

Chapter 1

Specific Weight

$$\gamma = \rho g$$

Ideal Gas Law

$$\rho = \frac{p}{RT}$$

Newtonian Fluid Shear Stress

$$\tau = \mu \frac{du}{dy}$$

Bulk Modulus

$$E_v = - \frac{dp}{dV/V}$$

Speed of Sound

$$c = \sqrt{\frac{dp}{d\rho}}$$

Capillary Rise in a Tube

$$h = \frac{2\sigma \cos \theta}{\gamma R}$$

Chapter 2

Hydrostatic Pressure

$$\frac{dp}{dz} = -\gamma$$

Force acting a plane surface

$$F_R = \gamma \sin \theta \int_A y dA$$

$$F_R = \gamma h_c A$$

Effective location of hydrostatic force

$$y_R = \frac{\int_A y^2 dA}{y_c A}$$

Buoyant Force

$$F_B = \gamma V$$

Chapter 3

Streamwise Acceleration

$$a_s = V \frac{\partial V}{\partial s}, \quad a_n = \frac{V^2}{\mathcal{R}}$$

Bernoulli equation

$$p + \frac{1}{2} \rho V^2 + \gamma z = \text{constant along streamline}$$

Flow Meter

$$Q = A_2 \sqrt{\frac{2(p_1 - p_2)}{\rho [1 - (A_2/A_1)^2]}}$$

Sluice Gate

$$Q = z_2 b \sqrt{\frac{2g(z_1 - z_2)}{1 - (z_2/z_1)^2}}$$

Equation Sheet 2

Reynold Transport Theorem

$$\frac{DM_{\text{sys}}}{Dt} = \frac{\partial M_{\text{cv}}}{\partial t} + \rho_2 A_2 V_2 - \rho_1 A_1 V_1$$

Chapter 5 – Control Volume Analysis

Conservation of Mass

$$\frac{\partial}{\partial t} \int_{\text{cv}} \rho dV + \sum \rho_{\text{out}} A_{\text{out}} V_{\text{out}} - \sum \rho_{\text{in}} A_{\text{in}} V_{\text{in}} = 0$$

Conservation of Momentum

$$\frac{\partial}{\partial t} \int_{\text{cv}} V \rho dV + \sum V_{\text{out}} \rho_{\text{out}} A_{\text{out}} V_{\text{out}} - \sum V_{\text{in}} \rho_{\text{in}} A_{\text{in}} V_{\text{in}} = \sum F_{\text{contents CV}}$$

Moment of Momentum

$$\sum (\mathbf{r} \times \mathbf{V})_{\text{out}} \rho_{\text{out}} A_{\text{out}} V_{\text{out}} - \sum (\mathbf{r} \times \mathbf{V})_{\text{in}} \rho_{\text{in}} A_{\text{in}} V_{\text{in}} = \sum (\mathbf{r} \times \mathbf{F})_{\text{contents of the control volume}}$$

Torque

$$T_{\text{shaft}} = -\dot{m}_{\text{in}}(\pm r_{\text{in}} V_{\theta \text{in}}) + \dot{m}_{\text{out}}(\pm r_{\text{out}} V_{\theta \text{out}})$$

Power

$$\dot{W}_{\text{shaft}} = -\dot{m}_{\text{in}}(\pm U_{\text{in}} V_{\theta \text{in}}) + \dot{m}_{\text{out}}(\pm U_{\text{out}} V_{\theta \text{out}})$$

Work Per Unit Mass

$$w_{\text{shaft}} = -(\pm U_{\text{in}} V_{\theta \text{in}}) + (\pm U_{\text{out}} V_{\theta \text{out}})$$

Energy Equation

$$\frac{p_{\text{out}}}{\rho} + \frac{V_{\text{out}}^2}{2} + gz_{\text{out}} = \frac{p_{\text{in}}}{\rho} + \frac{V_{\text{in}}^2}{2} + gz_{\text{in}} + w_{\text{shaft net in}} - \text{loss}$$

In terms of head

$$\frac{p_{\text{out}}}{\gamma} + \frac{V_{\text{out}}^2}{2g} + z_{\text{out}} = \frac{p_{\text{in}}}{\gamma} + \frac{V_{\text{in}}^2}{2g} + z_{\text{in}} + h_s - h_L$$

$$h_s = w_{\text{shaft net in}}/g = \frac{\dot{W}_{\text{shaft net in}}}{\dot{m}g} = \frac{\dot{W}_{\text{shaft net in}}}{\gamma Q}$$

Chapter 6

Volumetric Rate of Dilatation

$$\frac{1}{\delta V} \frac{d(\delta V)}{dt} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = \nabla \cdot \mathbf{V}$$

Vorticity

$$\omega_z = \frac{1}{2} \left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \right)$$

$$\omega_x = \frac{1}{2} \left(\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z} \right)$$

$$\omega_y = \frac{1}{2} \left(\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} \right)$$

Strain rate

$$\dot{\gamma} = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}$$

Conservation of Mass

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$$

Cylindrical

$$\frac{\partial \rho}{\partial t} + \frac{1}{r} \frac{\partial(r\rho v_r)}{\partial r} + \frac{1}{r} \frac{\partial(\rho v_\theta)}{\partial \theta} + \frac{\partial(\rho v_z)}{\partial z} = 0$$

Streamfunctions

$$u = \frac{\partial \psi}{\partial y} \quad v = -\frac{\partial \psi}{\partial x}$$

$$v_r = \frac{1}{r} \frac{\partial \psi}{\partial \theta} \quad v_\theta = -\frac{\partial \psi}{\partial r}$$

Navier Stokes Equations

$$\rho \left(\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right) = -\frac{\partial p}{\partial x} + \rho g_x + \mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right)$$

$$\rho \left(\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} \right) = -\frac{\partial p}{\partial y} + \rho g_y + \mu \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2} \right)$$

$$\rho \left(\frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} \right) = -\frac{\partial p}{\partial z} + \rho g_z + \mu \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2} \right)$$

Navier Stokes Equations (Cylindrical)

$$\begin{aligned} \rho \left(\frac{\partial v_r}{\partial t} + v_r \frac{\partial v_r}{\partial r} + \frac{v_\theta}{r} \frac{\partial v_r}{\partial \theta} - \frac{v_\theta^2}{r} + v_z \frac{\partial v_r}{\partial z} \right) \\ = -\frac{\partial p}{\partial r} + \rho g_r + \mu \left[\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial v_r}{\partial r} \right) - \frac{v_r}{r^2} + \frac{1}{r^2} \frac{\partial^2 v_r}{\partial \theta^2} - \frac{2}{r^2} \frac{\partial v_\theta}{\partial \theta} + \frac{\partial^2 v_r}{\partial z^2} \right] \end{aligned}$$

$$\begin{aligned} \rho \left(\frac{\partial v_\theta}{\partial t} + v_r \frac{\partial v_\theta}{\partial r} + \frac{v_\theta}{r} \frac{\partial v_\theta}{\partial \theta} + \frac{v_r v_\theta}{r} + v_z \frac{\partial v_\theta}{\partial z} \right) \\ = -\frac{1}{r} \frac{\partial p}{\partial \theta} + \rho g_\theta + \mu \left[\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial v_\theta}{\partial r} \right) - \frac{v_\theta}{r^2} + \frac{1}{r^2} \frac{\partial^2 v_\theta}{\partial \theta^2} + \frac{2}{r^2} \frac{\partial v_r}{\partial \theta} + \frac{\partial^2 v_\theta}{\partial z^2} \right] \end{aligned}$$

$$\begin{aligned} \rho \left(\frac{\partial v_z}{\partial t} + v_r \frac{\partial v_z}{\partial r} + \frac{v_\theta}{r} \frac{\partial v_z}{\partial \theta} + v_z \frac{\partial v_z}{\partial z} \right) \\ = -\frac{\partial p}{\partial z} + \rho g_z + \mu \left[\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial v_z}{\partial r} \right) + \frac{1}{r^2} \frac{\partial^2 v_z}{\partial \theta^2} + \frac{\partial^2 v_z}{\partial z^2} \right] \end{aligned}$$

Chapter 7

Reynolds Number

$$Re = \frac{VL\rho}{\mu}$$

Froude Number

$$Fr = \frac{V}{\sqrt{gL}}$$

Chapter 8

Head Loss due to Major Losses

$$h_{L,major} = \frac{l}{D} \frac{V^2}{2g} f\left(Re, \frac{\varepsilon}{D}\right)$$

Approximate formulas for friction factor

$$f = \frac{64}{Re} \quad \frac{1}{\sqrt{f}} = -1.8 \log \left[\left(\frac{\varepsilon/D}{3.7} \right)^{1.11} + \frac{6.9}{Re} \right]$$

Laminar

Turbulent

Head Loss due to Minor Losses

$$h_{L,min} = \sum K_L \frac{V^2}{2g}$$

Volume Flowrate for Orifice

$$Q = CQ_{ideal} = CA_0 \sqrt{\frac{2(p_1 - p_2)}{\rho(1 - \beta^4)}}$$

TABLE 1.5
Approximate Physical Properties of Some Common Liquids (SI Units)

Liquid	Temperature (°C)	Density, ρ (kg/m ³)	Specific Weight, γ (kN/m ³)	Dynamic Viscosity, μ (N · s/m ²)	Kinematic Viscosity, ν (m ² /s)	Surface Tension, ^a σ (N/m)	Vapor Pressure, P_v [N/m ² (abs)]	Bulk Modulus, ^b E_v (N/m ²)
Carbon tetrachloride	20	1,590	15.6	9.58 E-4	6.03 E-7	2.69 E-2	1.3 E+4	1.31 E+9
Ethyl alcohol	20	789	7.74	1.19 E-3	1.51 E-6	2.28 E-2	5.9 E+3	1.06 E+9
Gasoline ^c	15.6	680	6.67	3.1 E-4	4.6 E-7	2.2 E-2	5.5 E+4	1.3 E+9
Glycerin	20	1,260	12.4	1.50 E+0	1.19 E-3	6.33 E-2	1.4 E-2	4.52 E+9
Mercury	20	13,600	133	1.57 E-3	1.15 E-7	4.66 E-1	1.6 E-1	2.85 E+10
SAE 30 oil ^c	15.6	912	8.95	3.8 E-1	4.2 E-4	3.6 E-2	—	1.5 E+9
Sea water	15.6	1,030	10.1	1.20 E-3	1.17 E-6	7.34 E-2	1.77 E+3	2.34 E+9
Water	15.6	999	9.80	1.12 E-3	1.12 E-6	7.34 E-2	1.77 E+3	2.15 E+9

^aAt constant with air

TABLE 1.7
Approximate Physical Properties of Some Common Gases at Standard Atmospheric Pressure (SI Units)

Gas	Temperature (°C)	Density, ρ (kg/m ³)	Specific Weight, γ (N/m ³)	Dynamic Viscosity, μ (N · s/m ²)	Kinematic Viscosity, ν (m ² /s)	Gas Constant, ^a R (J/kg · K)	Specific Heat Ratio, ^b k
Air (standard)	15	1.23 E+0	1.20 E+1	1.79 E-5	1.46 E-5	2.869 E+2	1.40
Carbon dioxide	20	1.83 E+0	1.80 E+1	1.47 E-5	8.03 E-6	1.889 E+2	1.30
Helium	20	1.66 E-1	1.63 E+0	1.94 E-5	1.15 E-4	2.077 E+3	1.66
Hydrogen	20	8.38 E-2	8.22 E-1	8.84 E-6	1.05 E-4	4.124 E+3	1.41
Methane (natural gas)	20	6.67 E-1	6.54 E+0	1.10 E-5	1.65 E-5	5.183 E+2	1.31
Nitrogen	20	1.16 E+0	1.14 E+1	1.76 E-5	1.52 E-5	2.968 E+2	1.40
Oxygen	20	1.33 E+0	1.30 E+1	2.04 E-5	1.53 E-5	2.598 E+2	1.40

^aValues of the gas constant are independent of temperature.

^bValues of the specific heat ratio depend only slightly on temperature.