**1**

 **Fluid Mechanics Dr.Abdulkareem Abdulwahab**

 **Chapter One**

 **Properties of Fluids**

* 1. **/ Introduction :**

 **Fluid mechanics is that branch of science which deals with the behavior of the fluids ( liquids or gases ) at rest as well as in motion.**

* 1. **/ Properties of fluids :**
1. **Mass density (ρ )(ro) :**

**It is defined as the ratio of the mass of the fluid to its volume .**

**ρ =** $\frac{m}{V}$ **kg/m3 ( 1.1)**

 **in which ,**

 **m mass ( kg ) .**

 **v volume ( m3) .**

**ρ of water is 1 gm/cm3 or 1000 kg/ m3 .**

1. **Specific weight or Weight density (** $γ$ **) ( gama) :**

**It is define as the ratio of a weight of the fluid to its volume .**

$γ= $$\frac{W}{V}$ **N /m3 (1.2 )**

 **In which ,**

 **W weight N ( Newton )**

 **V volume m3**

 **From Second law of Newton ( F = ma ) , in which**

 **F - Force ( N ) , m – mass ( kg ) , a – acceleration ( m/s2 ) ,**

 **If the force is weight ( w ) , the acceleration ( a ) becomes ( g ) ,**

**2**

 **g - gravity acceleration ( m /s2 ) , therefore from second law of Newton ( w = m g ) , substituting this value in eq.(1.2 ) ,**

**( 1 )**

$γ=\frac{mg}{v}$ **, from eq. (1.1) ( ρ =** $\frac{m}{v}$ **)**

$γ=$**ρ g N/m3 ( 1.3 )**

**Therefore , if the value of g is 9.81 m /s2 ,** $γ$**of water is 1000 \* 9.81 = 9810 N/m3 .**

1. **Specific volume ( vs ):**

 **It is defined as the volume of a fluid occupied by a unit mass or volume per unit mass of a fluid .**

 **vs =** $\frac{volume}{mass}$ **=** $\frac{1}{\frac{mass}{volume}}$**=** $\frac{1}{ρ}$ **m3 / kg ( 1. 4 )**

1. **Specific gravity or Relative density ( S ) :**

**It is defined as the ratio of the weight density or mass density of a fluid to the weight density or mass density of water ( for liquids ) , and for gases to the weight density or mass density of air .**

**S ( for liquids ) =** $\frac{γ of liquid}{γ of water}$ **=** $\frac{ρ of liquid}{ρ of water}$ **( 1. 5 )**

**S ( for gases ) =** $\frac{γ of gas}{γ of air}$ **=** $\frac{ρ of gas}{ρ of air}$ **(1. 6 )**

 **( S is without units )**

**5 . Viscosity(** $μ$ **)( mu ) :**

 **Viscosity is defined as the property of a fluid which offers resistance to the movement of one layer of fluid over another adjacent layer of the fluid.**

 **When two layers of a fluid , a distance ( dy ) apart , move one over the other at different velocities , say u and u + du as shown in Fig.( 1.1) , the viscosity together with relative velocity causes a shear stress acting between the fluid layers. This shear stress is proportional to the rate of change of velocity with respect to y. It is denoted by symbol** $τ$ **called Tau .**

**3**

****

$$τ ∝ \frac{du}{dy }$$

$τ = μ\frac{du}{dy}$**( Newton׳s law of viscosity ) ( 1. 7)**

 **Where , μ ( called mu ) is the constant of proportionality and is known as dynamic viscosity ,** $\frac{du}{dy}$ **represents the rate of shear deformation or velocity gradient.**

 **From eq. ( 1.7) μ =** $\frac{τ}{\frac{du}{dy}}$ **( 1.8 )**

 **Unit of viscosity in SI unit is ( N s / m2 ) or ( Pa.s ) .**

 **The unit of viscosity in ( C G S ) ( centimeter – Gram – Second ) is called Poise which is equal to** $\frac{dyne-second}{cm^{2}}$ **.**

 **( One poise = 0.1 N.s / m2 ) and ( one poise = 100 centipoise )**

**Kinematic Viscosity ( ν )(nu)is defined as the ratio between the dynamic viscosity and mass density of fluid :**

**ν =** $\frac{viscosity}{density}$ **=** $\frac{μ}{ρ}$ **(1.9)**

**The unit of kinematic viscosity in SI unit is ( m2 / s ) , and in ( CGS unit ) is Stoke , one Stoke is one cm2/ s and equal 10-4 m2/s .**

 **( One Stoke = 100 centistoke ) .**

**Variation of Viscosity with temperature :**

1. **The viscosity of liquid decreases with increase of temperature.**
2. **The viscosity of gases increase with increase of temperature.**

**4**

* 1. **/ Thermodynamic properties :**

**Gases are compressible fluids and hence thermodynamic properties play an important role , with the change of pressure and temperature , the gases undergo large variation in density. The relationship between absolute pressure , specific volume, absolute temperature ( T) of a gas is given by the equation of state as , ( R is gas constant ) :**

**pvs = R T ( 1.10)**

$\frac{p}{ρ}$ **= R T (1.11 )**

**Units of R in SI unit ( J /kg.k ) ( R for air 287 J/kg.k )**

1. **Isothermal process :**

**If the change in density occurs at constant temperature , then process is called isothermal process and relationship between pressure and density is given by :**

$\frac{p}{ρ }=constant $**(1.12)**

1. **Adiabatic process :**

**If the change in density occurs with no heat exchange to and from gas , the process is called adiabatic .**

$\frac{p}{ρ^{k }}$ **= constant (1.13)**

$where$**,**

 **p is pressure .**

 **k is ratio of specific heat of a gas at constant pressure ( cp ) and constant volume ( cv ) ( k = cp / cv ) . ( k for air is 1.4 ).**

 **1.4/ Compressibility and Bulk Modulus:**

 **Compressibility is the reciprocal of the bulk modulus of elasticity ( K ) which is defined as the ratio of compressive stress to volumetric**

**5**

****

**Fig.(1.2)**

 **Consider a cylinder fitted with a piston as shown in Fig.(1.2),**

 **Let V is volume of gas enclosed in the cylinder.**

 **P is pressure of gas when volume is V.**

 **Let the pressure is increased to p + dp , the volume of gas decrease from V to V – dV ,**

**Volumetric strain = -** $\frac{dv}{v}$

**Bulk modulus ( K ) =** $\frac{increase of pressure}{volumetric strain}$**=** $\frac{dp}{\frac{-dv}{v}}$ **=** $\frac{-dp}{dv} v $**(1.14)**

 **Compressibility =** $\frac{1}{K}$ **( 1.15 )**

 **For Isothermal process ,**

**K = P ( P is pressure )**

 **For Adiabatic process ,**

**K = pk**

 **( where k is ratio of specific heat** $\frac{c\_{p}}{c\_{v}}$**)**

**1.5/ Surface Tension and Capillarity :**

 **Surface tension is defined as the tensile force acting on the surface of a liquid in contact with a gas or on the surface between two immiscible liquids . It is denoted by Greek letter σ ( called sigma ) .**

**The phenomenon of surface tension is explained by Fig.( 1. 3 ) .**

**6**

****

 **Fig.(1.3) Surface tension**

 **Consider three molecules A , B , C of a liquid in a mass of liquid. The molecule A is attracted in all directions equally by the surrounding molecules of the liquid. Thus the resultant force acting on the molecule A is zero. But the molecule B , which is situated near the free surface, is acted upon by upward and downward forces which are unbalanced. Thus a net resultant force on molecule B is acting in a downward direction . The molecule C , situated on the free surface of liquid, does experience a resultant downward force. All the molecules on the free surface experience a downward force. Thus the free**

**surface of the liquid acts like a very thin film under a tension of the surface of**

**the liquid act as though it is an elastic membrane under tension .**

**Types of Surface tensions**

1. **Surface tension on liquid droplet :**

**Consider a small spherical droplet of a liquid of radius r , let the droplet is cut into two halves , as shown in Fig.( 1.4 ) . ( 1 ) tensile force due to surface tension acting around the circumference of cut portion as shown in Fig.( 1.4 ) , and this is equal to :**

 **Tensile force = σ . Circumference = σ . π d**

 **Pressure force = p .** $\frac{π}{4}$**d2**

 **These forces will be equal and opposite under equilibrium conditions , i. e . ,**

**P.** $\frac{π}{4}$**d2 = σ . π d**

 **Then ,**

**σ =** $\frac{P d}{4}$ **N / m ( 1.16)**

**7**

****

**Fig.(1.4) Forces on droplet**

1. **Surface tension on a hollowBubble :**

 **A hollow bubble like a soap bubble in air has two surfaces in contact with air, one inside and other outside .Thus two surfaces are subjected to surface tension. In such case, we have ,**

**P.** $\frac{π}{4}$**d2 = 2. σ π d**

**σ =** $\frac{P d}{8} $**N / m ( 1. 17 )**

1. **Surface Tensionon a liquid Jet :**

 **Consider a liquid jet of diameter ( d ) and length ( L ) as shown in Fig.( 1.5) ,**

****

**Fig.(1.5) Forces on liquid jet**

 **Consider the equilibrium of the semi jet , we have ,**

 **Force due to pressure = P . Ld**

 **Force due to surface tension = σ . 2L**

 **Equating the two forces ,**

 **P.Ld = σ . 2L**

 **σ =** $\frac{Pd}{2}$ **N/m (1.18)**

**8**

**Capillarity :**

 **Capillarity is defined as a phenomenon of rise or fall of a liquid surface in a small tube relative to the adjacent general level of liquid when the tube is held vertically in the liquid. The rise of liquid surface is known as capillary rise , while the fall of the liquid surface is known as capillary depression. Its value depends upon the specific weight of the liquid , diameter of the tube and surface tension of liquid.**

**Expression for capillary Rise :**

****

 **Fig.(1.6) Capillary rise**

**Consider a glass tube of small diameter ( d ) opened at both ends and inserted in a liquid( water) ,as shown in Fig.(1.6). The liquid will rise in the tube above the level of the liquid.**

 **Let h is height of the liquid in the tube . Under a state of equilibrium , the weight of liquid of height h is balanced by the force at the surface of the liquid in the tube. But the force at the surface of the liquid in the tube is due to surface tension.**

**The weight of liquid of height h in the tube = Area of tube . h. ρg.**

 **=** $\frac{π}{4}$**d2 h ρ g**

**Vertical component of the surface tensile force = σ . Circumference.cos ϴ**

 **= σ . πd . cos ϴ**

 **For equilibrium , equating two equations :**

**9**

$\frac{π}{4}$**d2h ρ g = σ π d cos ϴ**

**h =** $\frac{4σ cosθ}{ρ g d}$ **( 1. 19)**

 **In which ( ϴ ) angle of contact between liquid and glass tube .**

**The value of ϴ between water and clean glass tube is equal to zero , ( cos ϴ= 1 ) , then , the equation (1.19 ) becomes :**

**h =** $\frac{4 σ }{ρ g d }$ **( 1.20 ) ( if the liquid is water and tube is glass)**

**Expression for Capillary Fall :**

**If the glass tube is dipped in mercury , the level of mercury is the**

 **tube will be lower than the general level of the outside as shown in Fig.(1.7)**

****

 **Fig.(1.7)**

 **Let h is height of depression in tube .**

 **There are two forces are acting on the mercury inside the tube.**

1. **Force due to surface tension acting in the downward direction**

**= σ π d cos ϴ**

1. **. Force due to hydrostatic force acting upward = p .** $\frac{π}{4}$ **d2**

**= ρgh .** $\frac{π}{4}$ **d2**

 **Then in equilibrium , equating the two forces ,**

 **ρ g h.**$\frac{π}{4}$ **d2 = σ π d cos ϴ**

 **h =** $\frac{4σ cosθ}{ρ g d}$ **( 1.21)**

**10**

 **( value of ϴ for mercury and glass tube is 1280 )**

**1.6/ Vapor pressure and Cavitation :**

**A change from the liquid state to the gaseous state is known as vaporization. Consider a liquid (say water) which is confined in closed vessel . Let the temperature of liquid is 200c and pressure is atmospheric , if the pressure above the liquid surface is reduced by vacuum blower, this value of reduce of pressure reach to vapor pressure or less than the vapor pressure , the boiling of the liquid will start , though the temperature of the liquid is 200c .**

 **Because , the vaporization takes place , when vapor molecules get accumulated in the space between the free liquid surface and top of the vessel , these accumulated of vapor molecules , exert a pressure on the liquid surface .**

**this pressure is known as Vapor pressure of the liquid ( at this pressure , the liquid is converted into vapor ).**

 **If the liquid ( say water) is flowing in a system , when the velocity of water is increased , the pressure is decreased , may be this decreasing of pressure reach to the value of vapor pressure of water , then the water start to boiling ( molecules of water convert to vapor bubbles ) , if these vapor bubbles flowing to the region of higher pressure , they are sudden collapsing , when the collapsing of these vapor bubbles , very high pressure and stress are created , the metallic surfaces which the liquid is flowing is pitting and damage , this process is known Cavitation .**