01 The Nature of Fluids

(Water Resources I)

Dave Morgan

Prepared using Lyx, and the Beamer class in $\LaTeX\,2_\varepsilon$,
on September 12, 2007

Recommended Text

A recommended text to accompany these notes is Applied Fluid Mechanics by Mott:

- Read sections:
  1.3, 1.4, 1.6 (omit US units), 1.7, 1.8, 1.9, 1.11
- Study Example Problems: 1.5 - 1.9

Elementary Properties of Fluids

- Fluids can be either liquid or gas
- A liquid tends to flow and conform to the shape of its container
- Liquids are not readily compressible (for the purpose of this course, we consider them to be imcompressible)
- A gas tends to expand to fill the closed container it is in (or to disperse if not contained).
- Gases are readily compressible
- We shall be primarily concerned with liquids

Primary Units

SI units are used. Four primary units will be used extensively in this course:

Quantity	SI unit	Dimension
Length	metre, m	L
Mass	kilogram, kg	M
Time	second, s	T
Temperature	Kelvin, K	θ

(Current and luminosity are the two other primary SI units.)

Derived Units

Quantity	SI Unit	Dimensions
velocity	m/s	LT^{-1}
acceleration	m/s^2	LT^{-2}
force	N, newton $kg{\cdot}m/s^2$	MLT^{-2}
energy (work)	J, joule $N \cdot m$ $kg\, m^2/s^2$	ML^2T^{-2}
power	$N \cdot m/s$ J/s	ML^2T^{-3}
pressure (stress)	Pa, pascal N/m^2 $kg/m/s^2$	$ML^{-1}T^{-2}$

Derived Units:

Quantity	SI Unit	Dimensions
Volume flow rate, Q	m^3/s L/s	L^3T^{-1}
Weight flow rate, W	N/s $kg/m/s^2$	$ML^{-1}S^{-2}$
Mass flow rate, M	kg/s	MT^{-1}
Specific weight, γ	N/m^3	$ML^{-2}T^{-2}$
Density, ρ	kg/m^3	ML^{-3}

Pressure

Pressure is given by:

$$p = \frac{F}{A}$$

It is the force per unit area on a surface, where

$$1\ \mathrm{N/m^2} = 1\ \mathrm{Pa}\ \text{(pascal)}$$

Pressure

Pressure is given by:

$$p = \frac{F}{A}$$

It is the force per unit area on a surface, where

$$1\ \mathrm{N/m^2} = 1\ \mathrm{Pa}\ \text{(pascal)}$$

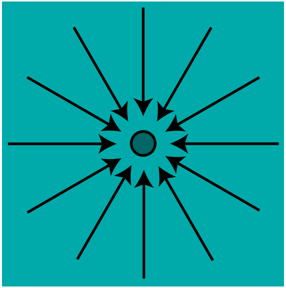
Blaise Pascal (1623 - 1662), after whom the Pascal programming language was named, determined the following principles:

1. Pressure acts uniformly in all directions on a "small" volume of a fluid at rest
2. In a fluid confined by solid boundaries, pressure acts perpendicularly to the boundaries

Pressure acts uniformly in all directions on a small volume of a fluid at rest.

The forces must balance out (i.e. $\Sigma F_x = \Sigma F_y = 0$); otherwise the volume of fluid will not be in equilibrium and cannot remain at rest.

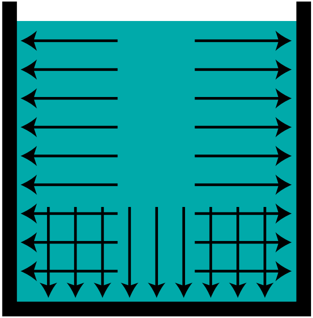
Also, the volume must be sufficiently "small" that we do not have to consider the mass, and therefore the weight, of the volume of fluid. If the weight is not negligible, the upward pressure on the bottom of the volume will have to be greater than the downward pressure on the top of the volume so that $\Sigma F_y = F_{up} - W - F_{down} = 0$.



In a fluid confined by solid boundaries, pressure acts perpendicularly to the boundaries.

Why is this true?

(Consider a small volume of fluid at rest against one of the boundaries? If this volume remains at rest, what are the forces that act upon it?)



Density

Density is mass per unit volume:

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

Density

Density is mass per unit volume:

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

The density of water between $0\,^\circ\text{C}$ and $15\,^\circ\text{C}$ is close to $1000\,\text{kg/m}^3$.
It has a maximum density at $4\,^\circ\text{C}$.
Above $15\,^\circ\text{C}$, the density drops steadily to a density of $958\,\text{kg/m}^3$ at $100\,^\circ\text{C}$.

(There is a table of values for the properties of water at the back of Applied Fluid Mechanics by Mott, or from numerous other sources)

Specific Weight

Specific weight is weight per unit volume:

$$\gamma = \frac{w}{V}$$

Specific Weight

Specific weight is weight per unit volume:

$$\gamma = \frac{w}{V}$$

Water has a specific weight of $9.81\,\mathrm{kN/m^3}$ between $0\,^\circ\mathrm{C}$ and $15\,^\circ\mathrm{C}$.

Specific Weight

Specific weight is weight per unit volume:

$$\gamma = \frac{w}{V}$$

Water has a specific weight of $9.81\,\mathrm{kN/m^3}$ between $0\,^\circ\mathrm{C}$ and $15\,^\circ\mathrm{C}$.

Since $w = mg$, it follows that:

$$\gamma = \frac{w}{V} = \frac{mg}{V} = \rho g$$

Specific gravity is the ratio of the density (or specific weight) of a substance to the density (or specific weight) of water at 4°C.
Then, the specific gravity of a substance s is given by

$$sg = \frac{\gamma_s}{\gamma_{w@4^\circ\mathrm{C}}} = \frac{\rho_s}{\rho_{w@4^\circ\mathrm{C}}}$$

Specific Gravity

Specific gravity is the ratio of the density (or specific weight) of a substance to the density (or specific weight) of water at 4 °C. Then, the specific gravity of a substance s is given by

$$sg = \frac{\gamma_s}{\gamma_{w@4\,^\circ\mathrm{C}}} = \frac{\rho_s}{\rho_{w@4\,^\circ\mathrm{C}}}$$

The density of gasoline at 25 °C is 680 $\mathrm{kg/m^3}$ and the density of water at 4 °C is 1000 $\mathrm{kg/m^3}$. Therefore, the specific gravity of gasoline at 25 °C is $sg = 680/1000 = 0.68$.

Specific Gravity

Specific gravity is the ratio of the density (or specific weight) of a substance to the density (or specific weight) of water at 4°C. Then, the specific gravity of a substance s is given by

$$sg = \frac{\gamma_s}{\gamma_{w@4^\circ\mathrm{C}}} = \frac{\rho_s}{\rho_{w@4^\circ\mathrm{C}}}$$

The density of gasoline at 25°C is 680 $\mathrm{kg/m^3}$ and the density of water at 4°C is 1000 $\mathrm{kg/m^3}$. Therefore, the specific gravity of gasoline at 25°C is $sg = 680/1000 = 0.68$.

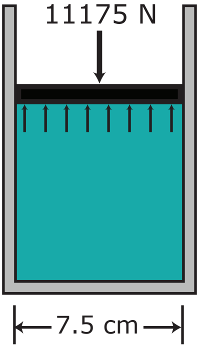
The specific weight of mercury at 25°C is 132.8 $\mathrm{kN/m^3}$ and the specific weight of water at 4°C is 9.81 $\mathrm{kN/m^3}$ so the specific gravity of mercury at 25°C is $sg = 13.54$

Example

Calculate the pressure produced in the oil in a closed cylinder by a piston with diameter 7.5 cm exerting a force of 11 175 N

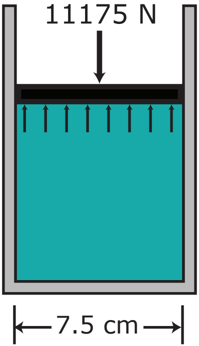
Example

Calculate the pressure produced in the oil in a closed cylinder by a piston with diameter 7.5 cm exerting a force of 11 175 N



Example

Calculate the pressure produced in the oil in a closed cylinder by a piston with diameter 7.5 cm exerting a force of 11 175 N



Solution

$$
\begin{aligned}
p &= \frac{F}{A} \\
&= \frac{11175\ \mathrm{N}}{\pi(0.075)^2/4\ \mathrm{m}^2} \\
&= 2529500\ \mathrm{Pa} \\
&= 2.53\ \mathrm{MPa}
\end{aligned}
$$

Example

Calculate the weight of 1 m^3 of kerosene if it has a mass of 823 kg

Example

Calculate the weight of 1 m^3 of kerosene if it has a mass of 823 kg

Solution

$$\begin{aligned} W &= mg \\ &= 823\,\text{kg} \times 9.81\,\text{m/s}^2 \\ &= 8070\,\text{N} \end{aligned}$$

Note: In general, use 5 significant figures for interim calculations and 3 significant figures for displayed solutions.

Example

Calculate the density and the specific weight of benzene if its specific gravity is 0.876.

Example

Calculate the density and the specific weight of benzene if its specific gravity is 0.876.

Solution

$$\begin{aligned}
0.876 &= \frac{\rho_b}{\rho_{water@4^\circ C}} \\
\rho_b &= 0.876 \times 1000\ \mathrm{kg/m^3} \\
&= 876\ \mathrm{kg/m^3}
\end{aligned}$$

$$\begin{aligned}
0.876 &= \frac{\gamma_b}{\gamma_{water@4^\circ C}} \\
\gamma_b &= 0.876 \times 9.81\ \mathrm{kN/m^3} \\
&= 8.59\ \mathrm{kN/m^3}
\end{aligned}$$

Example

A cylindrical tank with diameter 12.0 m contains water at 20°C to a depth of 4.0 m. If the water is heated to 65°C, what is the depth of the water? (Assume that the tank dimensions remain constant and that there are no losses due to evaporation.)

Example

A cylindrical tank with diameter 12.0 m contains water at 20°C to a depth of 4.0 m. If the water is heated to 65°C, what is the depth of the water? (Assume that the tank dimensions remain constant and that there are no losses due to evaporation.)

Solution

Volume at 20°C:

$$V_{20} = \frac{\pi d^2 h_{20}}{4} = \frac{\pi (12.0\,\mathrm{m})^2 (4.0\,\mathrm{m})}{4} = 452.39\,\mathrm{m}^3$$

Mass of water in the tank:

$$m = \rho V_{20} = 998\,\mathrm{kg/m}^3 \times 452.39\,\mathrm{m}^3 = 451490\,\mathrm{kg}$$

...continued

Solution (continued)

$$V_{20} = \frac{\pi d^2 h_{20}}{4} = \frac{\pi (12.0\ \text{m})^2 (4.0\ \text{m})}{4} = 452.39\ \text{m}^3$$

$$m = \rho_{20} V_{20} = 998\ \text{kg}/\text{m}^3 \times 452.39\ \text{m}^3 = 451490\ \text{kg}$$

Volume at 65°C:

$$V_{65} = \frac{m}{\rho_{65}} = \frac{451490\ \text{kg}}{981\ \text{kg}/\text{m}^3} = 460.23\ \text{m}^3$$

Depth at 65°C:

$$h_{65} = \frac{4 V_{65}}{\pi d^2} = \frac{4 \times 460.23\ \text{m}^3}{\pi (12.0)^2} = 4.0639\ \text{m}$$

The depth at 65°C is 4.06 m