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UNIVERSITI SAINS MALAYSIA

First Semester Examination  
2014/2015 Academic Session

December 2014 / January 2015

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

Duration : 3 hours  
*[Masa : 3 jam]*

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

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

**Instructions:** Answer **ALL** (4) questions.

**Arahan:** Jawab **SEMUA** (4) 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] A half-scale model is used to simulate the flow of a liquid hydrocarbon in a pipeline. The model uses water where the pressure drop per meter length is  $4 \text{ kN/m}^2$ . The respective densities of water and hydrocarbon are  $1000 \text{ kg/m}^3$  and  $800 \text{ kg/m}^3$ , and viscosities are  $1 \times 10^{-3} \text{ Ns/m}^2$  and  $9 \times 10^{-4} \text{ Ns/m}^2$ . By dimensional analysis, it can be shown that the pressure coefficient is a function of Reynolds number of the fluid in the pipe, i.e.

$$\frac{\Delta P}{\rho V^2} = \phi \left( \frac{\mu}{\rho V D} \right)$$

Determine the expected pressure drop along the full-scale pipe if the average velocity of the hydrocarbon in the full-scale pipe is expected to be  $1.8 \text{ m/s}$ .

[8 marks]

- [b] Water with density of  $998 \text{ kg/m}^3$  is flowing at a steady state mass flow rate through a uniform diameter pipe. The entrance pressure of the fluid is  $68.9 \text{ kN/m}^2$  abs in the pipe, which connects to a pump that actually supplies  $155.4 \text{ J/kg}$  of fluid flowing in the pipe. The exit pipe from the pump is the same diameter as the inlet pipe. The exit section of the pipe is  $3.05 \text{ m}$  higher than the entrance, and the exit pressure is  $137.8 \text{ kN/m}^2$  absolute. The Reynolds number in the pipe is above  $4000$  in the system. List all the assumptions needed and calculate the frictional loss ( $h_f$ ) in the pipe system as given in Figure Q.1.[b].

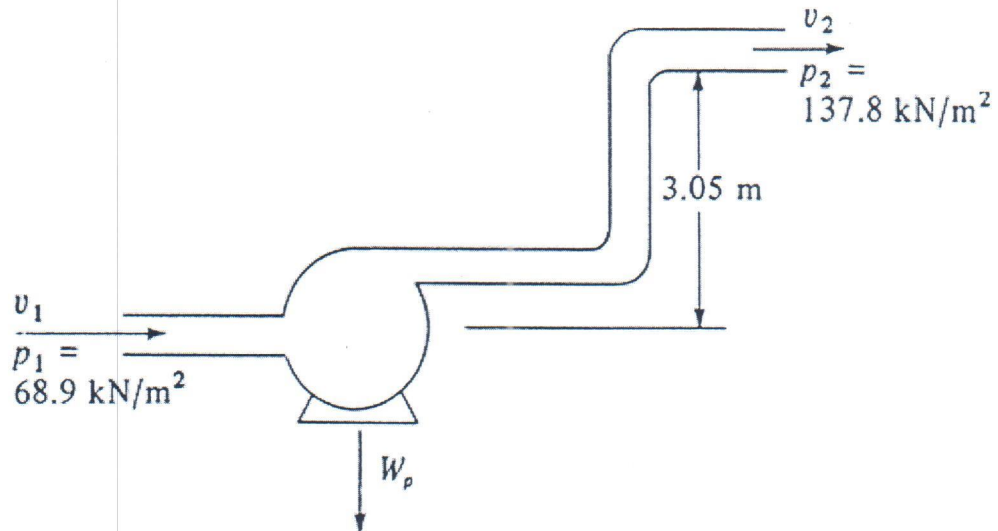


Figure Q.1.[b]

[17 marks]

Jawab SEMUA soalan.

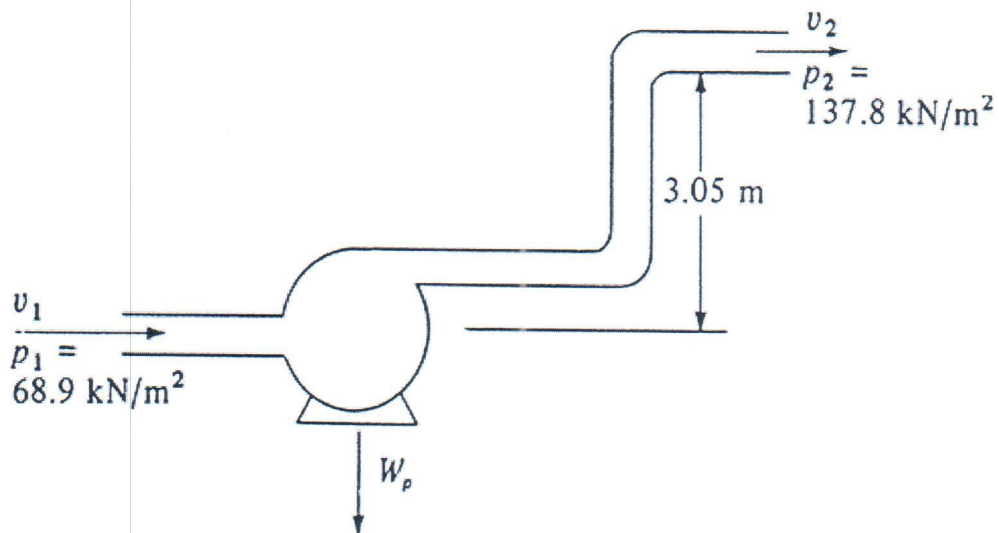
1. [a] Model berskala separa digunakan untuk mensimulasi aliran cecair hidrokarbon di dalam saluran paip. Model menggunakan air dengan susutan tekanan per meter panjang ialah  $4 \text{ kN/m}^2$ . Ketumpatan air dan cecair hidrokarbon masing-masing ialah  $1000 \text{ kg/m}^3$  dan  $800 \text{ kg/m}^3$ , dan kelikatan ialah  $1 \times 10^{-3} \text{ Ns/m}^2$  dan  $9 \times 10^{-4} \text{ Ns/m}^2$ . Analisis dimensi menunjukkan bahawa pemalar tekanan ialah fungsi kepada nombor Reynolds bagi cecair di dalam paip, iaitu:

$$\frac{\Delta P}{\rho V^2} = \phi \left( \frac{\mu}{\rho V D} \right)$$

Tentukan susutan tekanan yang dijangkakan sepanjang paip berskala penuh sekiranya halaju purata hidrokarbon di dalam paip berskala penuh ialah  $1.8 \text{ m/s}$ .

[8 markah]

- [b] Air dengan ketumpatan  $998 \text{ kg/m}^3$  mengalir pada kadar aliran jisim berkeadaan mantap melalui paip berdiameter seragam. Tekanan masuk bendalir di dalam paip ialah  $68.9 \text{ kN/m}^2$  mutlak, yang mana dihubungkan kepada sebuah pam yang membekalkan  $155.4 \text{ J/kg}$  bendalir yang mengalir di dalam paip. Paip keluar daripada pam mempunyai diameter yang sama dengan paip masuk. Bahagian keluar paip adalah  $3.05 \text{ m}$  lebih tinggi daripada bahagian masuk, dan tekanan keluar ialah  $137.8 \text{ kN/m}^2$  mutlak. Nombor Reynolds di dalam paip adalah melebihi  $4000$  di dalam sistem. Senaraikan kesemua andaian yang diperlukan dan kirakan kehilangan geseran ( $h_f$ ) di dalam sistem paip seperti yang diberikan dalam Rajah S.1.[b].



Rajah S.1.[b].

[17 markah]

...4/-

2. [a] Water at 20°C is being pumped from a tank to an elevated tank at a rate of  $5.0 \times 10^{-3} \text{ m}^3/\text{s}$ . All the piping in Figure Q.2.[a] is 4-in Schedule 40 commercial steel pipe. The pump has an efficiency of 65%. The total friction in the piping system includes contraction loss at tank exit, friction in the straight pipe, friction in the two elbows and expansion loss at the tank entrance. Calculate the kW power needed for the pump.

Water properties at 20°C:

Density,  $\rho = 998 \text{ kg/m}^3$

Viscosity,  $\mu = 1.005 \times 10^{-3} \text{ kg/m.s}$

$I J = 1 \text{ kg.m}^2/\text{s}^2$

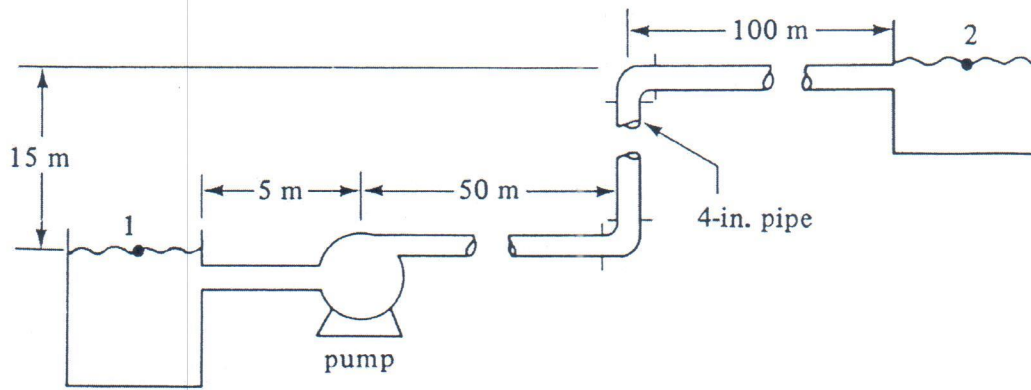


Figure Q.2.[a]

[16 marks]

- [b] Air ( $k = 1.4$ ) flows through a converging-diverging nozzle. At a section in the converging portion of the nozzle,  $A_1 = 0.1 \text{ m}^2$ ,  $p_1 = 600 \text{ kPa (abs)}$ ,  $T_1 = 20^\circ\text{C}$  and  $\text{Ma}_1 = 0.6$ . Assuming that the flow is adiabatic and frictionless, determine  $A_2$ ,  $p_2$  and  $T_2$  at the diverging part of the nozzle if  $\text{Ma}_2 = 3.0$ .

[9 marks]

3. [a] Define fluidization and how the minimum fluidization can be occurs?

[4 marks]

- [b] Solid particles having a size of 0.12 mm, a shape factor  $\phi_s$  of 0.88, and a density of  $1000 \text{ kg/m}^3$  are to be fluidized using air at 2.0 atm and 25°C. The bed diameter is 0.62 m and the bed contains 300 kg of solids. The minimum height of the fluidized bed is 1.72 m. Take air density as  $2.37 \text{ kg/m}^3$ , calculate the pressure drop at minimum fluidizing condition.

[9 marks]

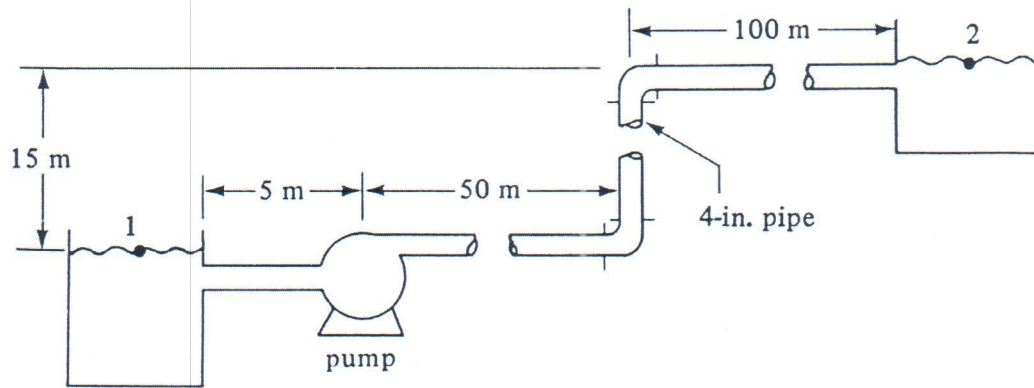
2. [a] Air pada suhu  $20^\circ\text{C}$  telah dipam daripada sebuah tangki kepada tangki ternaik pada kadar  $5.0 \times 10^{-3} \text{ m}^3/\text{s}$ . Kesemua paip dalam Rajah S.2.[a] ialah paip keluli komersial 4-in Schedule 40. Pam mempunyai kecekapan 65%. Jumlah geseran di dalam sistem perpaipan termasuk kehilangan penguncupan di pintu keluar paip, geseran di dalam paip lurus, geseran di dalam dua sesiku dan kehilangan pengembangan di pintu masuk tangki. Kirakan kuasa (kW) yang diperlukan untuk pam.

Sifat-sifat air pada  $20^\circ\text{C}$ :

Ketumpatan,  $\rho = 998 \text{ kg/m}^3$

Kelikatan,  $\mu = 1.005 \times 10^{-3} \text{ kg/m.s}$

$IJ = 1 \text{ kg.m}^2/\text{s}^2$



Rajah S.2.[a].

[16 markah]

- [b] Udara ( $\kappa = 1.4$ ) mengalir menerusi suatu muncung bertumpu-mencapah. Pada satu seksyen dalam bahagian bertumpu muncung,  $A_1 = 0.1 \text{ m}^2$ ,  $p_1 = 600 \text{ kPa}$  (mutlak),  $T_1 = 20^\circ\text{C}$  and  $Ma_1 = 0.6$ . Dengan mengandaikan bahawa aliran ialah adiabatik dan tanpa geseran, tentukan  $A_2$ ,  $p_2$  and  $T_2$  pada bahagian mencapah muncung sekiranya  $Ma_2 = 3.0$ .

[9 markah]

3. [a] Takrifkan pembendaliran dan bagaimana pembendaliran minimum boleh terhasil?

[4 markah]

- [b] Zarah-zarah pepejal bersaiz  $0.12 \text{ mm}$ , faktor bentuk  $\phi_s$  0.88 dan berketumpatan  $1000 \text{ kg/m}^3$  akan diterbendalirkan dengan menggunakan udara pada tekanan  $2.0 \text{ atm}$  dan suhu  $25^\circ\text{C}$ . Garis pusat lapisan ialah  $0.62 \text{ m}$  dan lapisan tersebut mengandungi  $300 \text{ kg}$  pepejal. Ketinggian minimum lapisan terbendalir ialah  $1.72 \text{ m}$ . Anggap ketumpatan udara sebagai  $2.37 \text{ kg/m}^3$ , kirakan kejatuhan tekanan pada keadaan terbendaliran minimum.

[9 markah]

[c] [i] Estimate the terminal velocity for 0.024 mm-0.040 mm particles of limestone falling in water at 30°C.

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

$$\text{Given : } \rho_{\text{limestone}} = 2450 \text{ kg/m}^3; \rho_{\text{water}} = 995.7 \text{ kg/m}^3;$$

$$\mu_{\text{water}} = 0.801 \times 10^{-3} \text{ kg/ms.}$$

[12 marks]

4. [a] Show that the fluid passes over the orifice meter (pressure drop is measured by U manometer) can be expressed as:

$$G = C_D A_2 \rho \sqrt{2gh_v}$$

where,  $G$  = mass flowrate,  $A_2$  = cross sectional area of orifice meter,  
 $C_D$  = discharge coefficient,  $\rho$  = fluid density,  $h_v$  = pressure drop

[7 marks]

[b] A fluid at 85°F is pumped through the system shown in Figure Q.4.[b] at the rate of 100 gpm. The specific gravity of fluid is 1.22, and its vapour pressure is 1.44 psi. The reservoir is at atmospheric pressure of 14.7 psi. The fluid level below pump centerline is 5.2 feet. The friction head is known to be 3.54 feet. If the pump manufacturer specifies a required NPSH of 18 feet, will the pump be suitable for this service?

[8 marks]

[c] [i] *Anggarkan halaju tamatan untuk partikel batu kapur bersaiz 0.024 mm - 0.040 mm yang jatuh kedalam air bersuhu 30 °C.*

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

*Diberi :  $\rho_{\text{batu kapur}} = 2450 \text{ kg/m}^3$ ;  $\rho_{\text{air}} = 995.7 \text{ kg/m}^3$ ;*

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

[12 markah]

4. [a] *Tunjukkan bahawa bendalir yang melalui meter orifis (kejatuhan tekanan diukur dengan menggunakan manometer U) dapat diterbitkan seperti persamaan dibawah ini:*

$$G = C_D A_2 \rho \sqrt{2gh_v}$$

*di mana,  $G$  = kadar aliran jisim,  $A_2$  = luas keratan rentas meter orifis,  
 $C_D$  = pekali luahan,  $\rho$  = ketumpatan bendalir,  
 $h_v$  = susutan tekanan*

[7 markah]

[b] *Suatu bendalir bersuhu 85°F dipamkan melalui sistem seperti yang ditunjukkan pada Rajah S.4.[b] pada kadar aliran 100 gpm. Graviti tentu bendalir adalah 1.22 dan tekanan pemeruapan adalah 1.44 psi. Takungan adalah pada tekanan atmosfera 14.7 psi. Aras bendalir dari bawah garis tengah pam adalah 5.2 kaki. Turus geseran ialah sebanyak 3.54 kaki. Sekiranya pengilang pam menetapkan turus sedutan positif bersih (NPSH) yang diperlukan adalah 18 kaki, adakah pam ini sesuai bagi perkhidmatan tersebut?*

[8 markah]

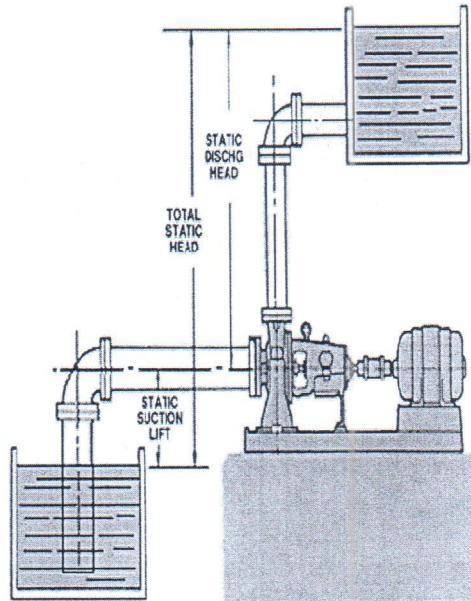
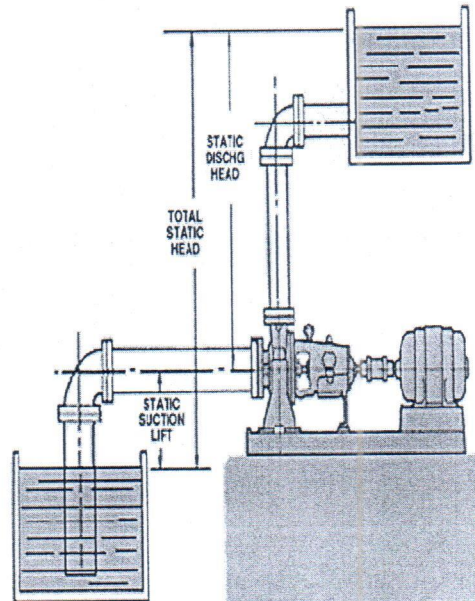


Figure Q.4.[b]

- [c] A flat-blade turbine with six blades is installed centrally in a vertical tank. The tank is 1.83 m in diameter, the turbine is 0.61 m in diameter and is positioned 0.61 m from the bottom of the tank. The turbine blades are 127 mm wide. The tank is filled to a depth of 1.83 m with a solution of 50% caustic soda at 65.6°C, which has a viscosity of 12 cP and a density of 1498 kg/m<sup>3</sup>. The turbine is operated at 90 rpm. The tank was unbuffered. Calculate the power required to operate the mixer?

[10 marks]



Rajah S.4.[b]

[c] Sebuah turbin berbilah rata dengan enam bilah dipasang ditengah-tengah sebuah tangki menegak. Tangki berdiameter 1.83 m serta turbin berdiameter 0.61 m berkedudukan 0.61 m dari dasar tangki. Bilah turbin ini berkelebaran 127 mm. Tangki diisi sedalam 1.83 m dengan larutan 50% soda kaustik bersuhu  $65.6^{\circ}\text{C}$ , berkelikatan 12cP dan berketumpatan  $1498 \text{ kg/m}^3$ . Turbin beroperasi pada kadar 90 rpm. Tangki ini dibina tanpa sesekat. Berapa kuasa yang diperlukan oleh turbin ini untuk beroperasi?

[10 markah]

Appendix

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 <sup>3</sup> = 0.028317 m <sup>3</sup> = 7.481 gal, 1 bbl = 42 U.S. gal 1 U.S. gal = 231 in <sup>3</sup> = 3.7853 L = 4qt = 0.833 Imp.gal. 1 L = 0.001 m <sup>3</sup> = 0.035315 ft <sup>3</sup> = 0.2642 U.S. gal
Mass	Density
1 slug = 32.174 lb <sub>m</sub> = 14.594 kg 1 lb <sub>m</sub> = 0.4536 kg = 7000 grains	1 slug/ft <sup>3</sup> = 515.38 kg/m <sup>3</sup> , 1 g/cm <sup>3</sup> = 1000 kg/m <sup>3</sup> 1 lb <sub>m</sub> /ft <sup>3</sup> = 16.0185 kg/m <sup>3</sup> , 1 lb <sub>m</sub> /in <sup>3</sup> = 27.68 g/cm <sup>3</sup>
Acceleration & Area	Velocity
1 ft/s <sup>2</sup> = 0.3048 m/s <sup>2</sup> 1 ft <sup>2</sup> = 0.092903 m <sup>2</sup>	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 <sub>m</sub> /s = 0.4536 kg/s 1 kg/m <sup>2</sup> s = 0.2046 lb <sub>m</sub> /ft <sup>2</sup> s = 0.00636 slug/ft <sup>2</sup> s	1 gal/min = 0.00228 ft <sup>3</sup> /s = 0.06309 L/s 1 million gal/day = 1.5472 ft <sup>3</sup> /s = 0.04381 m <sup>3</sup> /s
Pressure	Force and Surface Tension
1 lb <sub>f</sub> /ft <sup>2</sup> = 47.88 Pa, 1 torr = 1 mm Hg 1 psi = 144 psf, 1 bar = 10 <sup>5</sup> Pa 1 atm = 2116.2 psf = 14.696 psia = 101,325 Pa = 29.9 in Hg = 33.9 ft H <sub>2</sub> O	1 lb <sub>f</sub> = 4.448222 N = 16 oz, 1 dyne = 1 g cm/s <sup>2</sup> = 10 <sup>-5</sup> N 1 kg <sub>f</sub> = 2.2046 lb <sub>f</sub> = 9.80665 N 1 U.S. (short) ton = 2000 lb <sub>f</sub> , 1 N = 0.2248 lb <sub>f</sub> 1 N/m = 0.0685 lb <sub>f</sub> /ft
Power	Energy and Specific Energy
1 hp = 550 (ft.lb <sub>f</sub> )/s = 745.7 W 1 (ft.lb <sub>f</sub> )/s = 1.3558 W 1 Watt = 3.4123 Btu/h = 0.00134 hp	1 ft lb <sub>f</sub> = 1.35582 J, 1 hp·h = 2544.5 Btu 1 Btu = 252 cal = 1055.056 J = 778.17 ft lb <sub>f</sub> 1 cal = 4.1855 J, 1 ft.lb <sub>f</sub> /lb <sub>m</sub> = 2.9890 J/kg
Specific Weight	Heat Flux
1 lb <sub>f</sub> /ft <sup>3</sup> = 157.09 N/m <sup>3</sup>	1 W/m <sup>2</sup> = 0.3171 Btu/(h ft <sup>2</sup> )
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 <sup>2</sup> /h = 2.506 · 10 <sup>-5</sup> m <sup>2</sup> /s, 1 ft <sup>2</sup> /s = 0.092903 m <sup>2</sup> /s 1 stoke (st) = 1 cm <sup>2</sup> /s = 0.0001 m <sup>2</sup> /s = 0.001076 ft <sup>2</sup> /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 <sup>3</sup> /(gmol.K) = 62.361 mm Hg.L/(gmol.K) = 1.134 atm.ft <sup>3</sup> /(lbmol.K) = 0.083144 bar.L/(gmol.K) = 10.73 psi. ft <sup>3</sup> /(lbmol. °R) = 555.0 mm Hg.ft <sup>3</sup> /(lbmol. °R)
<p>• Note that the intervals in absolute (Kelvin) and °C are equal. Also, 1 °R = 1 °F.</p> <p>Latent heat: 1 J/kg = 4.2995 × 10<sup>-4</sup> Btu/lb<sub>m</sub> = 10.76 lb<sub>f</sub>.ft/slug = 0.3345 lb<sub>f</sub>.ft/lb<sub>m</sub>, 1 Btu/lb<sub>m</sub> = 2325.9 J/kg</p> <p>Heat transfer coefficient: 1 Btu/(h.ft<sup>2</sup>.°F) = 5.6782 W/(m<sup>2</sup>.°C).</p> <p>Heat generation rate: 1 W/m<sup>3</sup> = 0.09665 Btu/(h ft<sup>3</sup>)</p> <p>Heat transfer per unit length: 1 W/m = 1.0403 Btu/(h ft)</p> <p>Mass transfer coefficient: 1 m/s = 11.811 ft/h, 1 lb<sub>mol</sub>/(h.ft<sup>2</sup>) = 0.013562 kgmol/(s.m<sup>2</sup>)</p>	

# Dimensions, Capacities, and Weights of Standard Steel Pipe<sup>†</sup>

Nominal pipe size, in.	Outside diameter, in.	Schedule no.	Wall thickness, in.	Inside diameter, in.	Cross-sectional area of metal, in. <sup>2</sup>	Inside sectional area, ft <sup>2</sup>	Circumference, ft or surface, ft <sup>2</sup> /ft of length		Capacity at 1 ft/s velocity		Pipe weight, lb/ft
							Outside	Inside	U.S. gal/min	Water, lb/h	
1/8	0.405	40	0.068	0.269	0.072	0.00040	0.106	0.0705	0.179	89.5	0.24
		80	0.095	0.215	0.093	0.00025	0.106	0.0563	0.113	56.5	0.31
1/4	0.540	40	0.088	0.364	0.125	0.00072	0.141	0.095	0.323	161.5	0.42
		80	0.119	0.302	0.157	0.00050	0.141	0.079	0.224	112.0	0.54
3/8	0.675	40	0.091	0.493	0.167	0.00133	0.177	0.129	0.596	298.0	0.57
		80	0.126	0.423	0.217	0.00098	0.177	0.111	0.440	220.0	0.74
1/2	0.840	40	0.109	0.622	0.250	0.00211	0.220	0.163	0.945	472.0	0.85
		80	0.147	0.546	0.320	0.00163	0.220	0.143	0.730	365.0	1.09
3/4	1.050	40	0.113	0.824	0.333	0.00371	0.275	0.216	1.665	832.5	1.13
		80	0.154	0.742	0.433	0.00300	0.275	0.194	1.345	672.5	1.47
1	1.315	40	0.133	1.049	0.494	0.00600	0.344	0.275	2.690	1,345	1.68
		80	0.179	0.957	0.639	0.00499	0.344	0.250	2.240	1,120	2.17
1 1/4	1.660	40	0.140	1.380	0.668	0.01040	0.435	0.361	4.57	2,285	2.27
		80	0.191	1.278	0.881	0.00891	0.435	0.335	3.99	1,995	3.00
1 1/2	1.900	40	0.145	1.610	0.800	0.01414	0.497	0.421	6.34	3,170	2.72
		80	0.200	1.500	1.069	0.01225	0.497	0.393	5.49	2,745	3.63
2	2.375	40	0.154	2.067	1.075	0.02330	0.622	0.541	10.45	5,225	3.65
		80	0.218	1.939	1.477	0.02050	0.622	0.508	9.20	4,600	5.02
2 1/2	2.875	40	0.203	2.469	1.704	0.03322	0.753	0.647	14.92	7,460	5.79
		80	0.276	2.323	2.254	0.02942	0.753	0.608	13.20	6,600	7.66
3	3.500	40	0.216	3.068	2.228	0.05130	0.916	0.803	23.00	11,500	7.58
		80	0.300	2.900	3.016	0.04587	0.916	0.759	20.55	10,275	10.25
3 1/2	4.000	40	0.226	3.548	2.680	0.06870	1.047	0.929	30.80	15,400	9.11
		80	0.318	3.364	3.678	0.06170	1.047	0.881	27.70	13,850	12.51
4	4.500	40	0.237	4.026	3.17	0.08840	1.178	1.054	39.6	19,800	10.79
		80	0.337	3.826	4.41	0.07986	1.178	1.002	35.8	17,900	14.98
5	5.563	40	0.258	5.047	4.30	0.1390	1.456	1.321	62.3	31,150	14.62
		80	0.375	4.813	6.11	0.1263	1.456	1.260	57.7	28,850	20.78
6	6.625	40	0.280	6.065	5.58	0.2006	1.734	1.588	90.0	45,000	18.97
		80	0.432	5.761	8.40	0.1810	1.734	1.508	81.1	40,550	28.57
8	8.625	40	0.322	7.981	8.396	0.3474	2.258	2.089	155.7	77,850	28.55
		80	0.500	7.625	12.76	0.3171	2.258	1.996	142.3	71,150	43.39
10	10.75	40	0.365	10.020	11.91	0.5475	2.814	2.620	246.0	123,000	40.48
		80	0.594	9.562	18.95	0.4987	2.814	2.503	223.4	111,700	64.40
12	12.75	40	0.406	11.938	15.74	0.7773	3.338	3.13	349.0	174,500	53.56
		80	0.688	11.374	26.07	0.7056	3.338	2.98	316.7	158,350	88.57

<sup>†</sup>Based on ANSI B36.10-1959 by permission of ASME.

$$h_{fc} = K_c \frac{\bar{V}_b^2}{2} \quad K_c = 0.4 \left( 1 - \frac{S_{small}}{S_{big}} \right) \quad h_{fs} = 4f_{fanning} \frac{L}{D} \frac{\bar{V}^2}{2} \quad h_k = K_f \frac{\bar{V}_a^2}{2}$$

$$h_{fe} = K_e \frac{\bar{V}_a^2}{2} \quad K_e = \left( 1 - \frac{S_{small}}{S_{big}} \right)^2 \quad h_L = \left( 4f \frac{L}{D} + K_c + K_e + K_f \right) \frac{\bar{V}^2}{2}$$

$$\text{Power, } P = \dot{m}W_p$$

### 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

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

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

$$\frac{\bar{f}L_{\max}}{r_H} = \frac{1}{k} \left( \frac{1}{\text{Ma}_a^2} - 1 - \frac{k+1}{2} \ln \frac{2\{1 + [(k-1)/2] \text{Ma}_a^2\}}{\text{Ma}_a^2 (k+1)} \right)$$

### Isentropic Flow

$$\left( \frac{T_2}{T_1} \right)^{\frac{k}{k-1}} = \left( \frac{\rho_2}{\rho_1} \right)^k = \left( \frac{p_2}{p_1} \right) \quad \frac{T}{T_0} = \frac{1}{1 + [(k-1)/2] \text{Ma}^2} \quad \frac{p}{p_0} = \left\{ \frac{1}{1 + [(k-1)/2] \text{Ma}^2} \right\}^{k/(k-1)}$$

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

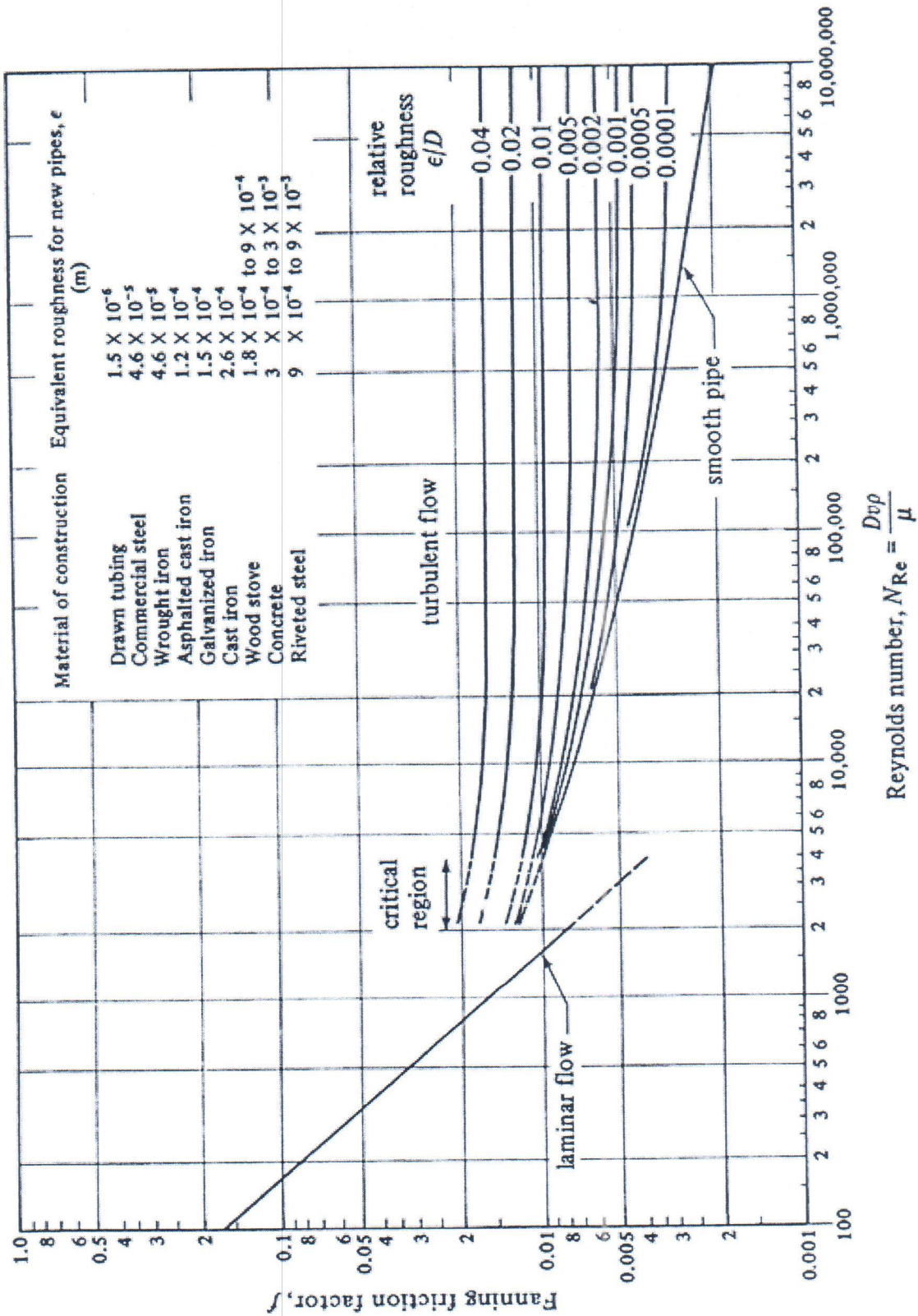
$$\frac{\rho}{\rho_0} = \left\{ \frac{1}{1 + [(k-1)/2] \text{Ma}^2} \right\}^{1/(k-1)}$$

...4/-

TABLE Friction Loss for Turbulent Flow Through Valves and Fittings

Type of Fitting or Valve	Frictional Loss, Number of Velocity Heads, $K_f$	Frictional Loss, Equivalent Length of Straight Pipe in Pipe Diameters, $L_e/D$
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.



Friction factors for fluids inside pipes. [Based on L. F. Moody, *Trans. A.S.M.E.*, 66, 671 (1944); *Mech. Eng.* 69, 1005 (1947). With permission.]

For fluidization;  $\frac{L_1}{L_{mf}} = \frac{(1 - \epsilon_{mf})}{(1 - \epsilon_1)}$ ;  $\Delta P_{mf} = L_{mf}(1 - \epsilon_{mf}) (\rho_s - \rho_f) g$

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

$u_t = \frac{g D_p^2 [\rho_p - \rho_f]}{18 \mu_f}$  for Stoke's law and  $u_t = 1.75 \sqrt{\frac{g D_p (\rho_p - \rho_f)}{\rho_f}}$  for Newton's law

For orifice;  $\frac{\Delta u^2}{2\alpha} + g\Delta Z + v \int_1^2 dP + W_s + F = 0$

Head =  $\frac{2.31 \times \text{pressure}}{SG}$ ; where head in ft and pressure in psi.

NPSH<sub>A</sub> = (h<sub>p</sub> - h<sub>vapor</sub>) - h<sub>f</sub> + Z<sub>s</sub>

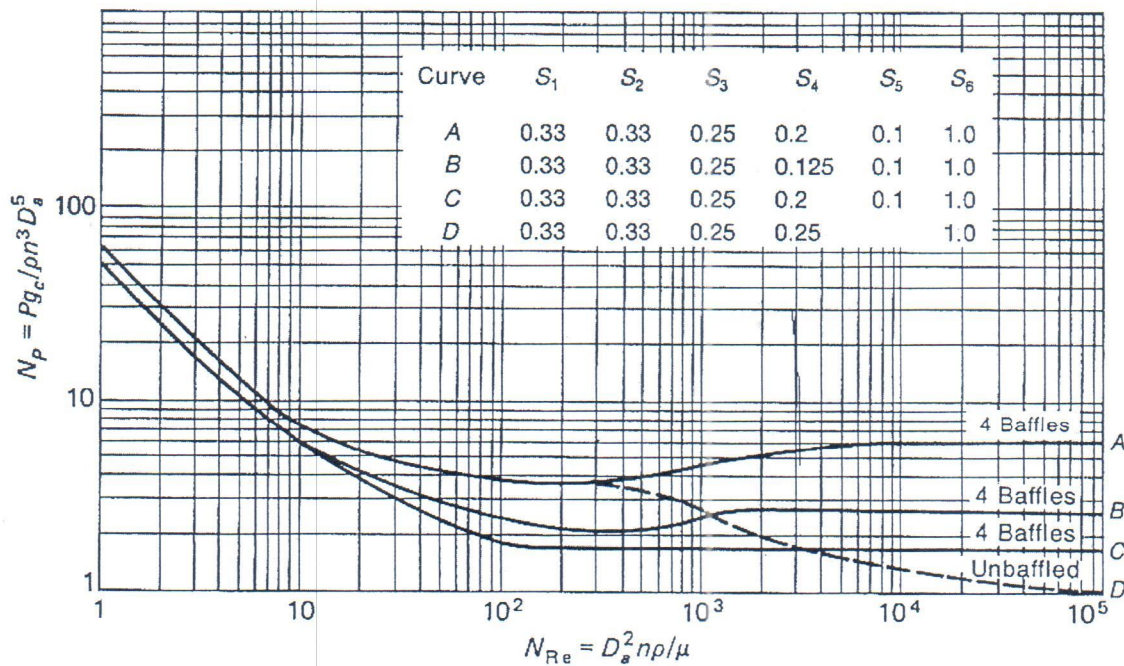


Figure Power number N<sub>p</sub> versus N<sub>Re</sub> for six-blade turbines. With the dashed portion of curve D, the value of N<sub>p</sub> read from the figure must be multiplied by N<sub>Fr</sub><sup>m</sup>.

$N_{RE} = \frac{D_a^2 n \rho}{\mu}$ ;  $N_{Fr} = \frac{n^2 D_a}{g}$

For six blades;  $m = \frac{1 - \log_{10} N_{Re}}{40}$ ;  $N_{P(Corr)} = N_P \times N_{Fr}^m$ ;  $P = \frac{N_P n^3 D_a^5 \rho}{g_c}$