CHAPTER TWO

PROPERTIES OF FLUIDS

2-1 Introduction

Any characteristic of a system is called a property. Some familiar properties are pressure P, temperature T, volume V, and mass m. The list can be extended to include less familiar ones such as viscosity, thermal conductivity, modulus of elasticity, thermal expansion coefficient, electric resistivity, and even velocity and elevation. Properties are considered to be either intensive or extensive. Intensive properties are those that are independent of the mass of the system, such as temperature, pressure, and density. Extensive properties are those whose values depend on the size—or extent—of the system. Total mass, total volume V, and total momentum are some examples of extensive properties. An easy way to determine whether a property is intensive or extensive is to divide the system into two equal parts with an imaginary partition, as shown in Fig. 2–1. Each part will have the same value of intensive properties as the original system, but half the value of the extensive properties. Extensive properties per unit mass are called specific properties. Some examples of specific properties are specific volume ($v = V/m$).

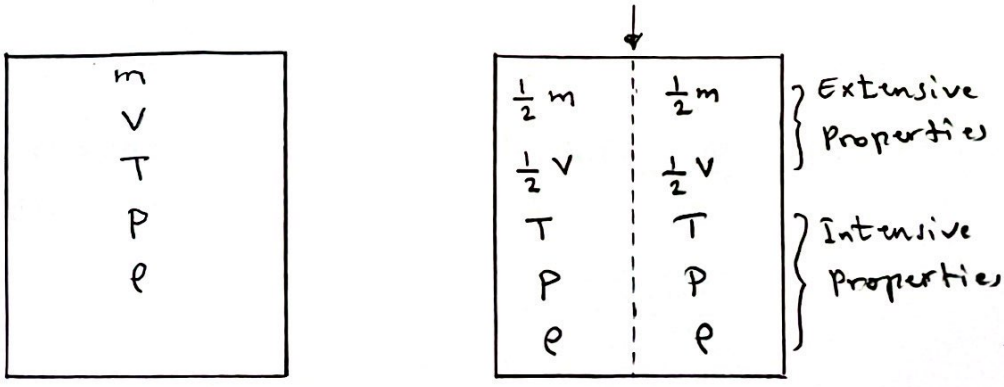

FIGURE 2–1Criterion to differentiate intensive and extensive properties.

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2–2 Density and Specific Gravity

Density is defined as *mass per unit volume.* That is,

$$\rho = m/V \qquad (kg/m^3)$$

The reciprocal of density is the specific volume *v*, which is defined as *volume per unit mass.* That is, $v = V/m = 1/\rho$. For a differential volume element of mass δm and volume δV, density can be expressed as $\rho = \delta m/\delta V$.

The density of a substance, in general, depends on temperature and pressure. The density of most gases is proportional to pressure and inversely proportional to temperature. Liquids and solids, on the other hand, are essentially incompressible substances, and the variation of their density with pressure is usually negligible. At 20°C, for example, the density of water changes from 998 kg/m3 at 1 atm to 1003 kg/m3 at 100 atm, a change of just 0.5 percent. The density of liquids and solids depends more strongly on temperature than it does on pressure. At 1 atm, for example, the density of water changes from 998 kg/m3 at 20°C to 975 kg/m3 at 75°C, a change of 2.3 percent, which can still be neglected in many engineering analyses.

Specific gravity, or relative density, is defined as *the ratio of the density of a substance to the density of some standard substance at a specified temperature* (usually water at 4°C, for which ρ_{H2O} = 1000 kg/m3). That is,

$$SG = \frac{\rho}{\rho_{H_2O}}$$

The weight of a unit volume of a substance is called specific weight or weight density and is expressed as

$$\gamma_s = \rho g \qquad (N/m^3)$$

where *g* is the gravitational acceleration.

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Density of Ideal Gases

Any equation that relates the pressure, temperature, and density (or specific volume) of a substance is called an equation of state. The simplest and best-known equation of state for substances in the gas phase is the ideal-gas equation of state, expressed as

$$Pv = RT \quad \text{or} \quad P = \rho RT$$

where P is the absolute pressure, v is the specific volume, T is the thermodynamic (absolute) temperature, ρ is the density, and R is the gas constant. The gas constant R is different for each gas and is determined from $R = Ru/M$, where Ru is the universal gas constant whose value is $Ru = 8.314$ kJ/ kmol·K and M is the *molar mass* (also called *molecular weight*) of the gas.

For an ideal gas of volume V, mass m, and number of moles $N = m/M$, the ideal-gas equation of state can also be written as $PV = mRT$ or $PV = NRuT$.

For a fixed mass m, writing the ideal-gas relation twice and simplifying, the properties of an ideal gas at two different states are related to each other by

$$P1V1/T1 = P2V2/T2.$$

The temperature scale in the SI is the Kelvin scale, and the temperature unit on this scale is the kelvin, designated by K. In the English system, it is the Rankine scale, and the temperature unit on this scale is the rankine, R. Various temperature scales are related to each other by,

$$T(\text{K}) = T(^\circ\text{C}) + 273.15 = T(R)/1.8$$

$$T(\text{R}) = T(^\circ\text{F}) + 459.67 = 1.8\,T(\text{K})$$

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EXAMPLE 2–1

Determine the density, specific gravity, and mass of the air in a room whose dimensions are 4 m x 5 m x 6 m at 100 kPa and 25°C (Fig. 2–2).

Solution

At specified conditions, air can be treated as an ideal gas.

$R_{air} = 0.287 \ kPa.m^3/kg.K$

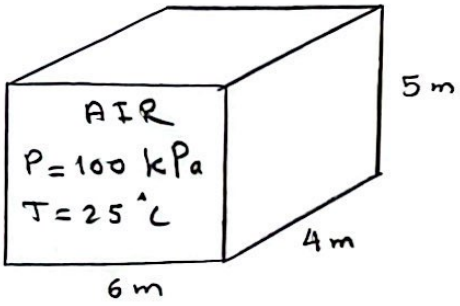

Figure 2-2, Schematic of Ex-2-1

$P = \rho RT$

$$\therefore \rho = \frac{P}{RT}$$

$$= \frac{100}{(0.287)(25+273.15)} = 1.17 \ kg/m^3$$

Then

$$SG = \frac{\rho}{\rho_{H_2O}} = \frac{1.17}{1000} = 0.00117$$

Finally,

$$V = 4 * 5 * 6 = 120 \ m^3$$

$$m = \rho V = 1.17 * 120$$

$$= 140 \ kg$$

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