
UNIVERSITI SAINS MALAYSIA

First Semester Examination
2015/2016 Academic Session

December 2015 / January 2016

EKC 212 – Fluids Flow For Chemical Engineering
[Aliran Bendalir Kejuruteraan Kimia]

Duration : 3 hours
[Masa : 3 jam]

Please check that this examination paper consists of NINE pages of printed material and NINE pages of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi SEMBILAN muka surat yang bercetak dan SEMBILAN muka surat Lampiran sebelum anda memulakan peperiksaan ini.]

Instructions: Answer **ALL** (5) questions.

Arahan: Jawab **SEMUA** (5) soalan.]

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai.]

Answer ALL questions.

1. A U-tube manometer is connected to a closed tank as shown in Figure Q.1. The air pressure in the tank is 0.50 psi and the liquid in the tank is oil ($\gamma = 54.0 \text{ lb/ft}^3$). The pressure at point *A* is 2.00 psi. Determine the following:

[a] The depth of oil, *z* (in m).

[3 marks]

[b] The differential reading, *h* (in m), on the manometer.

[5 marks]

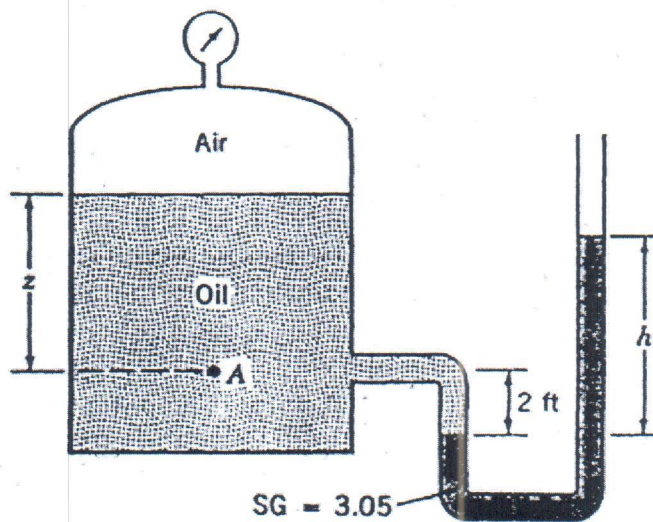


Figure Q.1

Jawab SEMUA soalan.

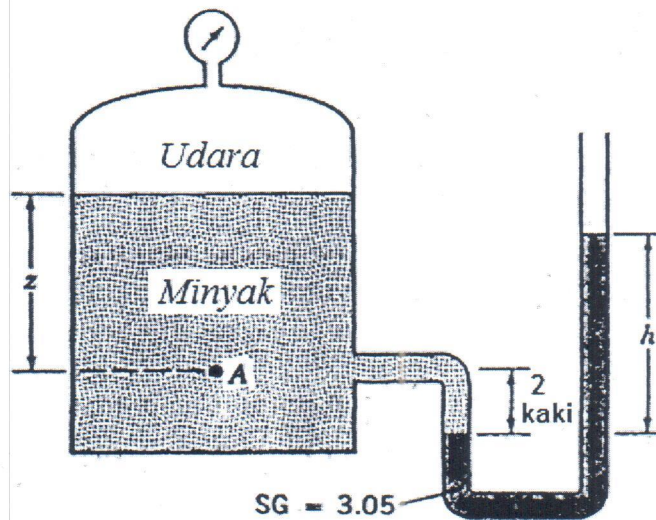
1. Manometer tiub-U dihubungkan kepada tangki tertutup seperti yang ditunjukkan dalam Rajah S.1. Tekanan udara di dalam tangki ialah 0.5 psi dan cecair di dalam tangki ialah minyak ($\gamma = 54.0 \text{ lb/kaki}^3$). Tekanan pada titik A ialah 2.00 psi. Tentukan yang berikut:

[a] Kedalaman minyak, z (dalam m)

[3 markah]

[b] Bacaan perbezaan, h (dalam m), pada manometer.

[5 markah]



Rajah S.1.

2. Figure Q.2 shows that water at 20°C is being pumped from a reservoir on the ground to a storage tank located at the top of a building. The volumetric flowrate is $5 \times 10^{-3} \text{ m}^3/\text{s}$. All the piping used are the 4-in. Schedule 40 steel pipe. The pump has an efficiency of 65%.

- [a] Identify all types of friction loss. [5 marks]
- [b] Calculate each of the friction loss as stated in [a]. [14 marks]
- [c] Calculate the power needed in kW for the pump to do the job as shown in Figure Q.2. [6 marks]

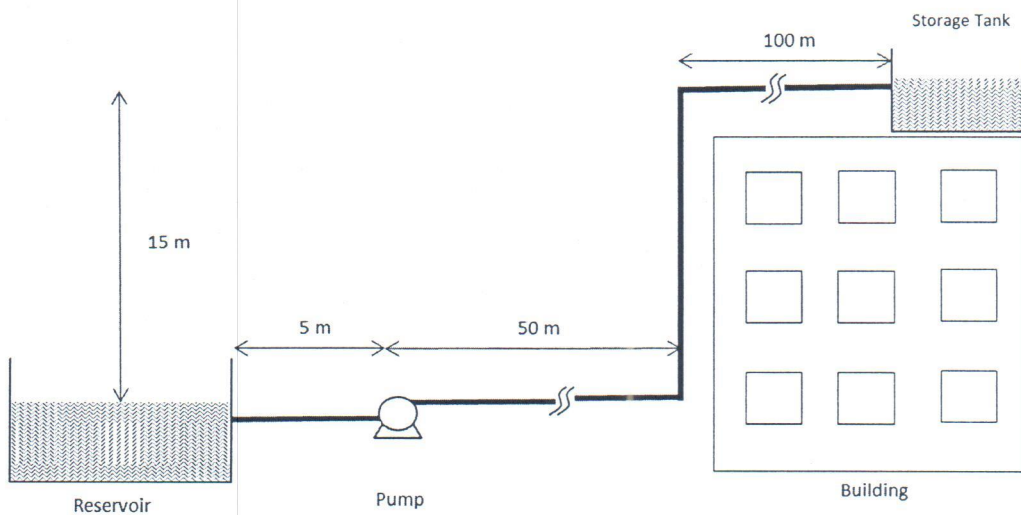


Figure Q.2.

2. Rajah S.2 menunjukkan air pada suhu 20°C dipam dari sebuah takungan yang terletak di atas permukaan bumi ke sebuah tangki penyimpanan yang terletak di atas sebuah bangunan. Kadar aliran isipadu ialah $5 \times 10^{-3} \text{ m}^3/\text{s}$. Kesemua paip yang digunakan adalah paip keluli 4-in. Schedule 40. Pam mempunyai kecekapan sebanyak 65%.

[a] Kenalpasti semua jenis kehilangan geseran.

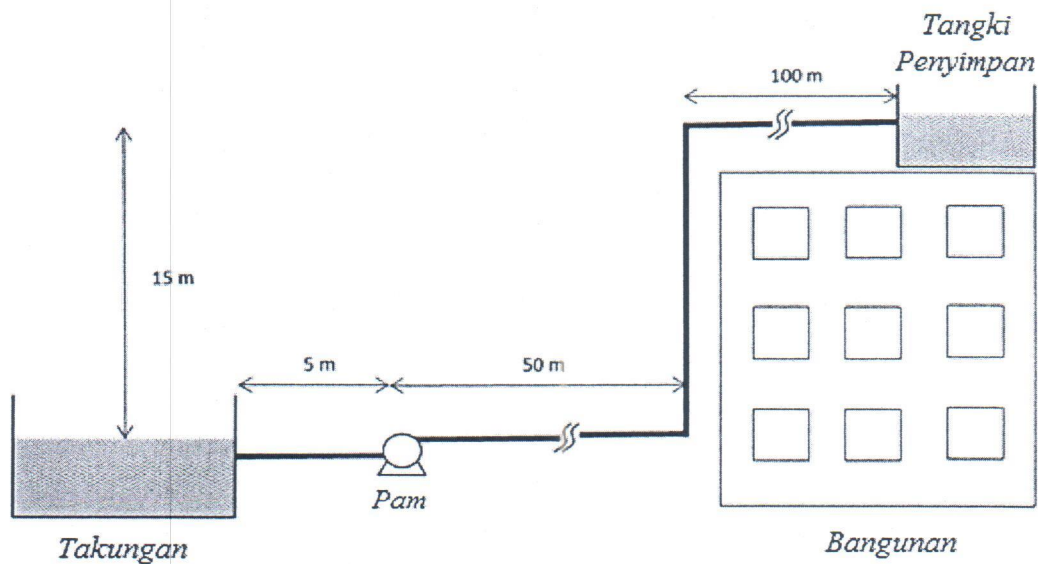
[5 markah]

[b] Kira setiap kehilangan geseran yang dinyatakan dalam [a].

[14 marks]

[c] Kira kuasa yang diperlukan dalam kW oleh pam untuk melaksanakan kerja seperti yang ditunjukkan dalam Rajah S.2.

[6 marks]



Rajah S.2

3. Air flows subsonically in an adiabatic 2-cm-diameter duct. At the entrance, $Ma_1 = 0.1$, $p_1 = 600$ kPa and $T_1 = 450$ K. At section 2 farther downstream, $Ma_2 = 0.5$. Assuming that the average friction factor is 0.024, calculate:

[a] the length of duct that is necessary to accelerate the flow from $Ma_1 = 0.1$ to $Ma_2 = 0.5$. [4 marks]

[b] the additional length that will accelerate air to $Ma_3 = 1.0$. [3 marks]

[c] p_2 , T_2 , V_2 and p_{o2} at section 2. [10 marks]

Given:

For air: Specific heat ratio, $k = 1.4$
Ideal gas constant, $R = 8314$ kg.m²/s².kgmol.K
 $MW_{air} = 29$ kg/kgmol

4. [a] Define fluidization and how the minimum fluidization can be occurred. [4 marks]

[b] A partial oxidation is carried out by passing 0.22 m/s air with containing 1 mol % hydrocarbon through 40-mm ID 2 m height vertical tubes packed with 1 mm catalyst pellets. The air enters the bed from the bottom at 200°C and 2 atm. The density of the catalyst pellets is 1200 kg/m³ and their sphericity is 0.92. The reactor operates at 200°C. The air viscosity and density are 2.6×10^{-5} Pa.s and 1.54 kg/m³, respectively. Assume voidage of packed bed = 0.45, calculate air flowrate that just enough to fluidize the pellets. Given : $\Phi_s \epsilon_{mf}^3 = 1/14$. [12 marks]

[c] [i] Calculate the terminal velocity for 0.020 mm - 0.044 mm particles of limestone ($\rho_{particle} = 2450$ kg/m³) falling in water at 30°C.

[ii] Using limestone particles in part [c].[i], how much the velocity be in a centrifugal separator where the acceleration is $20 \times g$?

Given : $\rho_{water} = 995.7$ kg/m³; $\mu_{water} = 0.801 \times 10^{-3}$ kg/ms.

[9 marks]

3. Udara mengalir secara subsonik di dalam saluran adiabatik berdiameter 2 sm. Pada laluan masuk, $Ma_1 = 0.1$, $p_1 = 600$ kPa dan $T_1 = 450$ K. Pada bahagian 2 jauh di hilir, $Ma_2 = 0.5$. Dengan mengandaikan bahawa faktor geseran purata ialah 0.024, kira:

[a] panjang saluran yang diperlukan untuk mempercepatkan aliran daripada $Ma_1 = 0.1$ kepada $Ma_2 = 0.5$. [4 markah]

[b] panjang tambahan yang akan mempercepatkan aliran udara kepada $Ma_3 = 1.0$. [3 markah]

[c] p_2 , T_2 , V_2 dan p_{o2} pada bahagian 2. [10 markah]

Diberi:

Untuk udara: Nisbah haba spesifik, $k = 1.4$
Pemalar gas unggul, $R = 8314$ kg.m²/s².kgmol.K
Berat molekul untuk udara = 29 kg/kmol

4. [a] Takrifkan pembendaliran dan bagaimana pembendaliran minimum boleh terhasil. [4 markah]

[b] Pengoksidaan separa dijalankan dengan mengalirkan 0.22 m/s udara yang mengandungi 1 mol % hidrokarbon melalui tiub menegak berketinggian 2 m dan ID 40-mm terpadat dengan pelet mangkin 1 mm. Udara memasuki lapisan dari bawah pada 200°C dan 2 atm. Ketumpatan pelet mangkin adalah 1200 kg/m³ dan kesferaannya 0.92. Reaktor beroperasi pada 200°C. Kelikatan dan ketumpatan udara masing-masing 2.6×10^{-5} Pa.s dan 1.54 kg/m³. Anggap lompangan untuk lapisan terpadat = 0.45, kirakan kadar aliran udara yang secukupnya untuk membendalirkan pelet. Diberi : $\Phi_s \epsilon_{mf}^3 = 1/14$. [12 markah]

[c] [i] Kira halaju tamatan untuk zarah batu kapur ($\rho_{\text{zarah}} = 2450$ kg/m³) bersaiz 0.020 mm - 0.044 mm yang jatuh ke dalam air bersuhu 30°C.

[ii] Dengan menggunakan zarah batu kapur di [c][i], berapakah halaju zarah jika ia berada dalam pemisah empar yang pecutannya $20 \times g$?

Diberi :

$\rho_{\text{air}} = 995.7$ kg/m³; $\mu_{\text{air}} = 0.801 \times 10^{-3}$ kg/ms;

[9 markah]

5. [a] What is the difference between required net positive suction head (NPSH_R) and available net positive suction head (NPSH_A)?

[4 marks]

- [b] From continuity equation, show that the fluid pass over the venturi meter can be expressed as:

$$G = \frac{C_D \rho A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{2gh_v}$$

where,

G = mass flowrate

A_1 = area of throat

A_2 = area of convergence

C_D = discharge coefficient

ρ = fluid density

h_v = pressure drop at convergence

[8 marks]

- [c] A propeller with three blades is installed centrally in a vertical tank. The tank is 2.7 m in diameter. The propeller is 0.81 m in diameter and is positioned 0.81 m from the bottom of the tank. The tank is filled to a depth of 2.7 m with a caustic soda solution, which has a viscosity of 1.5 cP and a density of 1498 kg/m³. The propeller is operated at 3.21 rpm. Calculate power required to operate the agitator if:

- [i] the tank was baffled.

[5 marks]

- [ii] the tank was unbaffled.

[5 marks]

- [iii] compare and discuss the results.

[3 marks]

5. [a] *Apakah perbezaan diantara turus sedutan positif bersih yang diperlukan ($NPSH_R$) dan turus sedutan positif bersih sedia ada ($NPSH_A$)?*

[4 markah]

[b] *Bermula daripada persamaan keterusan, tunjukkan bahawa aliran bendalir melalui meter venturi boleh diterbitkan sebagai:*

$$G = \frac{C_D \rho A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{2gh_v}$$

dimana,

G = kadar aliran jisim

A_1 = luas kerongkong

A_2 = luas penumpuan

C_D = pekali luahan

ρ = ketumpatan bendalir

h_v = kejatuhan tekanan pada penumpuan

[8 markah]

[c] *Sebuah kipas dengan tiga bilah dipasang di tengah-tengah sebuah tangki menegak. Tangki berdiameter 2.7 m serta kipas berdiameter 0.81 m berkedudukan 0.81 m dari dasar tangki. Tangki diisi sedalam 2.7 m dengan larutan soda kaustik, berkelikatan 1.5 cP dan berketumpatan 1498 kg/m³. Kipas beroperasi pada kadar 3.21 rpm. Kira kuasa yang diperlukan oleh kipas ini untuk beroperasi jika:*

[i] *Tangki ini dibina dengan sesekat.*

[5 markah]

[ii] *Tangki ini dibina tanpa sesekat.*

[5 markah]

[iii] *Banding dan bincangkan keputusannya.*

[3 markah]

Appendix

Isothermal flow

$$p_a^2 - p_b^2 = \frac{G^2 RT}{M} \left[2 \ln \frac{\rho_a}{\rho_b} + \frac{f(L_b - L_a)}{r_H} \right] \quad \text{Ma} = \frac{1}{\sqrt{k}} \quad \frac{\text{Ma}_a^2}{\text{Ma}_b^2} = 1 - k \text{Ma}_a^2 \left[2 \ln \frac{\text{Ma}_b}{\text{Ma}_a} + \frac{fL}{D} \right]$$

Fanno Flow

$$\text{Ma} \equiv \frac{u}{a} \quad a = \sqrt{\frac{kp}{\rho}} = \sqrt{\frac{kRT}{M}} \quad \frac{p_o}{p_o^*} = \frac{\rho_o}{\rho_o^*} = \frac{1}{\text{Ma}} \left[\frac{2 + (k-1)\text{Ma}^2}{k+1} \right]^{(1/2)(k+1)(k-1)}$$

$$\frac{\rho_a}{\rho_b} = \frac{p_a T_b}{p_b T_a} = \frac{\text{Ma}_b}{\text{Ma}_a} \sqrt{\frac{1 + [(k-1)/2]\text{Ma}_b^2}{1 + [(k-1)/2]\text{Ma}_a^2}} \quad \frac{p_a}{p_b} = \frac{\text{Ma}_b}{\text{Ma}_a} \sqrt{\frac{1 + [(k-1)/2]\text{Ma}_b^2}{1 + [(k-1)/2]\text{Ma}_a^2}}$$

$$\frac{T_a}{T_b} = \frac{1 + [(k-1)/2]\text{Ma}_b^2}{1 + [(k-1)/2]\text{Ma}_a^2} \quad G = \rho \text{Ma} \sqrt{\frac{kTR}{M}} = \text{Ma} \sqrt{\rho k p}$$

$$\frac{\bar{f}L^*}{D} = \frac{1 - \text{Ma}^2}{k\text{Ma}^2} + \frac{k+1}{2k} \ln \frac{(k+1)\text{Ma}^2}{2 + (k-1)\text{Ma}^2} \quad \frac{\bar{f}\Delta L}{D} = \left(\frac{\bar{f}L^*}{D} \right)_1 - \left(\frac{\bar{f}L^*}{D} \right)_2$$

Isentropic Flow

$$\left(\frac{T_2}{T_1} \right)^{\frac{k}{k-1}} = \left(\frac{\rho_2}{\rho_1} \right)^k = \left(\frac{P_2}{P_1} \right) \quad \frac{T}{T_0} = \frac{1}{1 + [(k-1)/2]\text{Ma}^2} \quad \frac{p}{p_0} = \left\{ \frac{1}{1 + [(k-1)/2]\text{Ma}^2} \right\}^{k/(k-1)}$$

$$\frac{A}{A^*} = \frac{1}{\text{Ma}} \left\{ \frac{1 + [(k-1)/2]\text{Ma}^2}{1 + [(k-1)/2]} \right\}^{\frac{k+1}{2(k-1)}} \quad G = u\rho = \sqrt{\frac{2k\rho_0 p_0}{k-1}} \left(\frac{p}{p_0} \right)^{1/k} \sqrt{1 - \left(\frac{p}{p_0} \right)^{1-1/k}}$$

$$\frac{\rho}{\rho_0} = \left\{ \frac{1}{1 + [(k-1)/2]\text{Ma}^2} \right\}^{1/(k-1)}$$

$$\left(\frac{\Delta P}{L}\right)_{mf} = (1 - \varepsilon_{mf})(\rho_p - \rho_f)g$$

$$\frac{\Delta P}{L} = \frac{150\mu V}{\phi_s^2 D_p^2} x \frac{(1 - \varepsilon)^2}{\varepsilon^3} + \frac{1.75\rho_f(V)^2}{\phi_s D_p} x \frac{1 - \varepsilon}{\varepsilon^3}$$

$$K = D_p \left[\frac{g\rho_f(\rho_p - \rho_f)}{\mu^2} \right]^{1/3}$$

$$u_t = \frac{gD_p^2[\rho_p - \rho_f]}{18\mu_f} \text{ for Stoke's law}$$

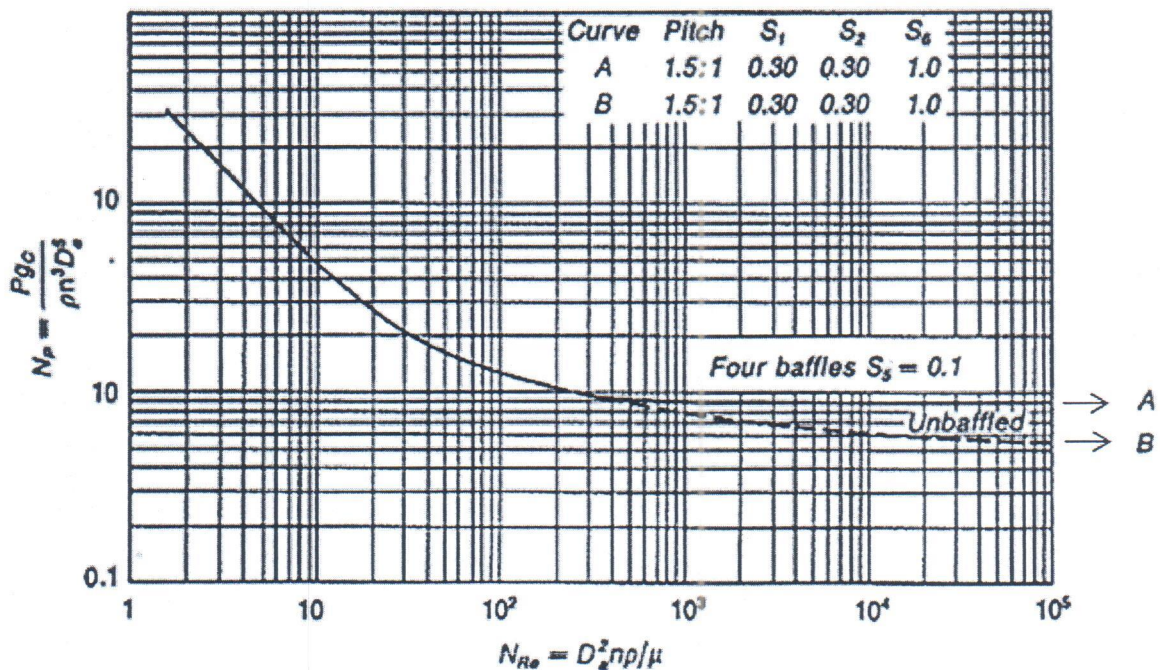
$$u_t = 1.75 \sqrt{\frac{gD_p(\rho_p - \rho_f)}{\rho_f}} \text{ for Newton's law}$$

$$\text{Continuity equation: } \frac{\Delta u^2}{2\alpha} + g\Delta Z + v \int_1^2 dP + W_s + F = 0$$

$$\text{For tank: } N_{RE} = \frac{D_a^2 n \rho}{\mu}; P = N_p n^3 D_a^5 \rho$$

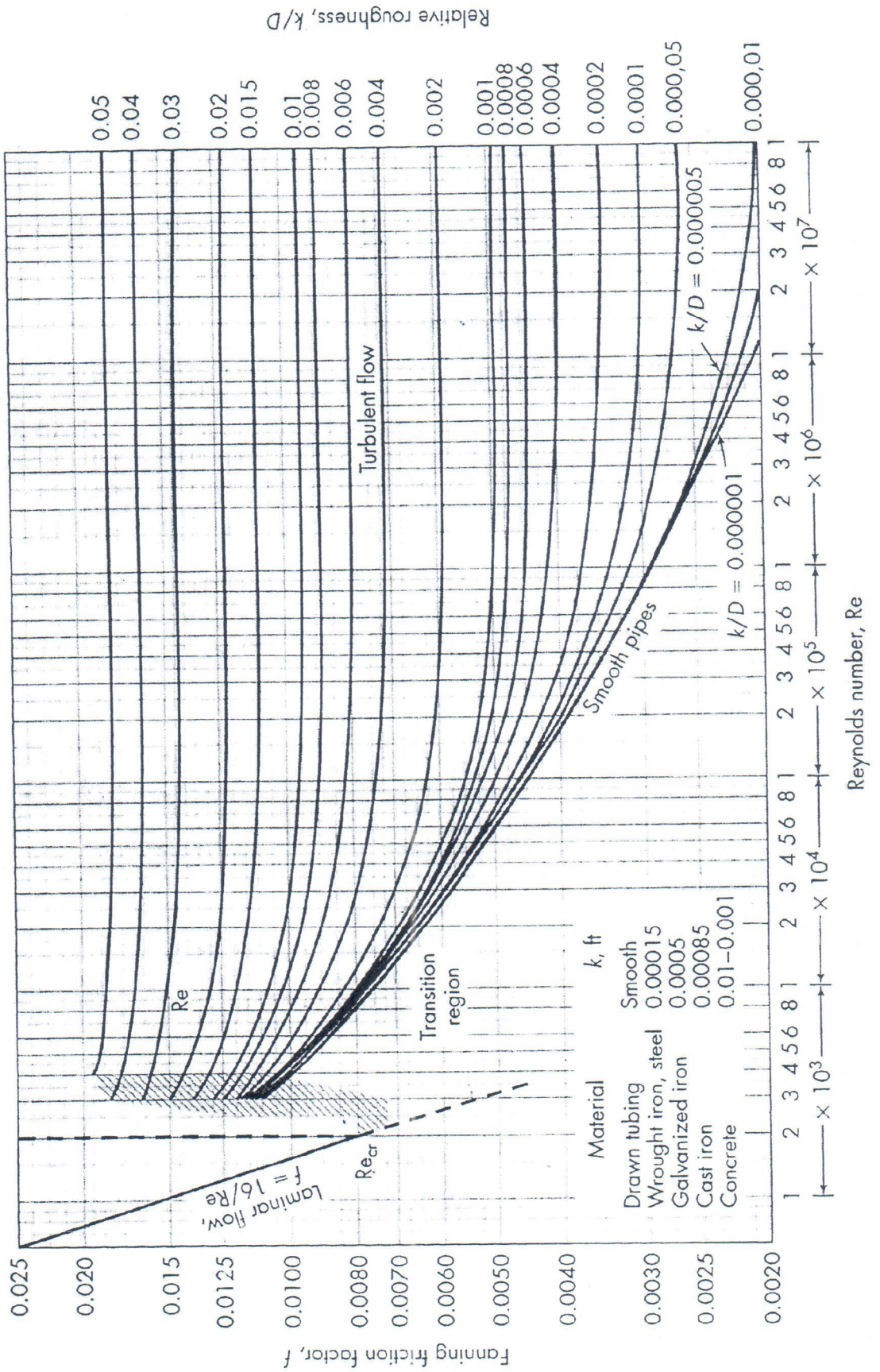
$$N_{Fr} = \frac{n^2 D_a}{g}; m = \frac{1.7 - \log_{10} N_{Re}}{18}; N_{P(Corr)} = N_p \times N_{Fr}^m$$

Figure 1



Power number N_p versus N_{Re} for three-blade propellers. (After Oldshue.³³) With the dashed portion of curve B, the value of N_p read from the figure must be multiplied by N_{Fr}^m .

Figure 2: Friction Factor Chart vs Reynold Number



Common Engineering Conversion Factors

Length	Volume
1 ft = 12 in = 0.3048 m, 1 yard = 3 ft 1 mi = 5280 ft = 1609.344 m 1 nautical mile (nmi) = 6076 ft	1 ft ³ = 0.028317 m ³ = 7.481 gal , 1 bbl = 42 U.S. gal 1 U.S. gal = 231 in ³ = 3.7853 L = 4qt = 0.833 Imp.gal. 1 L = 0.001 m ³ = 0.035315 ft ³ = 0.2642 U.S. gal
Mass	Density
1 slug = 32.174 lb _m = 14.594 kg 1 lb _m = 0.4536 kg = 7000 grains	1 slug/ft ³ = 515.38 kg/m ³ , 1 g/cm ³ = 1000 kg/m ³ 1 lb _m /ft ³ = 16.0185 kg/m ³ , 1 lb _m /in ³ = 27.68 g/cm ³
Acceleration & Area	Velocity
1 ft/s ² = 0.3048 m/s ² 1 ft ² = 0.092903 m ²	1 ft/s = 0.3048 m/s , 1 knot = 1 min/h = 1.6878 ft/s 1 min/h = 1.4666666 ft/s (fps) = 0.44704 m/s
Mass Flow & Mass Flux	Volume Flow
1 slug/s = 14.594 kg/s. 1 lb _m /s = 0.4536 kg/s 1 kg/m ² s = 0.2046 lb _m /ft ² s = 0.00636 slug/ft ² s	1 gal/min = 0.00228 ft ³ /s = 0.06309 L/s 1 million gal/day = 1.5472 ft ³ /s = 0.04381 m ³ /s
Pressure	Force and Surface Tension
1 lb _f /ft ² = 47.88 Pa, 1 torr = 1 mm Hg 1 psi = 144 psf, 1 bar = 10 ⁵ Pa 1 atm = 2116.2 psf = 14.696 psia = 101,325 Pa = 29.9 in Hg = 33.9 ft H ₂ O	1 lb _f = 4.448222 N = 16 oz, 1 dyne = 1 g cm/s ² = 10 ⁻⁵ N 1 kg _f = 2.2046 lb _f = 9.80665 N 1 U.S. (short) ton = 2000 lb _f , 1 N = 0.2248 lb _f 1 N/m = 0.0685 lb _f /ft
Power	Energy and Specific Energy
1 hp = 550 (ft.lb _f)/s = 745.7 W 1 (ft.lb _f)/s = 1.3558 W 1 Watt = 3.4123 Btu/h = 0.00134 hp	1 ft lb _f = 1.35582 J, 1 hp·h = 2544.5 Btu 1 Btu = 252 cal = 1055.056 J = 778.17 ft lb _f 1 cal = 4.1855 J, 1 ft.lb _f /lb _m = 2.9890 J/kg
Specific Weight	Heat Flux
1 lb _f /ft ³ = 157.09 N/m ³	1 W/m ² = 0.3171 Btu/(h ft ²)
Viscosity	Kinematic Viscosity
1 slug/(ft.s) = 47.88 kg/(m.s) = 478.8 poise (p) 1 p = 1 g/(cm.s) 0.1 kg/(m.s) = 0.002088 slug/(ft s)	1 ft ² /h = 2.506 .10 ⁻⁵ m ² /s, 1 ft ² /s = 0.092903 m ² /s 1 stoke (st) = 1 cm ² /s = 0.0001 m ² /s = 0.001076 ft ² /s
Temperature Scale Readings	
°F = (9/5)°C + 32 °C = (5/9) (°F - 32)	°R = °F + 459.69 °K = °C + 273.16
Thermal Conductivity*	Gas Constant*
1 cal/(s.cm.°C) = 242 Btu/(h.ft.°R) 1 Btu/(h.ft.°R) = 1.7307 W/(m.K)	R = 82.057 atm.cm ³ /(gmol.K) = 62.361 mm Hg.L/(gmol.K) = 1.134 atm.ft ³ /(lbmol.K) = 0.083144 bar.L/(gmol.K) = 10.73 psi. ft ³ /(lbmol. °R) = 555.0 mm Hg.ft ³ /(lbmol. °R)
<p>• Note that the intervals in absolute (Kelvin) and °C are equal. Also, 1 °R = 1 °F. Latent heat: 1 J/kg = 4.2995 × 10⁻⁴ Btu/lb_m = 10.76 lb_f.ft/slug = 0.3345 lb_f.ft/lb_m , 1 Btu/lb_m = 2325.9 J/kg Heat transfer coefficient: 1 Btu/(h.ft².°F) = 5.6782 W/(m².°C). Heat generation rate: 1 W/m³ = 0.09665 Btu/(h ft³) Heat transfer per unit length: 1 W/m = 1.0403 Btu/(h ft) Mass transfer coefficient: 1 m/s = 11.811 ft/h, 1 lb_{mol}/(h.ft²) = 0.013562 kgmol/(s.m²)</p>	

Table 1: Dimensions of Standard Steel Pipe

Dimensions of Standard Steel Pipe

Nominal Pipe Size (in.)	Outside Diameter		Sched- ule Number	Wall Thickness		Inside Diameter		Inside Cross- Sectional Area	
	in.	mm		in.	mm	in.	mm	ft ²	m ² × 10 ⁴
1/8	0.405	10.29	40	0.068	1.73	0.269	6.83	0.00040	0.3664
			80	0.095	2.41	0.215	5.46	0.00025	0.2341
1/4	0.540	13.72	40	0.088	2.24	0.364	9.25	0.00072	0.6720
			80	0.119	3.02	0.302	7.67	0.00050	0.4620
3/8	0.675	17.15	40	0.091	2.31	0.493	12.52	0.00133	1.231
			80	0.126	3.20	0.423	10.74	0.00098	0.9059
1/2	0.840	21.34	40	0.109	2.77	0.622	15.80	0.00211	1.961
			80	0.147	3.73	0.546	13.87	0.00163	1.511
3/4	1.050	26.67	40	0.113	2.87	0.824	20.93	0.00371	3.441
			80	0.154	3.91	0.742	18.85	0.00300	2.791
1	1.315	33.40	40	0.133	3.38	1.049	26.64	0.00600	5.574
			80	0.179	4.45	0.957	24.31	0.00499	4.641
1 1/4	1.660	42.16	40	0.140	3.56	1.380	35.05	0.01040	9.648
			80	0.191	4.85	1.278	32.46	0.00891	8.275
1 1/2	1.900	48.26	40	0.145	3.68	1.610	40.89	0.01414	13.13
			80	0.200	5.08	1.500	38.10	0.01225	11.40
2	2.375	60.33	40	0.154	3.91	2.067	52.50	0.02330	21.65
			80	0.218	5.54	1.939	49.25	0.02050	19.05
2 1/2	2.875	73.03	40	0.203	5.16	2.469	62.71	0.03322	30.89
			80	0.276	7.01	2.323	59.00	0.02942	27.30
3	3.500	88.90	40	0.216	5.49	3.068	77.92	0.05130	47.69
				0.300	7.62	2.900	73.66	0.04587	42.61
3 1/2	4.000	101.6	40	0.226	5.74	3.548	90.12	0.06870	63.79
			80	0.318	8.08	3.364	85.45	0.06170	57.35
4	4.500	114.3	40	0.237	6.02	4.026	102.3	0.08840	82.19
			80	0.337	8.56	3.826	97.18	0.07986	74.17
5	5.563	141.3	40	0.258	6.55	5.047	128.2	0.1390	129.1
			80	0.375	9.53	4.813	122.3	0.1263	117.5
6	6.625	168.3	40	0.280	7.11	6.065	154.1	0.2006	186.5
			80	0.432	10.97	5.761	146.3	0.1810	168.1
8	8.625	219.1	40	0.322	8.18	7.981	202.7	0.3474	322.7
			80	0.500	12.70	7.625	193.7	0.3171	294.7

Table 2: Loss Coefficient for Standard Threaded Pipe Fittings

Friction Loss for Turbulent Flow Through Valves and Fittings

<i>Type of Fitting or Valve</i>	<i>Frictional Loss, Number of Velocity Heads, K_f</i>	<i>Frictional Loss, Equivalent Length of Straight Pipe in Pipe Diameters, L_e/D</i>
Elbow, 45°	0.35	17
Elbow, 90°	0.75	35
Tee	1	50
Return bend	1.5	75
Coupling	0.04	2
Union	0.04	2
Gate valve		
Wide open	0.17	9
Half open	4.5	225
Globe valve		
Wide open	6.0	300
Half open	9.5	475
Angle valve, wide open	2.0	100
Check valve		
Ball	70.0	3500
Swing	2.0	100
Water meter, disk	7.0	350

Source: R. H. Perry and C. H. Chilton, Chemical Engineers' Handbook, 5th ed. New York: McGraw-Hill Book Company, 1973. With permission.

Table 3: Density of Liquid Water

Density of Liquid Water

<i>Temperature</i>		<i>Density</i>		<i>Temperature</i>		<i>Density</i>	
<i>K</i>	<i>°C</i>	<i>g/cm³</i>	<i>kg/m³</i>	<i>K</i>	<i>°C</i>	<i>g/cm³</i>	<i>kg/m³</i>
273.15	0	0.99987	999.87	323.15	50	0.98807	988.07
277.15	4	1.00000	1000.00	333.15	60	0.98324	983.24
283.15	10	0.99973	999.73	343.15	70	0.97781	977.81
293.15	20	0.99823	998.23	353.15	80	0.97183	971.83
298.15	25	0.99708	997.08	363.15	90	0.96534	965.34
303.15	30	0.99568	995.68	373.15	100	0.95838	958.38
313.15	40	0.99225	992.25				

Source: R. H. Perry and C. H. Chilton, Chemical Engineers' Handbook, 5th ed. New York: McGraw-Hill Book Company, 1973. With permission.

Table 4: Viscosity of Liquid Water

Viscosity of Liquid Water

Temperature		Viscosity [[Pa·s] 10 ³ , (kg/m·s) 10 ³ , or cp]	Temperature		Viscosity [[Pa·s] 10 ³ , (kg/m·s) 10 ³ , or cp]
K	°C		K	°C	
273.15	0	1.7921	323.15	50	0.5494
275.15	2	1.6728	325.15	52	0.5315
277.15	4	1.5674	327.15	54	0.5146
279.15	6	1.4728	329.15	56	0.4985
281.15	8	1.3860	331.15	58	0.4832
283.15	10	1.3077	333.15	60	0.4688
285.15	12	1.2363	335.15	62	0.4550
287.15	14	1.1709	337.15	64	0.4418
289.15	16	1.1111	339.15	66	0.4293
291.15	18	1.0559	341.15	68	0.4174
293.15	20	1.0050	343.15	70	0.4061
293.35	20.2	1.0000	345.15	72	0.3952
295.15	22	0.9579	347.15	74	0.3849
297.15	24	0.9142	349.15	76	0.3750
298.15	25	0.8937	351.15	78	0.3655
299.15	26	0.8737	353.15	80	0.3565
301.15	28	0.8360	355.15	82	0.3478
303.15	30	0.8007	357.15	84	0.3395
305.15	32	0.7679	359.15	86	0.3315
307.15	34	0.7371	361.15	88	0.3239
309.15	36	0.7085	363.15	90	0.3165
311.15	38	0.6814	365.15	92	0.3095
313.15	40	0.6560	367.15	94	0.3027
315.15	42	0.6321	369.15	96	0.2962
317.15	44	0.6097	371.15	98	0.2899
319.15	46	0.5883	373.15	100	0.2838
321.15	48	0.5683			

Source : Bingham, *Fluidity and Plasticity*. New York: McGraw-Hill Book Company, 1922. With permission.

Table 5: Isentropic Flow of a Perfect Gas, $k = 1.4$

Ma	p/p_0	ρ/ρ_0	T/T_0	A/A^*	Ma	p/p_0	ρ/ρ_0	T/T_0	A/A^*
0.00	1.0000	1.0000	1.0000	∞	2.10	0.1094	0.2058	0.5313	1.8369
0.10	0.9930	0.9950	0.9980	5.8218	2.20	0.0935	0.1841	0.5081	2.0050
0.20	0.9725	0.9803	0.9921	2.9635	2.30	0.0800	0.1646	0.4859	2.1931
0.30	0.9395	0.9564	0.9823	2.0351	2.40	0.0684	0.1472	0.4647	2.4031
0.40	0.8956	0.9243	0.9690	1.5901	2.50	0.0585	0.1317	0.4444	2.6367
0.50	0.8430	0.8852	0.9524	1.3398	2.60	0.0501	0.1179	0.4252	2.8960
0.60	0.7840	0.8405	0.9328	1.1882	2.70	0.0430	0.1056	0.4068	3.1830
0.70	0.7209	0.7916	0.9107	1.0944	2.80	0.0368	0.0946	0.3894	3.5001
0.80	0.6560	0.7400	0.8865	1.0382	2.90	0.0317	0.0849	0.3729	3.8498
0.90	0.5913	0.6870	0.8606	1.0089	3.00	0.0272	0.0762	0.3571	4.2346
1.00	0.5283	0.6339	0.8333	1.0000	3.10	0.0234	0.0685	0.3422	4.6573
1.10	0.4684	0.5817	0.8052	1.0079	3.20	0.0202	0.0617	0.3281	5.1210
1.20	0.4124	0.5311	0.7764	1.0304	3.30	0.0175	0.0555	0.3147	5.6286
1.30	0.3609	0.4829	0.7474	1.0663	3.40	0.0151	0.0501	0.3019	6.1837
1.40	0.3142	0.4374	0.7184	1.1149	3.50	0.0131	0.0452	0.2899	6.7896
1.50	0.2724	0.3950	0.6897	1.1762	3.60	0.0114	0.0409	0.2784	7.4501
1.60	0.2353	0.3557	0.6614	1.2502	3.70	0.0099	0.0370	0.2675	8.1691
1.70	0.2026	0.3197	0.6337	1.3376	3.80	0.0086	0.0335	0.2572	8.9506
1.80	0.1740	0.2868	0.6068	1.4390	3.90	0.0075	0.0304	0.2474	9.7990
1.90	0.1492	0.2570	0.5807	1.5553	4.00	0.0066	0.0277	0.2381	10.7188
2.00	0.1278	0.2300	0.5556	1.6875					

Table 6: Adiabatic Frictional Flow in a Constant-Area Duct for $k = 1.4$

Ma	fL/D	p/p^*	T/T^*	$\rho^*/\rho = V/V^*$	p_0/p_0^*
0.00	∞	∞	1.2000	0.0000	∞
0.10	66.9216	10.9435	1.1976	0.1094	5.8218
0.20	14.5333	5.4554	1.1905	0.2182	2.9635
0.30	5.2993	3.6191	1.1788	0.3257	2.0351
0.40	2.3085	2.6958	1.1628	0.4313	1.5901
0.50	1.0691	2.1381	1.1429	0.5345	1.3398
0.60	0.4908	1.7634	1.1194	0.6348	1.1882
0.70	0.2081	1.4935	1.0929	0.7318	1.0944
0.80	0.0723	1.2893	1.0638	0.8251	1.0382
0.90	0.0145	1.1291	1.0327	0.9146	1.0089
1.00	0.0000	1.0000	1.0000	1.0000	1.0000
1.10	0.0099	0.8936	0.9662	1.0812	1.0079
1.20	0.0336	0.8044	0.9317	1.1583	1.0304
1.30	0.0648	0.7285	0.8969	1.2311	1.0663
1.40	0.0997	0.6632	0.8621	1.2999	1.1149
1.50	0.1361	0.6065	0.8276	1.3646	1.1762
1.60	0.1724	0.5568	0.7937	1.4254	1.2502
1.70	0.2078	0.5130	0.7605	1.4825	1.3376
1.80	0.2419	0.4741	0.7282	1.5360	1.4390
1.90	0.2743	0.4394	0.6969	1.5861	1.5553
2.00	0.3050	0.4082	0.6667	1.6330	1.6875
2.10	0.3339	0.3802	0.6376	1.6769	1.8369
2.20	0.3609	0.3549	0.6098	1.7179	2.0050
2.30	0.3862	0.3320	0.5831	1.7563	2.1931
2.40	0.4099	0.3111	0.5576	1.7922	2.4031
2.50	0.4320	0.2921	0.5333	1.8257	2.6367
2.60	0.4526	0.2747	0.5102	1.8571	2.8960
2.70	0.4718	0.2588	0.4882	1.8865	3.1830
2.80	0.4898	0.2441	0.4673	1.9140	3.5001
2.90	0.5065	0.2307	0.4474	1.9398	3.8498
3.00	0.5222	0.2182	0.4286	1.9640	4.2346
3.10	0.5368	0.2067	0.4107	1.9866	4.6573
3.20	0.5504	0.1961	0.3937	2.0079	5.1210
3.30	0.5632	0.1862	0.3776	2.0278	5.6286
3.40	0.5752	0.1770	0.3623	2.0466	6.1837
3.50	0.5864	0.1685	0.3478	2.0642	6.7896
3.60	0.5970	0.1606	0.3341	2.0808	7.4501
3.70	0.6068	0.1531	0.3210	2.0964	8.1691
3.80	0.6161	0.1462	0.3086	2.1111	8.9506
3.90	0.6248	0.1397	0.2969	2.1250	9.7990
4.00	0.6331	0.1336	0.2857	2.1381	10.7187