Specific Weight, Specific Volume, and Specific Gravity I

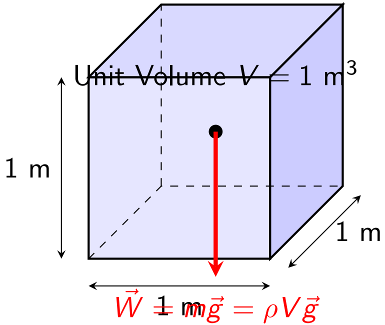
Course: Fluid Mechanics and Hydraulic Machinery Lecture 02: Fundamental Fluid Properties Instructor: Professor of Mechanical Engineering

Introduction to Specific Weight I

Specific weight, also known as unit weight, represents the weight of a fluid per unit volume. Denoted by the Greek letter gamma (γ) or sometimes 'w', it is a fundamental property in fluid mechanics that directly links the mass-based property (density) to the gravitational force acting on the fluid. Unlike density, specific weight is not absolute; it depends on the local gravitational acceleration (g), meaning the specific weight of a fluid will vary slightly depending on elevation and location on Earth, and significantly on other celestial bodies.

- Defined as weight per unit volume: $\gamma =$ W / V
- Mathematically related to density: $\gamma = \rho$ * g
- SI unit is Newtons per cubic meter (N/m^3), dimension is [M L^{-2} T^{-2}]
- Standard value for water at 4°C and standard gravity is 9810 N/m^3 (9.81 kN/m^3)

Visualizing Density vs. Specific Weight I



Mass $m = \rho$
Weight $W = \gamma$

- A unit volume (1 m^3) is used as the reference standard
- Mass contained within this volume is the density (ρ)
- The downward force exerted by gravity on this mass is the specific weight (γ)
- Equation: γ = W/V = (m*g)/V = ρ * g

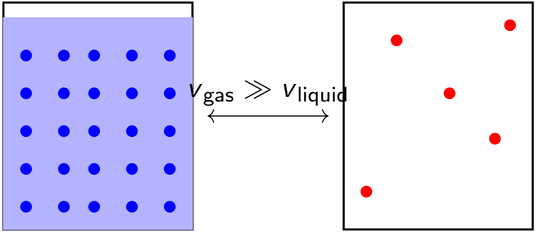
Specific Volume I

Specific volume (v) is defined as the volume occupied by a unit mass of a fluid. It is the reciprocal of mass density (ρ). This property is particularly important in thermodynamics and gas dynamics where compressibility is significant. While liquids have very small and relatively constant specific volumes due to their highly incompressible nature, gases exhibit large and highly variable specific volumes that change dramatically with pressure and temperature according to the equation of state.

- Defined as volume per unit mass: v = V / m
- Reciprocal relation to density: v = 1 / ρ
- SI unit is cubic meters per kilogram (m^3/kg), dimension is [L^3 M^{-1}]
- For water at standard conditions, v is approximately 0.001 m^3/kg

Specific Volume Comparison: Liquid vs. Gas I

For a constant Mass ($m = 1$ kg):



Liquid (Small v, High ρ)   Gas (Large v, Low ρ)

- Liquid molecules are closely packed, leading to small volume per unit mass
- Gas molecules are widely spaced, leading to large volume per unit mass
- The diagram contrasts 1 kg of liquid vs 1 kg of gas under standard conditions

Specific Gravity I

Specific gravity (S or SG), also called relative density, is a dimensionless ratio of the density of a fluid to the density of a standard reference fluid. For liquids, the standard reference fluid is pure water at its temperature of maximum density, which occurs at 4°C (where density is exactly 1000 kg/m^3 or specific weight is 9810 N/m^3). For gases, the reference fluid is typically air or hydrogen at standard temperature and pressure (STP). Because it is a ratio, specific gravity is independent of the system of units used.

- Mathematical definition: S $= \rho_{\text{fluid}} \,/\, \rho_{\text{ref}} = \gamma_{\text{fluid}} \,/\, \gamma_{\text{ref}}$
- For liquids, the reference is water at 4°C: S $= \rho_{\text{liquid}} \,/\, 1000$ kg/m^3
- Dimensionless quantity with no units
- Fluids with S ¡ 1 float on water; fluids with S ¿ 1 sink in water

Practical Significance and Engineering Applications I

These specific properties are vital in the analysis and design of hydraulic machinery, pipeline networks, and open channel flows. For instance, specific weight is directly used in hydrostatic pressure calculations ($p = \gamma * h$) to determine force on dams, gates, and submerged surfaces. Specific gravity simplifies calculations by allowing engineers to quickly determine density or specific weight of any fluid from a single ratio, and specific volume is crucial in pump and turbine design to analyze cavitation and fluid compression.

- Hydrostatic pressure: $P = \gamma * h$
- Manometer analysis: relates height difference to pressure using specific gravity
- Buoyancy force calculation: $F_B = \gamma * V_{submerged}$
- Pumping power requirements: $Power = \gamma * Q * H / \eta$

Temperature and Pressure Dependencies I

The specific properties of fluids are not static; they change with thermal and pressure variations. Liquids are generally assumed to be incompressible, meaning their density, specific weight, and specific volume change negligibly with pressure. However, they do expand with temperature, causing specific weight to decrease and specific volume to increase. Gases are highly compressible, and their properties are governed by the Ideal Gas Law: P $= \rho$ R T, which shows specific weight is directly proportional to pressure and inversely proportional to absolute temperature.

- For liquids: T increases -¿ ρ and γ decrease, v increases
- For liquids: P increases -¿ negligible change in ρ, γ, and v
- For gases: T increases (at constant P) -¿ ρ and γ decrease, v increases
- For gases: P increases (at constant T) -¿ ρ and γ increase, v decreases

Worked Example: Specific Weight and Volume Calculations I

Consider a container filled with 8 liters of a liquid that has a mass of 7.2 kg. Let's calculate its density, specific weight, specific volume, and specific gravity. First, convert volume to cubic meters: V = 8 L = 0.008 m^3. Density: ρ = m/V = 7.2 / 0.008 = 900 kg/m^3. Specific Weight: $\gamma = \rho$ * g = 900 * 9.81 = 8829 N/m^3 (8.83 kN/m^3). Specific Volume: v = 1/ρ = 1/900 = 0.00111 m^3/kg. Specific Gravity: S = ρ / ρ_{water} = 900 / 1000 = 0.90.

- Given: V = 8 L (0.008 m^3), m = 7.2 kg
- Density (ρ) = 900 kg/m^3
- Specific Weight (γ) = 8829 N/m^3
- Specific Volume (v) = 0.00111 m^3/kg
- Specific Gravity (S) = 0.90 (fluid floats on water)

Summary and Key Formulae I

In this lecture, we have defined three key volume-specific properties of fluids. Understanding these properties forms the bedrock of fluid mechanics, enabling the analysis of fluids at rest (hydrostatics) and in motion (hydrodynamics). In hydraulic machinery, these properties dictate pump selection, conduit sizing, and energy transmission efficiency. Always be mindful of the reference temperature when utilizing specific gravity and the local gravitational acceleration when working with specific weight.

- Specific Weight: $\gamma = \mathrm{W/V} = \rho * \mathrm{g}$ [N/m^3]
- Specific Volume: $\mathrm{v} = \mathrm{V/m} = 1/\rho$ [m^3/kg]
- Specific Gravity: $\mathrm{S} = \rho \,/\, \rho_{\text{water at } 4^\circ\text{C}}$ [-]
- Check units and reference standards to avoid dimensional inconsistency