UNIVERSITI SAINS MALAYSIA

First Semester Examination
2011/2012 Academic Session

January 2012

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 SIX pages of printed material and FOUR pages of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi ENAM muka surat yang bercetak dan EMPAT 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.
Jawab SEMUA soalan.

1. [a] The pressure rise, ΔP across a centrifugal pump from a given manufacture can be expected to depend on the angular velocity of the impeller (ω), the diameter (D) of the impeller, the volume flow-rate (Q), and the density of the fluid (ρ). By using the method of Buckingham Pi Theorem, show that

*Kenaikan tekanan, ΔP melalui pam empar yang diberi oleh pengilang dijangka bergantung kepada halaju sudut (ω), garis pusat pendesak (*D*), jumlah kadar aliran (*Q*), dan ketumpatan bendalir (ρ). Dengan menggunakan kaedah Teorem Pi Buckingham, tunjukkan bahawa*

$$\frac{\Delta P}{\rho \omega^2 D^2} = \Phi\left(\frac{Q}{\omega D^3}\right)$$

A model pump having an impeller diameter of 0.200 m is tested in the laboratory using water. The pressure rise when tested at an angular velocity of 40π rad/sec is shown in Figure Q.1.[a].

Pam model yang mempunyai diameter pendesak 0.200 m diuji dalam makmal dengan menggunakan air. Kenaikan tekanan apabila diuji pada halaju sudut 40π rad/saat ialah seperti ditunjukkan dalam Rajah S.1.[a].

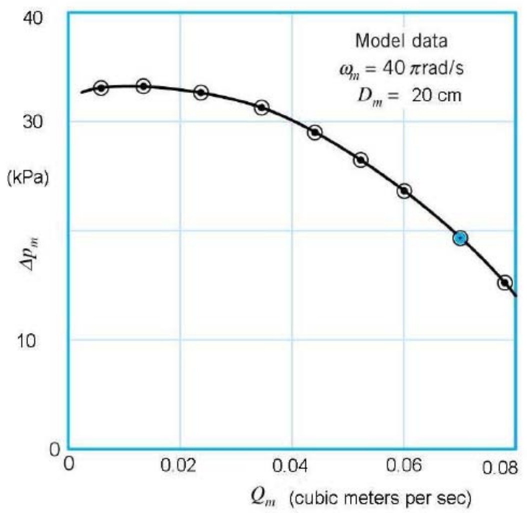

Figure Q.1.[a].
Rajah S.1.[a].

What would be the pressure rise for a geometrically similar pump with an impeller diameter of 0.35 m used to pump water operating at an angular velocity of 80π rad/sec and at a flow rate of 0.070 m^3/s?

Apakah kenaikan tekanan yang dijangkakan untuk pam yang serupa secara geometri tetapi dengan diameter pendesak 0.35 m dan digunakan untuk mengepam air pada halaju sudut 80π rad/saat dan kadar aliran sebanyak 0.070 m^3/s?

[15 marks/markah]

[b] Incompressible fluid flows steadily between two parallel plates, as shown in the Figure Q.1.[b]. At the inlet, the flow is uniform, with velocity, $u = U_0 = 8$ cm/s, while the flow develops into the parabolic laminar profile at downstream with $u = az(z_0 - z)$, where a is a constant. If $z_0 = 4$ cm and the fluid is SAE 30 oil at 20°C, what is the value of u_{max} in cm/s?

Bendalir tidak termampat mengalir di antara dua plat selari, seperti yang ditunjukkan dalam Rajah S.1.[b]. Pada salur masuk, aliran adalah seragam dengan halaju, $u = U_0 = 8$ *sm/s, manakala aliran berbentuk parabola dalam profil lamina berlaku di hiliran dengan* $u = az(z_0 - z)$, *di mana* a *ialah pemalar. Jika* $z_0 = 4$ *sm dan bendalir tersebut ialah minyak SAE 30 pada 20°C, apakah nilai* U_{max} *dalam sm/s?*

[10 marks/markah]

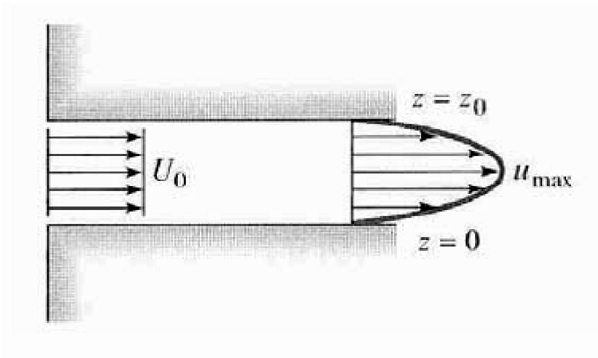

Figure Q.1.[b].
Rajah S.1.[b].

2. [a] Data were obtained from measurements on a vertical section of old, corroded, galvanized iron pipe of 2.5 cm inside diameter. At one section the pressure was $P_1 = 700$ kPa; at a second section, 5.5 meters lower, the pressure was $P_2 = 500$ kPa. The volume flow rate of 20°C water was 11.2 m^3/hr. What percent savings in pump power would result if the pipe was restored to its new, clean relative roughness?

Data diperolehi daripada pengukuran paip menegak tergalvani besi yang lama, berkarat dan bergaris pusat dalaman 2.5 sm. Pada satu bahagian, tekanan $P_1 = 700$ *kPa, pada bahagian kedua, 5.5 meter lebih rendah, tekanan* $P_2 = 500$ *kPa. Kadar alir isipadu air pada 20°C adalah 11.2* m^3*/jam. Berapakah peratusan penjimatan kuasa pam akan diperolehi jika paip baru dengan kekasaran relatif baru dan bersih digunakan?*

[15 marks/markah]

[b] A gas with specific heat ratio of 1.4 flows along a circular pipe with a diameter, *D* of 35 mm. The Mach number at the entrance to the pipe is 0.2. Assume adiabatic flow conditions with friction loss coefficient given by f = 0.0025. Calculate the distance from the entrance of the pipe to the section at which the Mach number will be 0.6. For compressible and adiabatic flow, does the wall friction accelerate or decelerate the flow? Explain.

Gas dengan nisbah haba tentu 1.4 mengalir di sepanjang paip bulat dengan diameter, D, 35 mm. Nombor Mach pada kemasukan paip ialah 0.2. Andaikan keadaan aliran adiabatik dengan pekali kehilangan geseran, f = *0.0025. Kira jarak dari kemasukan paip ke bahagian paip di mana nombor Mach adalah 0.6. Bagi aliran boleh mampat dan adiabatik, adakah geseran dinding mempercepatkan atau menurunkan kadar aliran? Terangkan.*

[10 marks/markah]

3. [a] A spherical particle is settling in still air at 30°C and 1 atm. The particle has a density of 1520 kg/m^3 and a diameter of 28 μm. Take air density and viscosity as 1.12 kg/m^3 and 1.7 x 10^{-5} kg/ms, respectively, calculate:

Satu zarah berbentuk sfera jatuh di dalam persekitaran udara tenang 30°C dan 1 atm. Zarah tersebut mempunyai ketumpatan 1520 kg/m^3 dan berdiameter 28 μm. Dengan mengambil ketumpatan dan kelikatan udara masing-masing 1.12 kg/m^3 and 1.7 x *10^{-5} kg/ms, kirakan:*

[i] Particle terminal velocity
Halaju terminal zarah

[ii] Drag force
Daya hela

[iii] Buoyancy force
Daya apungan

[iv] Drag coefficient
Pekali hela

[14 marks/markah]

[b] Water is flowing at a velocity of 0.02 m/s in a pipe of 0.25 m in diameter. In the pipe, there is an orifice with a hole diameter of 0.15 m. Take water density and viscosity as 1000 kg/m^3 and 1.0 x 10^{-3} kg/ms, respectively, calculate the pressure drop across the orifice?

Air mengalir pada kelajuan 0.02 m/s di dalam suatu paip berdiameter 0.25 m. Di dalam paip ini terdapat sebuah orifis berdiameter 0.15 m. Dengan mengambil ketumpatan dan kelikatan air masing-masing 1000 kg/m^3 dan 1.0 x *10^{-3} kg/ms, kirakan kejatuhan tekanan di sepanjang orifis tersebut.*

[6 marks/markah]

[c] Using velocity guidelines, what is the optimum pipe diameter for 165 gpm water?
Dengan menggunakan garis panduan halaju, apakah diameter paip optimum untuk air 165 gpm?

[5 marks/markah]

4. [a] A partial oxidation is carried out by passing 0.22 m/s air 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^{o}C and 2 atm. The density of the catalyst pellets is 1200 kg/m^3 and their sphericity is 0.92. The reactor operates at 200^{o}C. The air viscosity and density are 2.6 x 10^{-5} Pa.s and 1.54 kg/m^3, respectively. Assume voidage of packed bed = 0.45;

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 dan ianya dipadatkan dengan pelet mangkin 1 mm. Udara memasuki lapisan dari bawah pada 200^{o}C dan 2 atm. Ketumpatan pelet mangkin adalah 1200 kg/m^3 dan kesferaannya 0.92. Reaktor beroperasi pada 200^{o}C. Kelikatan dan ketumpatan udara masing-masing 2.6 x 10^{-5} Pa.s dan 1.54 kg/m^3. Anggap lompangan untuk lapisan terpadat = 0.45;

[i] Calculate outlet pressure from the packed bed.
Kirakan tekanan keluaran dari lapisan terpadat.

[ii] Calculate the air flowrate that just enough to fluidize the solids.
Kirakan kadar aliran udara yang secukupnya untuk membendalirkan pepejal.

[iii] Calculate velocity required to expand the fluidize bed by 30%.
Kirakan halaju yang diperlukan bagi mengembangkan lapisan terbendalir sebanyak 30%.

Given : $\Phi_s \varepsilon^3_{mf} = 1/14$
Diberi :

[15 marks/markah]

[b] What is the difference between required net positive suction head ($NPSH_R$) and available net positive suction head ($NPSH_A$)?

Apakah perbezaan di antara turus sedutan positif bersih yang diperlukan ($NPSH_R$) dan turus sedutan positif bersih sedia ada ($NPSH_A$)?

[3 marks/markah]

[c] A fluid at 85^{o}F is pumped through the system shown in Figure Q.4.[c] 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?

Suatu bendalir bersuhu 85^{o}F dipamkan melalui sistem seperti yang ditunjukkan pada Rajah S.4.[c]. 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 yang diperlukan adalah 18 kaki, adakah pam ini sesuai bagi perkhidmatan tersebut?

[7 marks/markah]

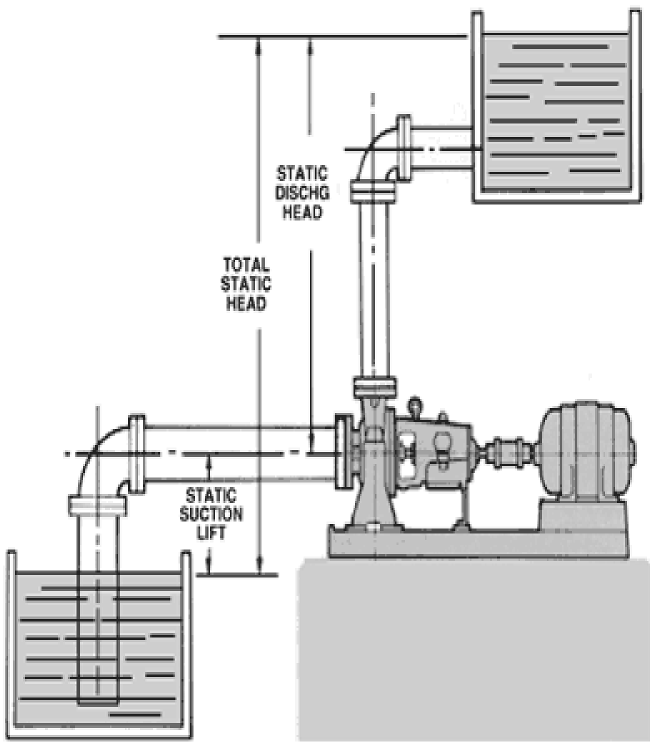

Figure Q.4.[c].
Rajah S.4.[c].

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Appendix

Isentropic Flow

$$\frac{dV}{V} = -\frac{dA}{A}\frac{1}{(1-Ma^2)} \qquad \frac{T}{T_o} = \frac{1}{1+[(k-1)/2]Ma^2} \qquad \frac{P}{P_o} = \left\{\frac{1}{1+[(k-1)/2]Ma^2}\right\}^{k/k-1}$$

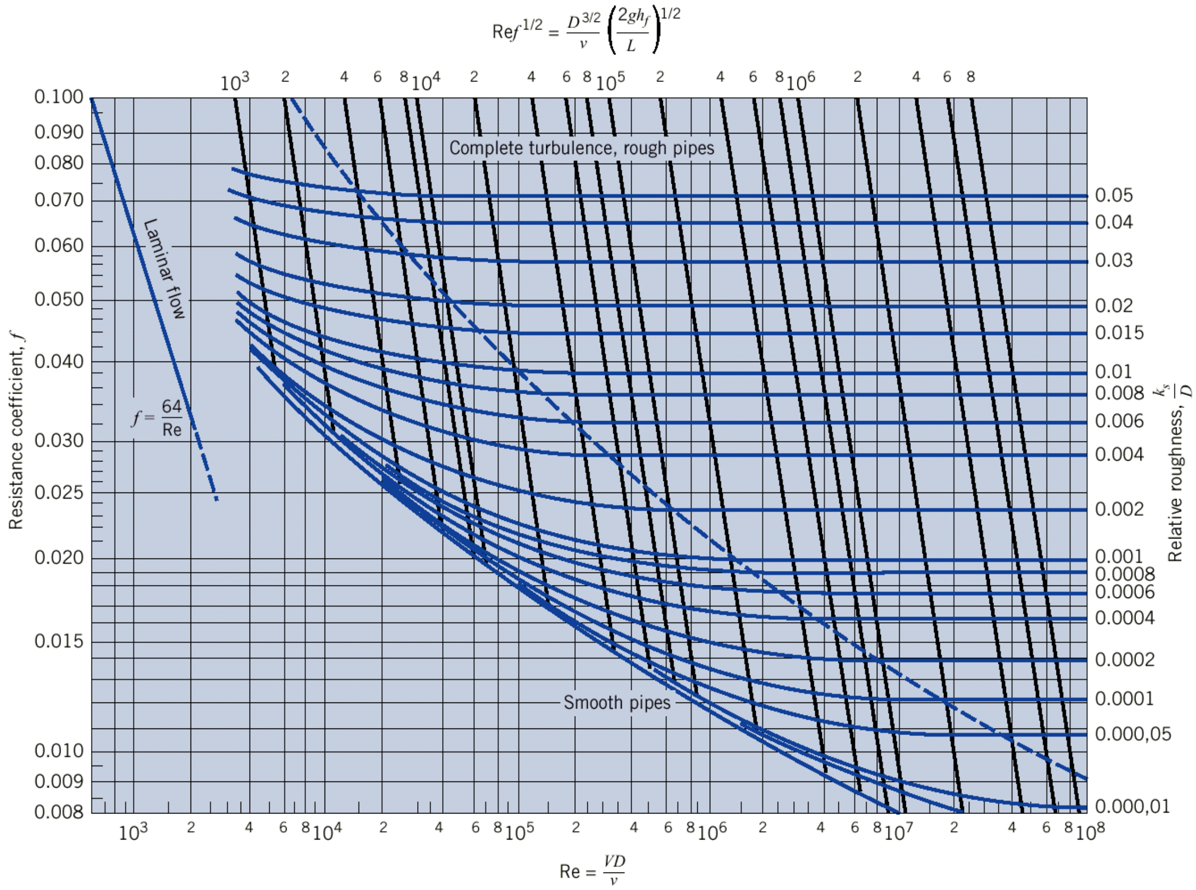
Fanno Flow

$$\frac{1}{k}\frac{(1-Ma^2)}{Ma^2} + \frac{k+1}{2k}\ln\left\{\frac{[(k+1)/2]Ma^2}{1+[(k-1)/2]Ma^2}\right\} = \frac{f(\ell^* - \ell)}{D} \qquad \frac{T}{T^*} = \frac{(k+1)/2}{1+[(k-1)/2]Ma^2} \qquad \frac{P}{P^*} = \frac{1}{Ma}\left\{\frac{(k+1)/2}{1+[(k-1)/2]Ma^2}\right\}^{1/2}$$

Isothermal flow

$$\frac{f(X_T - X_M)}{D} = \ln\left(DMa^2\right) + \frac{(1-kMa^2)}{kMa^2} \qquad P_a^2 - P_b^2 = G^2RT\left[2\ln\frac{\rho_a}{\rho_b} + \frac{f(L_b - L_a)}{r_H}\right]$$

Moody Chart



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Dimensionless number

Re	Reynolds number	ratio of inertia and viscous forces	$\rho dv/\eta$
Fr	Froude number	ratio of inertia and gravity forces	v^2/gd
Nu	Nusselt number	ratio of total and molecular heat transfer	hd/λ
Sh	Sherwood number	ratio of total and molecular mass transfer	kd/D
Pr	Prandtl number	ratio of molecular and momentum heat transfer	$\eta C/\lambda$
Sc	Schmidt number	ratio of molecular and momentum mass transfer	$\eta/\rho D$
Fo	Fourier number	dimensionless time characterising heat flux into a body	$\lambda t/\rho Cd^2$
f	Fanning friction factor	dimensionless pressure drop	$d\Delta P/2L\rho v^2$
j_H	Colburn j factor	dimensionless heat transfer coefficient	$NuRe^{-1}Pr^{-0.33}$
j_M	Colburn j factor	dimensionless mass transfer coefficient	$ShRe^{-1}Sc^{-0.33}$

Approximate Physical Properties of Water at Atmospheric Pressure

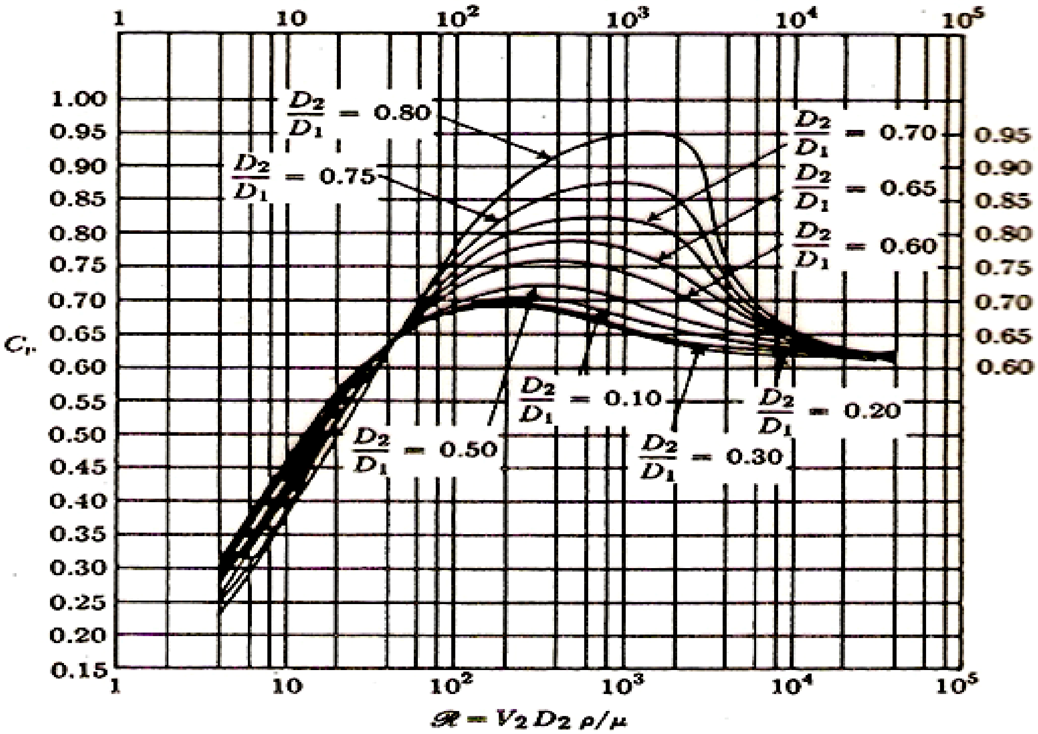
Temperature	Density	Specific Weight	Dynamic Viscosity	Kinematic Viscosity	Vapor Pressure
	kg/m^3	N/m^3	$N \cdot s/m^2$	m^2/s	N/m^2 abs.
0°C	1000	9810	1.79×10^{-3}	1.79×10^{-6}	611
5°C	1000	9810	1.51×10^{-3}	1.51×10^{-6}	872
10°C	1000	9810	1.31×10^{-3}	1.31×10^{-6}	1230
15°C	999	9800	1.14×10^{-3}	1.14×10^{-6}	1700
20°C	998	9790	1.00×10^{-3}	1.00×10^{-6}	2340
25°C	997	9781	8.91×10^{-4}	8.94×10^{-7}	3170
30°C	996	9771	7.97×10^{-4}	8.00×10^{-7}	4250
35°C	994	9751	7.20×10^{-4}	7.24×10^{-7}	5630
40°C	992	9732	6.53×10^{-4}	6.58×10^{-7}	7380
50°C	988	9693	5.47×10^{-4}	5.53×10^{-7}	12,300
60°C	983	9643	4.66×10^{-4}	4.74×10^{-7}	20,000
70°C	978	9594	4.04×10^{-4}	4.13×10^{-7}	31,200
80°C	972	9535	3.54×10^{-4}	3.64×10^{-7}	47,400
90°C	965	9467	3.15×10^{-4}	3.26×10^{-7}	70,100
100°C	958	9398	2.82×10^{-4}	2.94×10^{-7}	101,300

Equivalent Sand Grain Roughness, k_s, For Various Pipe Materials

Boundary Material	**k_s, millimeters**	**k_s, inches**
Glass, plastic	Smooth	Smooth
Copper or brass tubing	0.0015	6×10^{-5}
Wrought iron, steel	0.046	0.002
Asphalted cast iron	0.12	0.005
Galvanized iron	0.15	0.006
Cast iron	0.26	0.010
Concrete	0.3 to 3.0	0.012–0.12
Riveted steel	0.9–9	0.035–0.35
Rubber pipe (straight)	0.025	0.001

Immersed body, $u_t = \dfrac{g\, d_p^{\,2}\left[\dfrac{\rho_s}{\rho_f} - 1\right]}{18 \nu_f}$; $F_d = 3\pi\mu_f d_p u_t$; $F_B = \pi(\dfrac{d_p^{\,3}}{6})\rho_f . g$; $C_d = \dfrac{24\mu_f}{\rho_f u_t d_p}$

For orifice; $\Delta P = \dfrac{\rho u_2^2}{2C_D^2}(1-\beta^4)$; $\beta = d_2 / d_1$



For velocity guidelines

sizing steel pipelines

Turbulent flow	
Type of fluid	Reasonable velocity, ft/s
Water or fluid similar to water	3–10

Viscous flow (liquids)			
Nominal pipe diameter, in.	Reasonable velocity, ft/s		
	μ_c = 50	μ_c = 100	μ_c = 1000
1	1.5–3	1–2	0.3–0.6
2	2.5–3.5	1.5–2.5	0.5–0.8
4	3.5–5.0	2.5–3.5	0.8–1.2
8		4.0–5.0	1.3–1.8

μ_c = viscosity, centipoises.

1 ft^3 = 7.4805 gallon

For fluidization;

$$\frac{\Delta P}{L} = \frac{150 \mu V}{\phi_S^2 D_P^2} x \frac{(1-\varepsilon)^2}{\varepsilon^3} + \frac{1.75 \rho_f (V)^2}{\phi_S D_P} x \frac{1-\varepsilon}{\varepsilon^3} \; ; \; \left(\frac{\Delta P}{L}\right)_{mf} = (1-\varepsilon_{mf})(\rho_p - \rho_f) g \quad ;$$

$$\frac{(1-\varepsilon_2)}{(1-\varepsilon_{mf})} = \frac{L_{mf}}{L_2}$$

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

$NPSH_A = (h_p - h_{vapor}) - h_f + Z_s$