HCM UNIVERSITY OF TECHNOLOGY

FLUID MECHANICS

CI2003

Assignment

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PhD

Fluid Mechanics

Department

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Properties of Fluids

Q1.1

A steel vessel of 1% increase in volume when the pressure is increased by 70 MPa. At standard condition (pressure $P = 101.3\,\text{KPa}$), the vessel is filled with $m = 450\,\text{kg}$ of water ($\rho = 1000\,\text{kg/m}^3$). Given bulk modulus of elasticity, $\kappa = 2.06 \times 10^9\,\text{Pa}$. Compute the mass of water to add into the vessel to increase the pressure to 70 MPa.

Ans:

$$V = \frac{m}{\rho} = \frac{450}{1000} = 0.45\ (\text{m}^3)$$

$$\kappa = -V\frac{dP}{dV} \Rightarrow dm = \rho dV = -\rho V \frac{dP}{\kappa}$$

$$= -1000 \times 0.45 \times \frac{101.3 \times 10^3 - 70 \times 10^6}{2.06 \times 10^9} = 15.27\ (\text{kg})$$

Q1.2

Determine the change in volume of $V_i = 3\,\text{m}^3$ of air when the pressure increases from $P_i = 100\,\text{kPa}$ to $P_f = 500\,\text{kPa}$. Air is at $T = 23\,^\circ\text{C}$ (assume ideal gas)

Ans:

Assume isothermal condition: $P_i V_i = P_f V_f$

$$\Rightarrow \Delta V = V_f - V_i = \frac{P_i V_i}{P_f} - V_i = \frac{100 \times 3}{500} - 3 = -2.4\ (\mathrm{m}^3)$$

Q1.3

They compress the air into a vessel having volume, $V_1 = 0.3\,\mathrm{m}^3$ under pressure $P_1 = 100\,\mathrm{at}$. After a period of leakage, the air pressure in the vessel is lowered to $P_2 = 90\,\mathrm{at}$. Regardless of the deformation of the vessel, determine the volume of air that is leaked during that period (corresponding to the atmospheric pressure, 1 atm), if the constant temperature and atmospheric pressure are considered to be at 1 at.

Ans:

For ideal gas, $\kappa = P_2 = -V_1 \dfrac{dP}{d_V}$

$$\Rightarrow dV = -\frac{V_1}{P_2} dP = -\frac{0.3}{90}(90 - 100 - 1) = -0.0367\ (\mathrm{m}^3)$$

Q1.4

A diameter piston $d = 50\,\mathrm{mm}$ moves evenly in a cylinder $D = 50.1\,\mathrm{mm}$. Determine the decrease in force acting on the piston (as a percentage) when the speed decreases by 5%.

Ans:

Assume constant speed: $\dfrac{\Delta V}{V_1} = -5\%$

We also have $\tau = \dfrac{F}{A} = \mu \dfrac{du}{dy} = \mu \dfrac{V}{l} \Rightarrow \dfrac{F_1}{V_1} = \dfrac{F_2}{V_2} = \mu \dfrac{A}{l}$

From the relation: $\dfrac{\Delta F}{F_1} = \dfrac{\Delta V}{V_1} = -5\%$

Q1.5

A machine axis having diameter, $D = 75\,\text{mm}$, with uniform movement with $V = 0.1\,\text{m/s}$ under the force, $F = 100\,\text{N}$. The lubricating layer thickness, l in the bearing is $l = 0.07\,\text{mm}$. Length of bearing $L = 200\,\text{mm}$. Determine oil dynamic viscosity.

Ans:

$A = (D{+}2l)\pi{\times}L = (75{+}2{\times}0.07)\pi{\times}200 = 47211.85\ (\text{mm}^3) = 4.72{\times}10^{-5}\ (\text{m}^3)$

$\tau = \dfrac{F}{A} = \mu\dfrac{V}{l} \Rightarrow \mu = \dfrac{F}{A}\dfrac{l}{V} = \dfrac{100}{4.72\times10^{-5}} \times \dfrac{0.07\times10^{-3}}{0.1} = 1.483\ (\text{kg/m}\cdot\text{s})$

Q1.9

Determine the frictional force at the inner wall of a water supply pipe segment at $T = 20\,°\text{C}$, radius $R = 80\,\text{mm} = 0.08\,\text{m}$, $L = 10\,\text{m}$. The velocity at the points on the pipe cross-section varies according to the following:

$$u(r) = 0.5\left(1 - \frac{r^2}{R^2}\right)$$

where r is the radius of considered point.

Ans:

From table at $T = 20\,°\text{C} \Rightarrow \mu = 1.002\times10^{-3}\ (\text{kg/m}\cdot\text{s})$

$A = 2\pi RL = 2\pi\times0.08\times10 = 5.03\ (\text{m}^2)$

$F = \tau A = \mu\dfrac{du}{dr}A = \mu\dfrac{(-2)R}{R^2}A$

$= 1.002\times10^{-3}\times\dfrac{(-2)\times0.08}{0.08^2}\times5.03 = -0.126\ (\text{N})$

Q1.10

Determine the gauge pressure inside a water drop of diameter $d = 2\,\text{mm} = 0.002\,\text{m}$. The temperature of water is $T = 25\,°\text{C}$.

Ans:

From table at $T = 25\,°\text{C} \Rightarrow \sigma_s = 0.072$ (N/m)
$$P_g = \Delta P_{droplet} = \frac{2\sigma_s}{d/2} = \frac{2 \times 0.072}{0.002/2} = 144 \text{ (Pa)}$$

Q1.11

A gas has a molar mass of $R = 32\,\text{kg/mol}$ under a pressure condition of $P = 5\,\text{at} = 490332.5\,\text{Pa}$, a temperature of $T = 30\,°\text{C}$

1. Determine the gas density.
2. Determine the density of this gas if $P = const$, while temperature drops to $T_f = 15\,°\text{C}$.
3. Determine the density of this gas if holding $T = const$, while the pressure drops to $P_f = 2\,\text{at}$.

Ans:

1. $P = \rho RT \Rightarrow \rho = \dfrac{P}{RT} = \dfrac{32}{490332.5 \times (30 + 273)} = 0.215 \times 10^{-6}\ (\text{kg/m}^3)$
2. adiabatic condition
   $\rho T = \rho_f T_f \Rightarrow \rho_f = \dfrac{\rho T}{T_f} = \dfrac{0.215 \times 10^{-6} \times (30 + 273)}{15 + 273} = 0.226{\times}10^{-6}\ (\text{kg/m}^3)$
3. isothermal condition
   $\dfrac{P}{\rho} = \dfrac{P_f}{\rho_f} \Rightarrow \rho_f = \dfrac{\rho P_f}{P} = \dfrac{0.215 \times 10^{-6} \times 2}{5} = 0.086 \times 10^{-6}\ (\text{kg/m}^3)$

Q1.12

A liquid is compressed in a cylinder, the water initially has a volume of $V_o = 4\,\text{l}$ at normal pressure, $P_o = 1\,\text{at} = 98066.5\,\text{Pa}$. The pressure in the cylinder increases to $p_1 = 6\,\text{at}$, the water volume decreases by $1\,\text{cm}^3$.

1. Compute the bulk modulus of elasticity of water.

2. If the pressure in the cylinder increases to 20 at, calculate the volume of water V_f in the cylinder.

3. Calculate the pressure in the cylinder, if the volume of the water is reduced by 0.1%.

Ans:

1. $\kappa = -V_o \dfrac{dP}{dV} = -4 \times 10^{-3} \times \dfrac{6 \times 98066.5}{(-1) \times 10^{-6}} = 2.36 \times 10^9 \text{ (Pa)}$
2. Cylinder increase pressure to 20 at
$\Rightarrow dV = V_f - 4 \times 10^{-3} = \dfrac{-20}{6} = -3.33 \text{ (cm}^3\text{)} = -3.33 \times 10^{-3} \text{ (l)}$
$\Rightarrow V_f = 3.997 \text{ (l)}$
3. $dP = P_f - P_o = -\kappa \times \dfrac{dV}{V_o} = -2.36 \times 10^9 \times \dfrac{(-0.1)}{100} = 2.36 \times 10^6 \text{ (Pa)}$
$\Rightarrow P_f = 2.458 \text{ (MPa)}$

Q1.13

The air moving through a narrow tube into a water tank forms a stream of bubbles $d = 3$ mm in diameter. Calculate the difference between air pressure in the narrowed section and surrounding water pressure. Give the surface tension of water $\sigma_s = 0.0728$ N/m.

Ans: