UNIVERSITI SAINS MALAYSIA

Second Semester Examination
Academic Session 2003/2004

February/March 2004

# IEK 103/3 – UNIT OPERATIONS I

Duration : 3 hours

Please check that the examination paper consists of **EIGHT (8)** printed pages before you commence this examination.

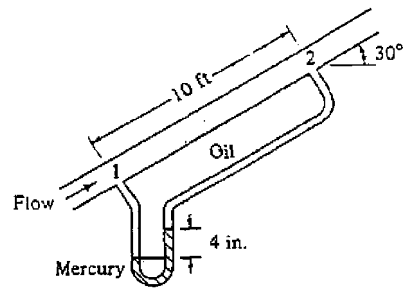
Answer <u>FIVE</u> questions only. Students are allowed to answer all questions in English <u>OR</u> Bahasa Malaysia <u>OR</u> combinations of both.

1. (a) Water flows through a pipe of 0.15 m diameter fitted with an orifice meter of 0.10 m diameter. A vertical manometer is fitted across the orifice meter. The manometer fluid is mercury of specific gravity 13.6. Water fills the arms of the manometer. The reading of the manometer is 0.254 cm. If the coefficient of the orifice can be taken as 0.60, what is the volumetric flow rate of water at 15.56 °C ? The density of water at 15.56 °C is 999.0 $kg/m^3$.

(70 marks)

(b) A manometer is fitted on to a pipeline as shown below. An oil of specific gravity 0.9 flows in the pipe. The manometer fluid is mercury (S.G. = 13.6), and the manometer reading is 4.0 in. What is the value of $p_1 - p_2$ ?

(30 marks)




2. A horizontal steel pipe has a diameter of 0.0526 m and a length of 30.48 m. The pipe roughness is k = 0.000045 m. A fluid of density 1200 $kg/m^3$ and viscosity 0.01 $N.s/m^2$ flows in the pipe at a rate of 9.085 $m^3/h$. Calculate
   (i) pressure drop, in $N/m^2$;
   (ii) power required for the flow.

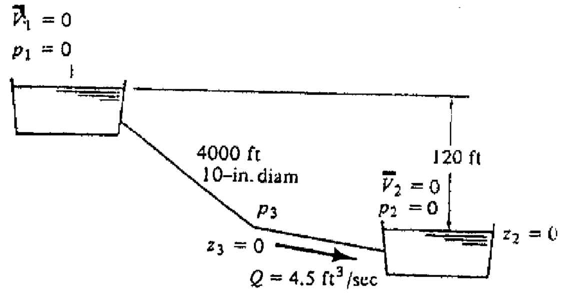
(100 marks)

3. (a) A tank is filled with a fluid of viscosity 0.08 $N.s/m^2$ and density 975 $kg/m^3$. The tank is without baffle. A 6 flat-blade turbine of diameter 0.15 m rotating at 18 rps is fitted in the tank 0.15 m from the bottom. What power is required for the operation ?

(50 marks)

(b) Two open water reservoirs as shown are connected through a smooth pipe of 10 in diameter and 4000 ft long. The water level in the upper tank is 120 ft above that of the lower tank. The volumetric flow rate is 4.5 $ft^3/s$ at 70 °F. Calculate
   (i) the friction loss for the system;
   (ii) What is the value of the pressure $p_3$ ?

(50 marks)




4. A liquid of density 63.5 $lb/ft^3$ and viscosity 1.35 cP is pumped through a steel pipe of 2 in diameter to the top of a storage tank open to the atmosphere. The volumetric flow rate of the liquid is 120 gal/min. The idscharge of the pipe is 60 ft above the pump and the equivalent length of the steel pipe from the pump to the tank is 175 ft. If the pressure at the suction of the pump is 20 $lb_f/in^2$, and the pump efficiency is 65%, calculate
   (i) the brake horsepower of the pump;
   (ii) pressure at the discharge of the pump;
   (iii) If the electrical energy cost is 7 cent for every kWh (kilowatt-hour), what is the energy cost for pumping the liquid per day ?

(100 marks)

5. Consider the heat transfer by natural convection between a hot (or cold) vertical plate with a height of L at uniform temperature $T_w$ and a surrounding fluid that is cooler of (hotter) with a uniform temperature $T_a$. The local heat transfer coefficient $h_x$ at a height x is proportional to the local temperature difference between the plate and the fluid: $h_x = (dq/dA)/(T_w - T_a)$ It is found that the following physical factors are involved in the process:

$$f(h_x, x, k, C_p, \rho, \mu, \beta, \Delta T, g) = 0$$

With the use of Buckingham Theorem, obtain the relation among the above variables. The dimensional matrix is as follows:

| | $h_x$ | x | k | $C_p$ | ρ | μ | β | ΔT | g |
|---|---|---|---|---|---|---|---|---|---|
| $\bar{M}$ | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 |
| $\bar{L}$ | 0 | 1 | 1 | 2 | -3 | -1 | 0 | 0 | 1 |
| $\bar{t}$ | -3 | 0 | -3 | -2 | 0 | -1 | 0 | 0 | -2 |
| $\bar{T}$ | -1 | 0 | -1 | -1 | 0 | 0 | -1 | 1 | 0 |

(100 marks)

6. (a) A horizontal venturi meter of throat diameter 2.50 cm is fitted to a pipeline of diameter 7.82 cm. Water at 26.67 °C flows through the pipeline. Mercury (S.G. = 13.6) manometer is used. If the manometer reading is 39.0 cm, what is the mass flow rate, in kg/s ? If 10% of the differential pressure is lost, what is the power consumption of the meter ?

(60 marks)

(b) Oil ($\rho = 900$ kg/m$^3$ and $\nu = 2 \times 10^{-4}$ m$^2$/s) flows in a smooth 5 x 5 cm square duct at an average velocity of 4.0 m/s. What is the pressure drop in 25 m long of the duct ?

(40 marks)

# CONVERSION FACTORS AND CONSTANTS OF NATURE

| To convert from | To | Multiply by† |
|---|---|---|
| acre | ft$^2$ | 43,560* |
| | m$^2$ | 4046.85 |
| atm | N/m$^2$ | 1.01325* × $10^5$ |
| | lb$_f$/in.$^2$ | 14.696 |
| Avogadro number | particles/g mol | 6.022169 × $10^{23}$ |
| barrel (petroleum) | ft$^3$ | 5.6146 |
| | gal (U.S.) | 42* |
| | m$^3$ | 0.15899 |
| bar | N/m$^2$ | 1* × $10^5$ |
| | lb$_f$/in.$^2$ | 14.504 |
| Boltzmann constant | J/K | 1.380622 × $10^{-23}$ |
| Btu | cal$_{IT}$ | 251.996 |
| | ft-lb$_f$ | 778.17 |
| | J | 1055.06 |
| | kWh | 2.9307 × $10^{-4}$ |
| Btu/lb | cal$_{IT}$/g | 0.55556 |
| Btu/lb-°F | cal$_{IT}$/g-°C | 1* |
| Btu/ft$^2$-h | W/m$^2$ | 3.1546 |
| Btu/ft$^2$-h-°F | W/m$^2$-°C | 5.6783 |
| | kcal/m$^2$-h-K | 4.882 |
| Btu-ft/ft$^2$-h-°F | W-m/m$^2$-°C | 1.73073 |
| | kcal/m-h-K | 1.488 |
| cal$_{IT}$ | Btu | 3.9683 × $10^{-3}$ |
| | ft-lb$_f$ | 3.0873 |
| | J | 4.1868* |
| cal | J | 4.184* |
| cm | in. | 0.39370 |
| | ft | 0.0328084 |
| cm$^3$ | ft$^3$ | 3.531467 × $10^{-5}$ |
| | gal (U.S) | 2.64172 × $10^{-4}$ |
| cP (centipoise) | kg/m-s | 1* × $10^{-3}$ |
| | lb/ft-h | 2.4191 |
| | lb/ft-s | 6.7197 × $10^{-4}$ |
| cSt (centistoke) | m$^2$/s | 1* × $10^{-6}$ |
| faraday | C/g mol | 9.648670 × $10^4$ |
| ft | m | 0.3048* |
| ft-lb$_f$ | Btu | 1.2851 × $10^{-3}$ |
| | cal$_{IT}$ | 0.32383 |
| | J | 1.35582 |
| ft-lb$_f$/s | Btu/h | 4.6262 |
| | hp | 1.81818 × $10^{-3}$ |
| ft$^2$/h | m$^2$/s | 2.581 × $10^{-5}$ |
| | cm$^2$/s | 0.2581 |
| ft$^3$ | cm$^3$ | 2.8316839 × $10^4$ |
| | gal (U.S.) | 7.48052 |
| | L | 28.31684 |
| ft$^3$-atm | Btu | 2.71948 |
| | cal$_{IT}$ | 685.29 |
| | J | 2.8692 × $10^3$ |
| ft$^3$/s | gal (U.S)/min | 448.83 |
| gal (U.S.) | ft$^3$ | 0.13368 |
| | in.$^3$ | 231* |
| gravitational constant | N-m$^2$/kg$^2$ | 6.673 × $10^{-11}$ |
| gravity acceleration, standard | m/s$^2$ | 9.80665* |
| h | min | 60* |
| | s | 3600* |
| hp | Btu/h | 2544.43 |
| | kW | 0.74624 |
| hp/1000 gal | kW/m$^3$ | 0.197 |
| in. | cm | 2.54* |
| in.$^3$ | cm$^3$ | 16.3871 |
| J | erg | 1* × $10^7$ |
| | ft-lb$_f$ | 0.73756 |
| kg | lb | 2.20462 |
| kWh | Btu | 3412.1 |
| L | m$^3$ | 1* × $10^{-3}$ |
| lb | kg | 0.45359237* |
| lb/ft$^3$ | kg/m$^3$ | 16.018 |
| | g/cm$^3$ | 0.016018 |
| lb$_f$/in.$^2$ | N/m$^2$ | 6.89473 × $10^3$ |
| lb mol/ft$^2$-h | kg mol/m$^2$-s | 1.3562 × $10^{-3}$ |
| | g mol/cm$^2$-s | 1.3562 × $10^{-4}$ |
| light, speed of | m/s | 2.997925 × $10^8$ |
| m | ft | 3.280840 |
| | in. | 39.3701 |
| m$^3$ | ft$^3$ | 35.3147 |
| | gal (U.S.) | 264.17 |
| N | dyn | 1* × $10^5$ |
| | lb$_f$ | 0.22481 |
| N/m$^2$ | lb$_f$/in.$^2$ | 1.4498 × $10^{-4}$ |
| Planck constant | J-s | 6.626196 × $10^{-34}$ |
| proof (U.S.) | percent alcohol by volume | 0.5 |
| ton (long) | kg | 1016 |
| | lb | 2240* |
| ton (short) | lb | 2000* |
| ton (metric) | kg | 1000* |
| | lb | 2204.6 |
| yd | ft | 3* |
| | m | 0.9144* |

† Values that end in an asterisk are exact by definition

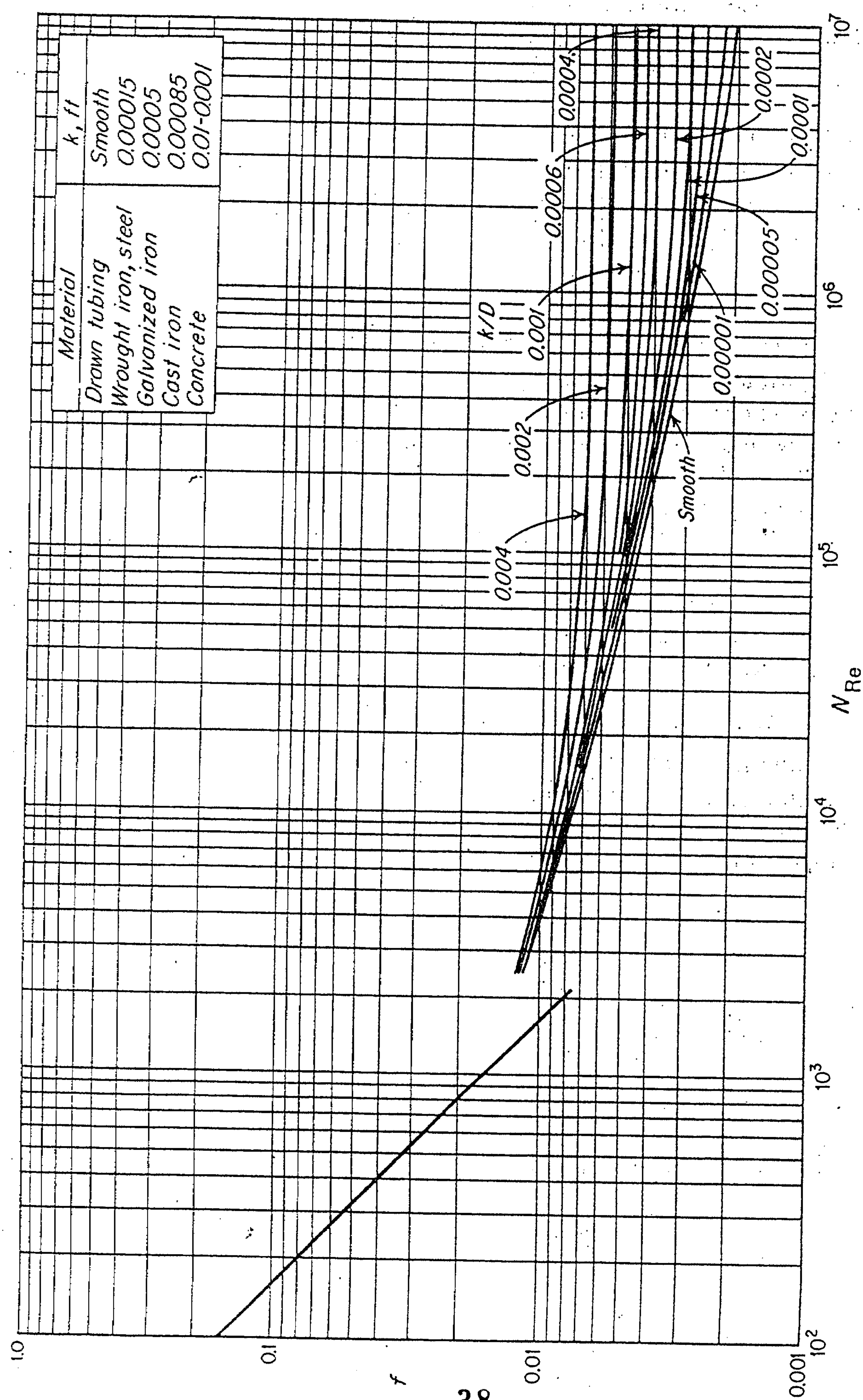


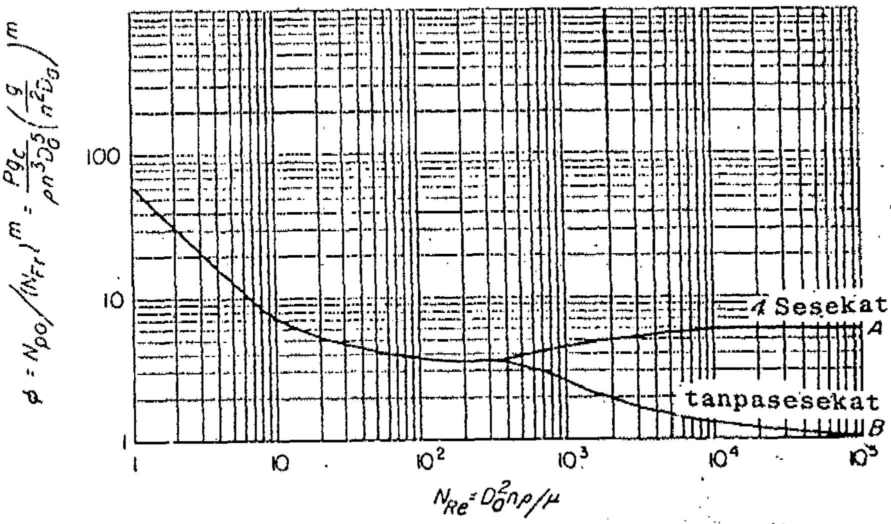

FIGURE
Friction-factor chart.

# PROPERTIES OF LIQUID WATER



| Temperature $T$, °F | Viscosity† $\mu'$, cP | Thermal conductivity‡ $k$, Btu/ft-h-°F | Density§ $\rho$, lb/ft$^3$ | $\psi_f = \left(\frac{k^3\rho^2 g}{\mu^2}\right)^{1/3}$ |
|---|---|---|---|---|
| 32 | 1.794 | 0.320 | 62.42 | 1,410 |
| 40 | 1.546 | 0.326 | 62.43 | 1,590 |
| 50 | 1.310 | 0.333 | 62.42 | 1,810 |
| 60 | 1.129 | 0.340 | 62.37 | 2,050 |
| 70 | 0.982 | 0.346 | 62.30 | 2,290 |
| 80 | 0.862 | 0.352 | 62.22 | 2,530 |
| 90 | 0.764 | 0.358 | 62.11 | 2,780 |
| 100 | 0.682 | 0.362 | 62.00 | 3,020 |
| 120 | 0.559 | 0.371 | 61.71 | 3,530 |
| 140 | 0.470 | 0.378 | 61.38 | 4,030 |
| 160 | 0.401 | 0.384 | 61.00 | 4,530 |
| 180 | 0.347 | 0.388 | 60.58 | 5,020 |
| 200 | 0.305 | 0.392 | 60.13 | 5,500 |
| 220 | 0.270 | 0.394 | 59.63 | 5,960 |
| 240 | 0.242 | 0.396 | 59.10 | 6,420 |
| 260 | 0.218 | 0.396 | 58.53 | 6,830 |
| 280 | 0.199 | 0.396 | 57.94 | 7,210 |
| 300 | 0.185 | 0.396 | 57.31 | 7,510 |

† From *International Critical Tables*, vol. 5, McGraw-Hill Book Company, New York, 1929, p. 10.
‡ From E. Schmidt and W. Sellschopp, *Forsch. Geb. Ingenieurw.*, 3:277 (1932).
§ Calculated from J. H. Keenan and F. G. Keyes, *Thermodynamic Properties of Steam*, John Wiley & Sons., Inc., New York, 1937.




Rajah Fungsi kuasa $\phi$ lwn $N_{Re}$ bagi turbin 6 bilah.

$S_1 = D_t/D_a$

$S_2 = E/D_a$

$S_3 = L/D_a$

$S_4 = W/D_a$

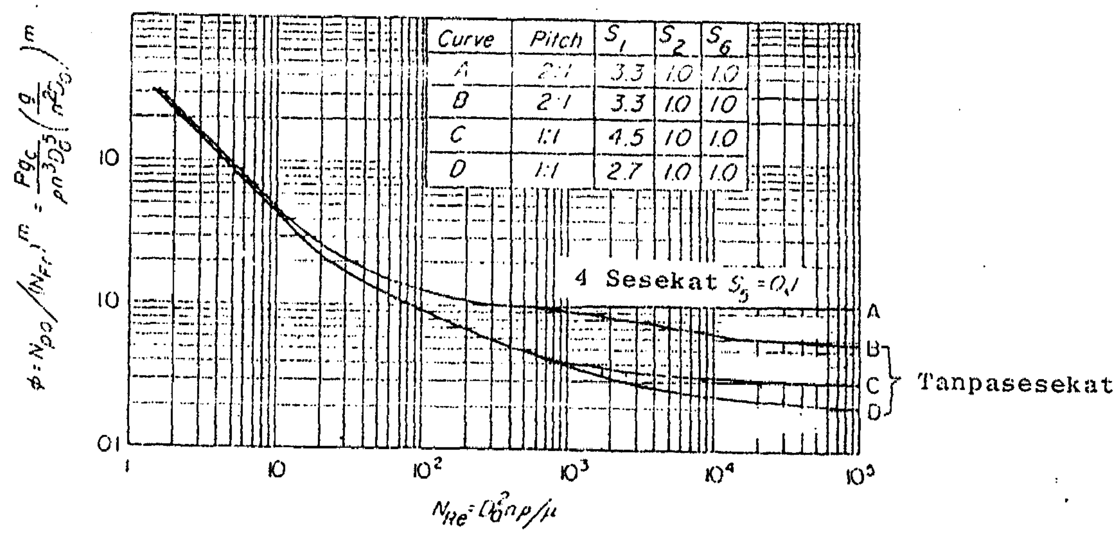
$S_5 = J/D_t$

$S_6 = H/D_t$

$m = (a - \log N_{Re})/b$

Jadual Pemalar a dan b.

| *Fig.* | *Line* | *a* | *b* |
|---|---|---|---|
| 9-14 | *B* | 1.0 | 40.0 |
| 9-15 | *B* | 1.7 | 18.0 |
| 9-15 | *C* | 0 | 18.0 |
| 9-15 | *D* | 2.3 | 18.0 |




Rajah Fungsi kuasa $\phi$ lwn $N_{Re}$ bagi propeler 3 bilah