04-CHEM-A2, MECHANICAL and THERMAL OPERATIONS

December 2016

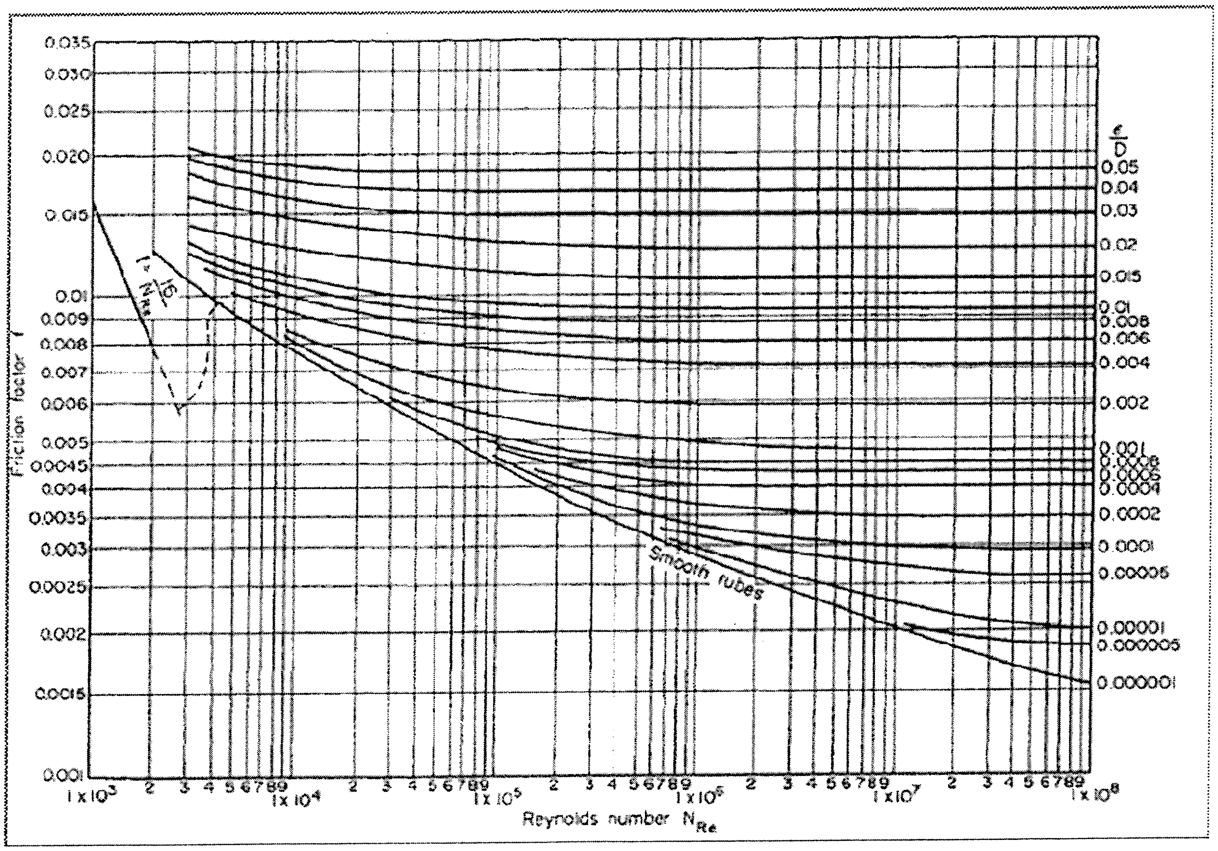
3 hours duration

NOTES

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
2. The examination is an **open book exam.** One textbook of your choice with notations listed on the margins etc., but no loose notes are permitted into the exam.
3. Candidates may use any **non-communicating** scientific calculator.
4. All problems are worth 25 points. At least **two problems** from **each** of sections **A** and **B** must be attempted.
5. **Only the first two** questions as they appear in the answer book **from each section** will be marked.
6. State all assumptions clearly.

Section A: Mechanical Operations

A1. Crude oil is to be transferred from one tank to another by way of a pump and standard 8-inch Schedule 40 steel pipe (internal diameter = 20.27 cm) at a rate of 4000 liters per minute. The suction line to the pump is 15 meters long, and the discharge is a further 180 meters. The discharge tank is 10 meters higher than the feed tank. The entrance to the feed tank and to the discharge tank are both square-edged, and there is a fully open globe valve in the line. There are two bends between the globe valve and discharge tank. If the crude oil has a specific gravity of 0.88 and dynamic viscosity of 8.5×10^{-2} N.s/m^2 and the roughness of the steel pipe is 0.046 mm, determine the power requirement assuming a pump efficiency of 70%. Allow for entrance and exit head losses of 1.5 velocity heads. The valve used to regulate the flow has an equivalent length-to-diameter ratio of 340, and the two bends have an equivalent length-to-diameter ratio of 30.



Fanning friction factor (f) vs. Reynolds number (Re) for pipes

Transactions of the American Society of Mechanical Engineers, vol. 66, p.672 (1944)

A2. Oil (viscosity = 3 x 10^{-3} Ns/m^2 and density = 900 kg/m^3) is passed vertically upwards through a bed of catalyst consisting of approximately spherical particles (diameter = 0.1 mm and and density = 2600 kg/m^3). The voidage of catalyst bed is 0.48.

(a) **[15 points]** At approximately what mass flow rate per unit area of will fluidization occur?

(b) **[10 points]** At approximately what mass flow rate per unit area of will transport of particles occur?

A3. A slurry containing 40% by mass solid is to be filtered on a rotary drum filter (diameter = 2 meters and length = 2 meters), which normally operates with 40% of its surface immersed in the slurry and under a pressure of 17 kN/m^2. A laboratory test on a sample of the slurry using a leaf filter (area = 200 cm^2) and covered with a similar cloth to that on the drum produced 300 cm^3 of filtrate in the first 60 seconds and 140 cm^3 in the next 60 seconds, when the leaf was under an absolute pressure of 17 kN/m^2. The bulk density of the dry cake was 1500 kg/m^3 and the density of the filtrate was 1000 kg/m^3. The minimum thickness of cake, which could be readily removed from the cloth, was 5 mm.

(a) **[20 points]** At what speed should the drum rotate for maximum throughput?

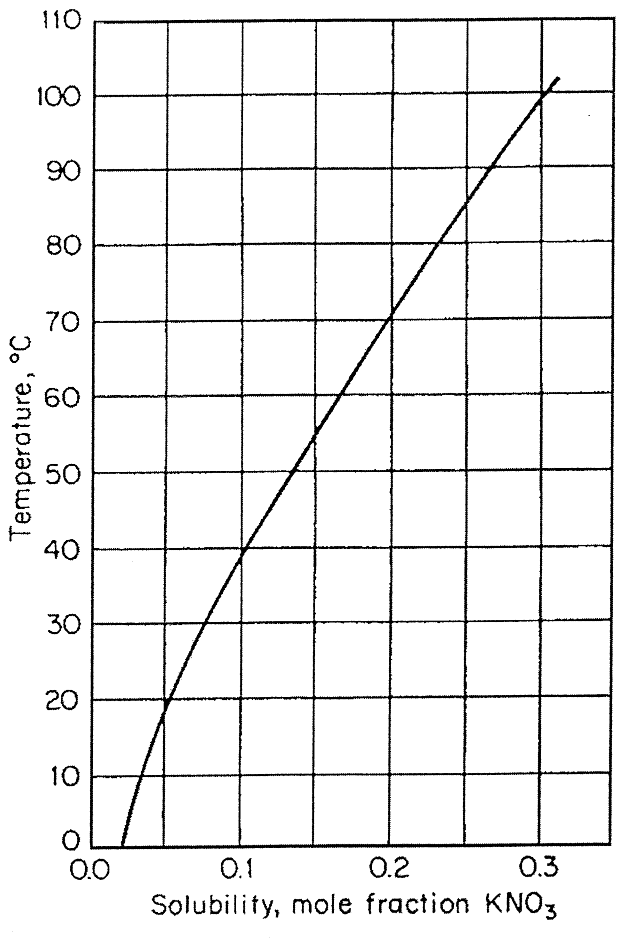
(b) **[5 points]** What is the maximum throughput in terms of the mass of the slurry fed to the unit per unit time?

Section B: Thermal Operations

B1. A 62.5% by weight aqueous solution of potassium nitrate (KNO_3) originally at 100 °C is gradually cooled to 10 °C in a crystallizer.

(a) **[20 points]** What is the yield of KNO_3 solids as a function of temperature?

(b) **[5 points]** How many kilograms of KNO_3 solids are produced 10 °C if the original solution weighed 22,680 kg?



Solubility of KNO_3 in water versus temperature
Perry's Chemical Engineers' Handbook, 8th Edition (2007)

B2. A countercurrent rotary dryer at 295 K is fed granular material containing 40% moisture and the material is withdrawn at 305 K containing 5% moisture. The air supplied, which contains 0.006 kg water vapor per kg of dry air, enters the dryer at 385 K and leaves at 310 K. The dryer handles 0.125 kg/sec wet stock of granular material. Assuming that radiation losses amount to 20 kJ/kg of dry air used, determine the following:

(a) **[18 points]** Mass flow of dry air supplied to the dryer

(b) **[7 points]** Humidity of air leaving the dryer.

DATA:

Specific heat capacity of dried granular material = 0.88 kJ/kg K
Specific heat capacity of dry air = 1.00 kJ/kg K
Specific heat capacity of water vapor = 2.01 kJ/kg K
Latent heat of water vapor at 295 K = 2449 kJ/kg

B3. A shell-and-tube heat exchanger with one shell-side pass and one tube-side pass has the following geometry:

Shell diameter = 63.5 cm
Number of tubes = 532
Length of a tube = 4.8 m
Outer diameter of tube = 1.9 cm
Inner diameter of tube = 1.6 cm
Spacing between tubes (triangular arrangement) = 2.4 cm
Baffle spacing = 24.1 cm

The tube material is stainless steel with a thermal conductivity of 17 W/m K. The fouling heat-transfer coefficient is 5670 W/m^2 K. The change in viscosity with temperature can be assumed negligible. Calculate the overall heat-transfer coefficient for this heat exchanger under the following service conditions:

Tube side liquid undergoing sensible-heat transfer

Flow rate = 226,795 kg/hr — Specific heat = 2.1 kJ/kg K
Viscosity = 5 x 10^{-4} Pa.s — Specific gravity = 0.8
Thermal conductivity = 0.13 W/m K

Tube side liquid undergoing sensible-heat transfer

Flow rate = 90,718 kg/hr — Specific heat = 4.19 kJ/kg K
Viscosity = 8.3 x 10^{-4} Pa.s — Specific gravity = 1.0
Thermal conductivity = 0.62 W/m K

The Periodic Table of the Elements

- ☐ Alkali metals
- ☐ Alkaline earth metals
- ☐ Transition metals
- ☐ Other metals
- ☐ Metalloids (semi-metal)
- ☐ Nonmetals
- ☐ Halogens
- ☐ Noble gases

Element name → Mercury
80 ← Atomic #
Symbol → Hg
200.59 ← Avg. Mass

1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Hydrogen 1 H 1.01																		Helium 2 He 4.00
Lithium 3 Li 6.94	Beryllium 4 Be 9.01												Boron 5 B 10.81	Carbon 6 C 12.01	Nitrogen 7 N 14.01	Oxygen 8 O 16.00	Fluorine 9 F 19.00	Neon 10 Ne 20.18
Sodium 11 Na 22.99	Magnesium 12 Mg 24.31												Aluminum 13 Al 26.98	Silicon 14 Si 28.09	Phosphorus 15 P 30.97	Sulfur 16 S 32.07	Chlorine 17 Cl 35.45	Argon 18 Ar 39.95
Potassium 19 K 39.10	Calcium 20 Ca 40.08		Scandium 21 Sc 44.96	Titanium 22 Ti 47.88	Vanadium 23 V 50.94	Chromium 24 Cr 52.00	Manganese 25 Mn 54.94	Iron 26 Fe 55.85	Cobalt 27 Co 58.93	Nickel 28 Ni 58.69	Copper 29 Cu 63.55	Zinc 30 Zn 65.39	Gallium 31 Ga 69.72	Germanium 32 Ge 72.61	Arsenic 33 As 74.92	Selenium 34 Se 78.96	Bromine 35 Br 79.90	Krypton 36 Kr 83.80
Rubidium 37 Rb 85.47	Strontium 38 Sr 87.62		Yttrium 39 Y 88.91	Zirconium 40 Zr 91.22	Niobium 41 Nb 92.91	Molybdenum 42 Mo 95.94	Technetium 43 Tc (98)	Ruthenium 44 Ru 101.07	Rhodium 45 Rh 102.91	Palladium 46 Pd 106.42	Silver 47 Ag 107.87	Cadmium 48 Cd 112.41	Indium 49 In 114.82	Tin 50 Sn 118.71	Antimony 51 Sb 121.76	Tellurium 52 Te 127.60	Iodine 53 I 126.90	Xenon 54 Xe 131.29
Cesium 55 Cs 132.91	Barium 56 Ba 137.33	57-70 *	Lutetium 71 Lu 174.97	Hafnium 72 Hf 178.49	Tantalum 73 Ta 180.95	Tungsten 74 W 183.84	Rhenium 75 Re 186.21	Osmium 76 Os 190.23	Iridium 77 Ir 192.22	Platinum 78 Pt 195.08	Gold 79 Au 196.97	Mercury 80 Hg 200.59	Thallium 81 Tl 204.38	Lead 82 Pb 207.20	Bismuth 83 Bi 208.98	Polonium 84 Po (209)	Astatine 85 At (210)	Radon 86 Rn (222)
Francium 87 Fr (223)	Radium 88 Ra (226)	89-102 **	Lawrencium 103 Lr (262)	Rutherfordium 104 Rf (267)	Dubnium 105 Db (268)	Seaborgium 106 Sg (271)	Bohrium 107 Bh (272)	Hassium 108 Hs (270)	Meitnerium 109 Mt (276)	Darmstadtium 110 Ds (281)	Roentgenium 111 Rg (280)	Copernicium 112 Cn (285)	Ununtrium 113 Uut (284)	Ununquadium 114 Uuq (289)	Ununpentium 115 Uup (288)	Ununhexium 116 Uuh (293)	Ununseptium 117 Uus (294?)	Ununoctium 118 Uuo (294)

*lanthanides	Lanthanum 57 La 138.91	Cerium 58 Ce 140.12	Praseodymium 59 Pr 140.91	Neodymium 60 Nd 144.24	Promethium 61 Pm (145)	Samarium 62 Sm 150.36	Europium 63 Eu 151.97	Gadolinium 64 Gd 157.25	Terbium 65 Tb 158.93	Dysprosium 66 Dy 162.50	Holmium 67 Ho 164.93	Erbium 68 Er 167.26	Thulium 69 Tm 168.93	Ytterbium 70 Yb 173.04
**actinides	Actinium 89 Ac (227)	Thorium 90 Th 232.04	Protactinium 91 Pa 231.04	Uranium 92 U 238.03	Neptunium 93 Np (237)	Plutonium 94 Pu (244)	Americium 95 Am (243)	Curium 96 Cm (247)	Berkelium 97 Bk (247)	Californium 98 Cf (251)	Einsteinium 99 Es (252)	Fermium 100 Fm (257)	Mendelevium 101 Md (258)	Nobelium 102 No (259)