Thermodynamics

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Module 1: Thermodynamic Properties

Learning Objectives

By the end of this section, you will be able to:

- **Define** key thermodynamic properties including specific volume, density, specific gravity, and humidity.
- **Differentiate** between intensive and extensive thermodynamic properties.
- **Calculate** the weight and mass of a body using the gravitational constant (gc) in the English system of units.

Executive Summary: Thermodynamic properties are measurable characteristics used to define the state of a system. Understanding the distinction between mass-dependent (extensive) and mass-independent (intensive) properties is fundamental to performing energy balance and fluid flow calculations.

Mass and Weight Relationships

In engineering thermodynamics, it is critical to distinguish between mass and weight, particularly when working with the English system of units. **Mass (m)** represents the quantity of material, while **weight (wt)** is the force exerted by that mass in a gravitational field.

Equation 1-1:

$$wt = \frac{mg}{g_c}$$

Where:

- **wt** = weight, lbf
- **m** = mass, lbm
- **g** = acceleration of gravity, 32.17 ft/sec2
- **gc** = gravitational constant, 32.17 lbm-ft/lbf-sec2

The Role of gc

The constant **gc** is a dimensional constant used to align Newton's Second Law with the English system. It ensures that on the surface of the earth, 1 pound-mass (lbm) exerts a force of 1 pound-force (lbf).

Equation 1-2:

$$F = \frac{ma}{g_c}$$

Where:

- **F** = Force (lbf)
- **m** = mass (lbm)
- **a** = acceleration (ft/sec^2)
- **gc** = 32.17 lbm-ft/lbf-sec^2

🧮 **Calculation Note:** While mass remains constant regardless of location, weight changes based on the local gravitational acceleration (g). In most earth-bound engineering applications, "a" is substituted with "g".

Primary Thermodynamic Properties

Specific Volume (n)

Specific volume is the volume per unit mass. It is the reciprocal of density.

Equation 1-3:

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

Where:

- **n** = specific volume (ft^3/lbm)
- **V** = total volume (ft^3)
- **m =** total mass (lbm)

Density (r) Density is the mass per unit volume.

Equation 1-4:

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

Where:

- **ρ** = density (lbm/ft^3)
- **m** = mass (lbm)
- **V** = volume (ft^3)
- **n** = specific volume (ft^3/lbm)

Specific Gravity (S.G.)

Specific gravity compares the density of a substance to the density of water at a standard temperature (typically 60°F for engineers).

- **Dimensionless:** Because it is a ratio, S.G. has no units.
- **Temperature Sensitivity:** Since fluid density varies with temperature, the specific gravity must be specified for a particular temperature.

Humidity

Describes the water vapor content in the air:

- **Absolute Humidity:** The mass of water vapor per unit volume of air.
- **Relative Humidity:** The ratio of current water vapor to the maximum possible water vapor the air can hold at that specific temperature (expressed as a percentage).

Classification: Intensive vs. Extensive

Properties are categorized based on their dependence on the size of the system.

- **Intensive Properties:** These are **independent** of the amount of mass present. If you divide a system in half, these values remain unchanged.
    - Examples: Temperature, pressure, density, and specific volume.
- **Extensive Properties:** These vary **directly** with the mass of the system.
    - Examples: Total mass and total volume.

💡 **Design Tip:** To convert an extensive property into an intensive one, divide it by the mass. This is why "volume" (extensive) becomes "specific volume" (intensive).

Checkpoint Quiz

1. **A substance has a density of 62.4 lbm/ft^3. What is its specific volume?**
   a) 1.0 ft^3/lbm
   b) 0.016 ft^3/lbm
   c) 62.4 ft^3/lbm
   d) 32.17 ft^3/lbm

Answer: (b). Specific volume (n) is the reciprocal of density (1 / r). 1 / 62.4 = 0.016 ft^3/lbm.

2. **Which of the following is an intensive property?**
   a) Total Mass
   b) Total Volume
   c) Temperature
   d) Total Weight

Answer: (c). Temperature does not change if the mass of the system is divided, making it an intensive property.

3. **In the English system, how is 1 lbf defined in relation to 1 lbm on Earth?**
   a) 1 lbf is the force exerted by 1 lbm at sea level.
   b) 1 lbf is equal to 1 lbm multiplied by gc.
   c) 1 lbf is only applicable in outer space.
   d) 1 lbf is the mass of 32.17 slugs.

Answer: (a). Due to the use of the gravitational constant (gc), 1 lbf = 1 lbm specifically where g = 32.17 ft/sec^2.

Module 2: Temperature and Pressure Measurements

Learning Objectives

By the end of this section, you will be able to:

- **Define** the thermodynamic properties of temperature and pressure.
- **Convert** values between Fahrenheit, Celsius, Kelvin, and Rankine temperature scales.
- **Calculate** absolute pressure using gauge and vacuum pressure readings.
- **Evaluate** pressure units across different scales including psi, inches of water, and millimeters of mercury.

Executive Summary: Understanding the relationship between relative and absolute scales for both temperature and pressure is vital for accurate thermodynamic modeling. Engineering calculations generally require the use of absolute scales (Rankine/Kelvin and psia) to maintain physical consistency.

Temperature Fundamentals

Temperature is a physical measure of the **molecular activity** within a substance. As molecular movement increases, the temperature rises. Effectively, it serves as a relative indicator of "hot" or "cold," allowing engineers to predict the direction of heat transfer between systems.

Temperature Scales and Conversions

Standard measurements utilize the **Fahrenheit (F)** and **Celsius (C)** scales, which are based on the freezing and boiling points of water at standard atmospheric pressure.

- **Celsius:** 100 units between freezing (0°C) and boiling (100°C).
- **Fahrenheit:** 180 units between freezing (32°F) and boiling (212°F).

For thermodynamic calculations, **absolute scales** are required. **Kelvin (K)** corresponds to Celsius, and **Rankine (R)** corresponds to Fahrenheit. Absolute zero represents the state where all molecular motion ceases.

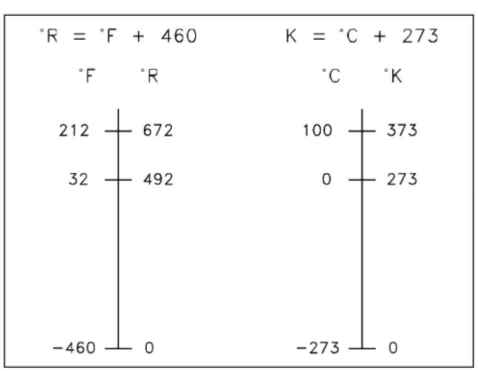

Figure 1: Comparison of Temperature Scales