Laboratory 8: Density Measurement of Chemicals and Fuels

Topics Covered

- Density as a physical property of chemical compounds
- Changes in density based on temperature
- Determining densities of pure chemicals and mixture/blends of methyl esters and diesel fuel, such as methanol, glycerol, vegetable oils, methyl esters, and diesel

Equipment Needed (per pair or group)

- Three 150 mL measuring cylinders
- Weighting scale to measure 100 g of chemicals
- A glass bulb thermometer or a thermocouple

Reagents Needed (per pair or group)

- Vegetable oil – approximately 150 mL
- Biodiesel made from the same oil as above – approximately 150 mL
- Petroleum diesel – approximately 100 mL

Background Information – Density

The density of a substance is defined as mass per unit volume. Density is a way of quantifying how heavy or light a substance is for a given amount of volume. Mathematically:

$$Density = \frac{Mass}{Volume} \tag{8.1}$$

Example:
If 1 L of vegetable oil weighs 930 g, the density of the oil can be calculated as:
Density = 930 g/1000 mL = 0.93 g/mL

The mass of a substance is the sum of the masses of all individual molecules. Therefore, the density of a substance can be changed by changing the number of molecules occupying a unit volume. For instance when a substance is heated, the heat energy increases the molecular vibration, pushing tightly packed neighboring molecules farther apart. As a result, a given number of molecules occupies more volume without increasing its mass. Therefore, from equation 8.1, when volume increases without increasing the mass, the density decreases.

Therefore the density of a substance is somewhat temperature dependent. Usually the density is decreased with increasing temperature. There may be other factors that affect the intermolecular distance other than temperature, and hence general density-temperature relation may not hold. One such example is the density of water, which is highest at 4°C.

When two substances are mixed together, several things could happen. Let's imagine mixing substance A with substance B. If the intermolecular distance of substance A is large enough that substance B can snugly fit into the void, the density of the mixture will be higher than that of substance A. Imagine pouring some sand into a bucket of gravel. The sand will fill in the spaces between the pieces of gravel, and hence the density of the mixture of sand and gravel is greater than that of gravel alone.

This also holds true when a chemical compound is dissolved. For example, quite a lot of sugar or salt can dissolve in water without increasing the water volume. The process increases the density of the chemical mixture. This is the reason sea water is about 2.5% heavier than fresh water.

The density of a mixture with two components can be calculated as:

$$Mixture\ Density = \frac{Mass\ of\ A + Mass\ of\ B}{Mixture\ Volume} \tag{8.2}$$

If all of component B can fit into the voids of component A, then the mixture volume is essentially the same as the volume of component A. It is worth noting that when component B fits into the voids of component A, the mixture density is always greater than component A, but not necessarily greater than the density of component B. This is because the mixture volume is usually greater than the volume of component B. Imagine a sponge with some water sprinkled onto it. The mixture density will be higher than the density of the dry sponge, but less than the density of water.

In the second type of mixture, the voids are not big enough for substance A to accommodate substance B. In this case the mixture volume in equation 8.2 is the sum of the volume of the individual components. A mixture of atmospheric gases (such as nitrogen and oxygen) is an example.

In the third type of mixture, component A chemically reacts with component B and the product of the reaction may have lower or higher density, depending on the chemical reaction. The density of the product depends on the chemical structure of the molecule formed.

The density of matter in the gaseous phase can be calculated mathematically from its molecular formula. However, the density of liquids and solids is not as straightforward as that of gases. One mole of gas always occupies 22.4 L at standard temperature (0° C) and pressure (1 atm). Therefore the density of a gas at standard temperature and pressure can be calculated as:

$$Density\ of\ gas = \frac{Molecular\ weight\ of\ the\ gas\ in\ grams}{22.4}\ g/L \tag{8.3}$$

Pre-Lab Questions

1. Why does the density of a substance usually decrease at higher temperatures?
2. What is the density of CO_2 at standard temperature and pressure (STP)? (The molecular weight of CO_2 = 44)

Safety Note: In this lab you will be handling petroleum diesel. Use gloves and an apron when handling this chemical, because it can irritate skin, and also can cause an odor that is difficult to remove from skin and clothes.

Laboratory Procedure

1. Calculate the mass of methanol needed, and how much biodiesel and glycerol are produced, from 100 mL of soybean oil reacted. The biodiesel transesterification is given by the following chemical reaction:

   1 mole of triglyceride + 3 moles of methanol → 3 moles of biodiesel + 1 mole of glycerol

   Given:
   Average molecular weight of soybean oil = 872.33 g/mol
   Molecular weight of methanol = 32.04 g/mol
   Average Molecular weight of biodiesel = 292.12 g/mol
   Molecular weight of glycerol = 92.09 g/mol

2. Now calculate the mass of the chemicals required to react with approx. 100 g of soybean oil to 0.01 accuracy. Since 3 moles of methanol are required for each mole of soybean oil, the mass of the methanol reacted with 100 g of oil is given by:

$$\text{Mass of the methanol} = \frac{3 \times Molecular\ weight\ of\ methanol}{Molecular\ weight\ of\ soybean\ oil} \times 100 = \_\_\_\_\_\_\_ g$$

Similarly, the mass of biodiesel produced and glycerol can be calculated as:

$$\text{Mass of the biodiesel} = \frac{3 \times Molecular\ weight\ of\ biodiesel}{Molecular\ weight\ of\ soybean\ oil} \times 100 = \_\_\_\_\_\_\_ g$$

$$\text{Mass of the glycerol} = \frac{Molecular\ weight\ of\ glycerol}{Molecular\ weight\ of\ soybean\ oil} \times 100 = \_\_\_\_\_\_\_\_ g$$

Measurements

- Take the temperatures of the soybean oil, biodiesel and petroleum diesel and ensure that they are all at room temperature. If not wait until they all come to room temperature.
- Pour weighed mass (weight in grams) of soybean oil in a measuring cylinder using a dropper and a weighing scale.
- Pour calculated mass (weight in grams) of biodiesel in a separate measuring cylinder using a dropper and a weighing scale.
- Pour 50 g of petroleum diesel in the third measuring cylinder using a using a dropper and a weighing scale.

Observe the volume of biodiesel fuel produced compared to the volume of the soybean oil used to make the fuel. Note down your observations along with following measurements.

Volume of the soybean oil used to make biodiesel = ______mL

Volume of biodiesel produced = ______mL

Volume of petroleum diesel = ______mL

Now carefully pour biodiesel into petroleum diesel until the mixture weights 100 g. Measure the volume of the fuel mixture.

Volume of the fuel mixture = ______mL

Data processing

Calculate the density of the soybean oil, biodiesel and petroleum diesel

$$\text{Soybean oil Density} = \_\_\_\_\_\_\_\_ g/L$$

$$\text{Biodiesel Density} = \_\_\_\_\_\_\_\_ g/L$$

$$\text{Petroleum diesel Density} = \_\_\_\_\_\_\_\_ g/L$$

$$\text{Biodiesel and Diesel Mixture Density} = \_\_\_\_\_\_\_\_ g/L$$

Biodiesel to oil ratio in mass basis = _________________g of biodiesel/g of oil

Biodiesel to oil ratio in volume basis = _________________mL of biodiesel/mL of oil