. Neglecting this leads to the assumption that the liquids are incompressible -which is not far from the truth. For engineering calculations this assumption works well providing realistic solutions.

Specific gravity, usually denoted by SG, is a concept associated with density. Specific gravity of a substance gives the density of that substance relative to the density of water.

$$SG = \left[\frac{\rho}{\rho_{water}}\right]$$

Table 1.1: Properties of common gasses and liquids at 20 C and 1 atm pressure

Fluid	**Density/(Kg m-3)**	**Viscosity/(Pa s)**
Gases		
Air	1.205	1.8×10-5
Ammonia	0.717	9.8×10-6
Carbon dioxide	1.842	1.4×10-5
Chlorine	2.994	1.29×10-5
Oxygen	1.331	1.92×10-5
Liquids		
Water	998	0.001
Olive oil	800	0.081
Castor oil	955	0.985
Glycerol	1260	1.495
Kerosene	820	0.0025

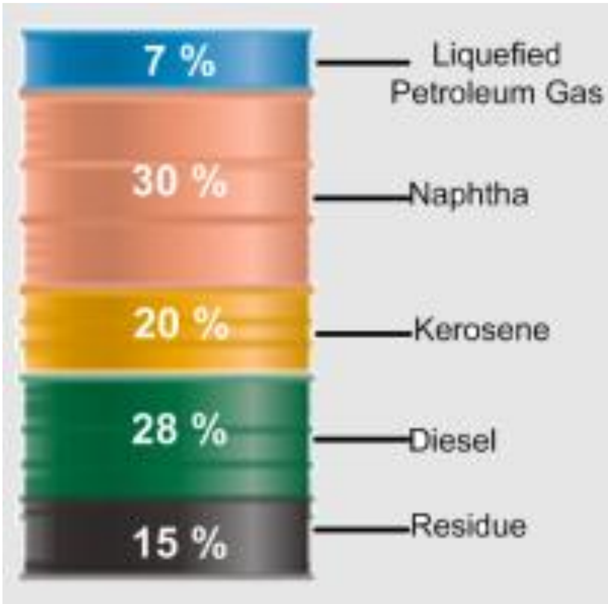
API Gravity Calculation:

The American Petroleum Institute (API) gravity is a measure of how heavy or light a petroleum liquid is compared to water. **API Gravity** is important for crude oil because it helps classify the oil in terms of its **density**, which directly impacts its quality, refinement process, and price. The formula to calculate API gravity is:

$$\text{API Gravity} = \frac{141.5}{\text{Density (g/cm}^3\text{)}} - 131.5$$

The effects of **temperature** and **pressure** on Density

- **Temperature:** As temperature increases, the density of most fluids decreases. This happens because the molecules in the fluid gain kinetic energy and spread out, causing the fluid to expand. For liquids, this effect is more noticeable than for gases, but in gases, it is much more pronounced.
- **Pressure:** For liquids, changes in pressure have a minimal effect on density since they are nearly incompressible. However, for gases, increasing pressure typically increases density as the gas molecules are pushed closer together.


7 %
Liquefied Petroleum Gas
30 %
Naphtha
20 %
Kerosene
28 %
Diesel
15 %
Residue


42 ° API
43 ° API
45 ° API
47 ° API
53 ° API
- ° API
+ ° API
+ VISCOSITY
- VISCOSITY

1.2.2 Viscosity

Viscosity is a measure of how thick or sticky a fluid is and how easily it flows. Imagine trying to pour two liquids—honey and water. Honey is much thicker and flows slowly, while water is thin and flows quickly. The reason for this difference is viscosity.

In simple terms:

- **High viscosity** means a fluid is thick and flows slowly (like honey or syrup).
- **Low viscosity** means a fluid is thin and flows easily (like water or air).

Viscosity depends on the type of fluid and temperature. For example, when you heat up a fluid, it usually becomes less viscous (flows more easily), and when you cool it down, it becomes more viscous (flows more slowly).

The effects of **temperature** and **pressure** on viscosity:

- **Temperature:** Viscosity tends to decrease with increasing temperature for most liquids. This is because higher temperatures reduce the internal friction between molecules, making it easier for them to flow. For gases, viscosity increases with temperature, since higher temperatures result in more energetic molecular motion, leading to increased resistance to flow.
- **Pressure:** The effect of pressure on viscosity is relatively small for most liquids. For gases, increasing pressure at a constant temperature can lead to a slight increase in viscosity due to the increased frequency of molecular collisions.

1.2.3 Surface Tension

Consider a liquid at rest in an open vessel. The liquid surface is in contact with the air at the room temperature. Consider a molecule of the liquid in the bulk surrounded by other molecules as shown by A in Figure 1.5. This molecule is attracted to the neighbouring molecules making it to move. If the time averaged distance is considered, the molecule will be in the close vicinity of its initial location as the force exerted by the neighbouring molecules acts on all directions.

Consider a molecule sitting at the air/liquid interface (B in Figure 1.5). It is surrounded by liquid molecules below the interface and liquid vapour molecules in the air above the interface. The liquid molecules, larger in number and in the close vicinity, attract the molecule inward while a weaker attractive force outward. The net force acts into the fluid which makes the molecule to move inwards. However, the adjacent molecules at the surface exert a higher force to keep the molecule in place. This gives the liquid surface a flexible membrane like property which we call the “surface tension”.

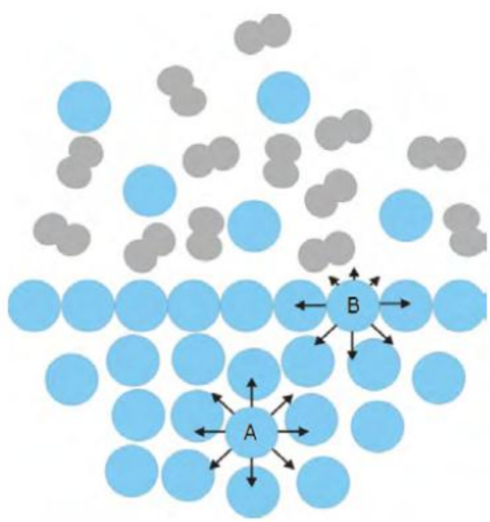


Figure 1.5. Intermolecular forces acting on liquid molecules.

The effects of **temperature** and **pressure** on Surface tension:

- **Temperature**: Surface tension decreases as temperature increases. This occurs because the thermal energy reduces the cohesive forces between molecules at the surface of the liquid. The higher the temperature, the less the liquid molecules tend to stick together, leading to a reduction in surface tension.
- **Pressure**: The effect of pressure on surface tension is generally small, especially for liquids. However, for gases, increasing pressure can lead to a slight increase in surface tension because molecules are forced into closer proximity.

1.2.4 Compressibility

Seventeenth century British philosopher/physicist Robert Boyle published his observations on the influence of pressure on a fixed volume of gas in the second edition of his book1 "New Experiments Physico-Mechanicall, Touching the Spring of the Air,⋯.." published in 1662. He observed that for a fixed amount of an ideal gas maintained at a constant temperature, the volume (V) is inversely proportional to the pressure (P).

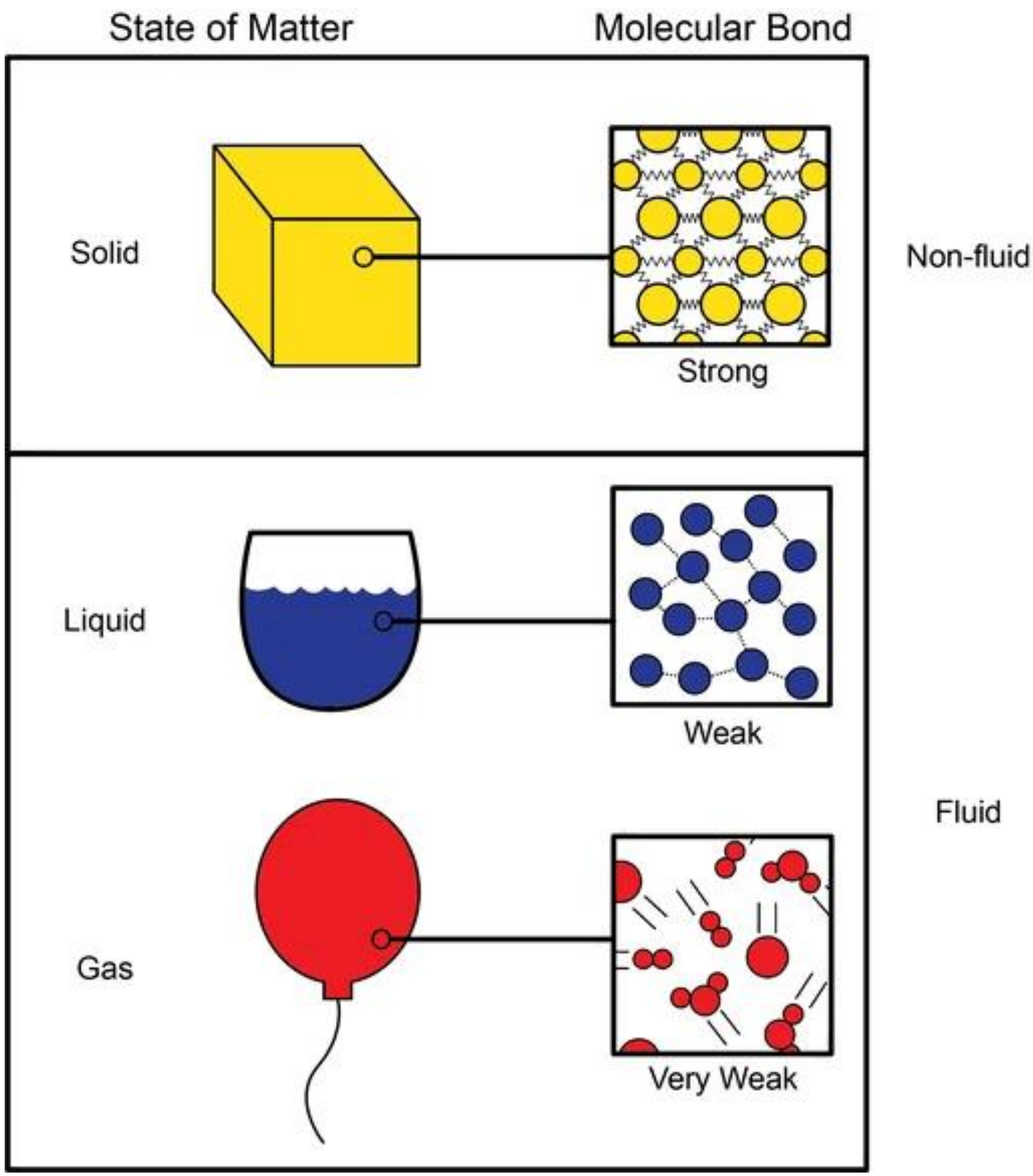
$$V \propto \frac{1}{P}$$

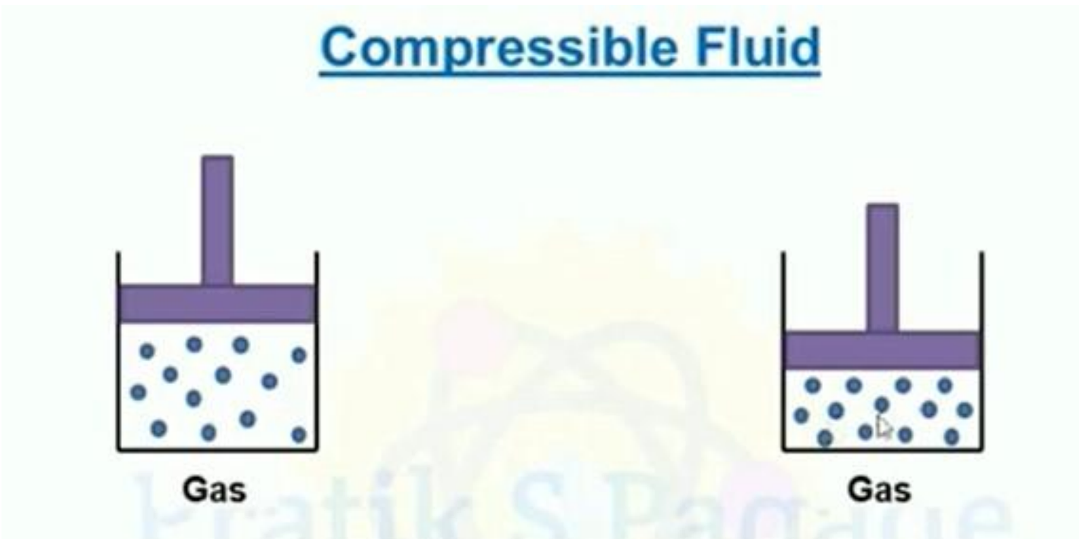
Change of volume in a unit volume per unit change of pressure is defined as the compressibility.

The decrease in volume at higher pressure results in increasing the density. For gasses where the volume change is significant the change in density becomes considerably large. For fluids, since the molecules are closely packed than that of gasses, the volume change is small. Increase of pressure has very little effect on the volume of solids.

The effects of **temperature** and **pressure** on compressibility:

- **Temperature**: As temperature increases, the compressibility of a fluid generally increases as well. This is more pronounced in gases, as higher temperatures cause the gas molecules to move faster and spread out more, making the gas more compressible. For liquids, the effect is minimal since they are already quite incompressible.
- **Pressure**: Compressibility decreases with increasing pressure, especially for gases, as the molecules are forced closer together, reducing the available space for compression. For liquids, compressibility remains almost constant with increasing pressure due to their low compressibility in the first place.


State of Matter
Molecular Bond
Solid
Strong
Non-fluid
Liquid
Weak
Gas
Very Weak
Fluid



In Summary:

- **Temperature** typically decreases **density**, **viscosity** (for liquids), and **surface tension** while increasing **compressibility** (more significantly in gases).
- **Pressure** has a stronger effect on **gases** than **liquids**, typically increasing **density** and **viscosity** for gases, while having little effect on liquids' **viscosity**, **surface tension**, and **compressibility**.

1.3 The importance of density, viscosity, compressibility and surface tension for crude oil

1. **Density**:
    - Determines whether crude oil is **light** or **heavy**.
    - Affects **extraction**, **transportation**, and **refining**.
    - **Lighter oil** flows easier and is cheaper to transport and refine.
2. **Viscosity**:
    - Measures the **thickness** or **flow resistance** of oil.
    - Higher viscosity oils are harder to extract, **transport**, and refine.
    - Light crude is easier to flow through pipelines and refine.
3. **Compressibility**:
    - Describes how much crude oil's volume changes under pressure.
    - Affects **oil extraction** efficiency and **reservoir management**.
    - Plays a role in **enhanced oil recovery** and **pipeline design**.
4. **Surface Tension**:
    - Influences **oil-water separation** and **emulsion stability**.
    - Affects **spills** and how oil behaves when mixed with other substances (like water or gas).
    - Lower surface tension leads to faster spreading on water surfaces.

Each property impacts how crude oil is **extracted**, **transported**, **refined**, and how it behaves in **reservoirs** and the **environment**. Understanding these factors helps optimize oil operations and reduce costs.