MANILA REVIEW INSTITUTE, INC.
3F Consuelo Building, 929 Nicanor Reyes St. (formerly Morayta), Manila
Tel. No. 8-736-MRII (6744)
www.manilareviewinstitute.com

CHEMICAL ENGINEERING REFRESHER COURSE

UNIT OPERATIONS

Problems 1 and 2 are based on the following information:

An irreversible gas-phase reaction is carried out in a batch reactor at 25°C. The reaction is: A + B → C with a rate of $-r_A = 3.5E\text{-}5\ C_A C_B$ in $mol/m^3\text{-}s$. The reactor is filled with an equal amount of moles of A and B. The initial concentration of A is 50 mol/m^3.

1. Calculate the conversion of A after 5000 s for a variable-volume batch reactor in which the pressure is held constant.
   a. 95.43%
   b. 86.68%
   c. 93.65%
   d. 89.51%

2. If the reaction is changed to: A + B → 2C + D while other initial conditions and variables held constant, what is the conversion of A after 5000 s?
   a. 95.43%
   b. 93.65%
   c. 89.51%
   d. 86.68%

Problems 3 and 5 are based on the following information:

The liquid-phase bromination (B) of 2,4,6-trimethylacetophenone (A) is: A + B → C + D with a rate of $-r_A = 0.0434 C_A C_B$ in M/s. A battery of three identical CSTR's in series will be used. The volumetric flow rate of the feed is 1 L/s while the initial concentration of feed A is 0.05 M and B is 0.06 M

3. What is the overall conversion of the first CSTR?
   a. 36.4%
   b. 48.7%
   c. 21.9%
   d. 52.8%

4. What is the overall conversion of the second CSTR?
   a. 49.2%
   b. 53.1%
   c. 77.7%
   d. 69.4%

5. What is the volume of the third CSTR?
   a. 613 L
   b. 316 L
   c. 428 L
   d. 248 L

6. In a laboratory experiment, a sample is pumped at a constant pressure drop of 5 psi through 0.25 ft2 of filter medium with negligible resistance. After 3 minutes, 1 gallon of filtrate was collected. The slurry is then filtered using a plate-and-frame press with 16 frames, 4 ft2 of filtering area per frame, and operating at constant flow rate of 30 gpm. It takes 15 minutes to disassemble, clean, and reassemble the press. The press must be shut down for disassembly when the pressure difference builds up to 10 psi. What is the net filtration rate in gpm for the plate-and-frame filter press?
   a. 26.0
   b. 12.9
   c. 16.7
   d. 20.4

7. Calculate the specific cake resistance in ft/lbm from the following CaCO3 slurry in water filtration data at 20 °C at a constant pressure of 30 kPa abs. The area of the plate-and-frame press is 0.045 m2 and the slurry concentration was 25 kg solid/L filtrate.

V (L)	0.5	1.0	1.5	2.0	2.5	3.0
t (s)	17.3	41.3	72.0	108.3	152.0	201.7

   a. 2.49×10^{10}
   b. 1.65×10^{11}
   c. 5.61×10^{11}
   d. 9.42×10^{10}

Problems 8 and 10 are based on the following information:

A two-stage centrifugal compressor will be used to supply a pressure of 600 kPag of 575 kg/h hydrogen gas from standard ambient conditions. Take the efficiency for both compressors as 76% with interstage cooling and assume ideal gas behavior.

8. Determine the actual power requirement at isothermal conditions.
   a. 949 kW
   b. 499 kW
   c. 379 kW
   d. 739 kW

9. Determine the actual power requirement at isentropic conditions.
   a. 755 kW
   b. 575 kW
   c. 437 kW
   d. 347 kW

10. Determine the actual power requirement at polytropic conditions.
   a. 602 kW
   b. 602 kW
   c. 458 kW
   d. 584 kW

11. What type of compressor is recommended to be used if the desired volumetric flow rate is 1000 cfm and the discharge pressure is 400 psia?
   a. mixed
   b. centrifugal
   c. axial
   d. reciprocating

12. Which of the following is true when compressible flow is choked?
   a. exit velocity greater than speed of sound
   b. reducing the downstream pressure will not increase the flow
   c. mass flow rate is not affected by upstream pressure
   d. Mach number is less than unity

Problems 13 and 15 are based on the following information:

Air flowing at a 0.90 kg/s is warmed from 283 K to 366 K by passing through pipes of a bank consisting of 20 pipes in each row. The arrangement is in-line with center-center spacing, in both directions, equal to twice the pipe diameter. The heating medium is flue gas with a mass velocity of 10 kg/m2-s; and enters at 700 K and leaves at 366 K, passes across outside of the pipes. For simplicity, the diameter of the other and inner pipes can be taken as 12 mm. The specific heat capacity of air and flue gas is 1.0 kJ/kg-K. Values for k and μ are shown:

T (K)	k (W/m-k)	μ (mPa-s)
250	0.022	0.0165
500	0.044	0.0276
800	0.055	0.0367

13. What is the mass velocity of the air inside the pipe in kg/m2-s?
   a. 23.1
   b. 29.1
   c. 21.9
   d. 19.9

14. Calculate the overall heat transfer coefficient in W/m2-K.
   a. 66.5
   b. 63.7
   c. 67.3
   d. 65.6

15. Neglecting gas radiation, how long should the pipes be?
   a. 962 m
   b. 926 m
   c. 629 m
   d. 692 m

16. What is the maximum allowable vapor velocity of a short-tube vertical evaporator maintained at 85 °C with dilute aqueous solution?
    a. 2.68 m/s
    b. 0.32 m/s
    c. 7.85 m/s
    d. 1.41 m/s

17. If the feed is above boiling point and has too high temperature rise through the heating element, what losses can be encountered in operating a forced-circulation evaporator?
    a. bubbling
    b. splashing
    c. foaming
    d. flashing

Problems 18 and 20 are based on the following information:

A double-effect evaporator system is to be used to concentrate glycerol-water solution from 10 to 40 percent glycerol by weight at a rate of 1000 kg/h of feed. Identical long-tube natural circulation evaporators are to be used, with overall heat transfer coefficients of 2270 and 1703 W/m2-C° expected for the first and second effects, respectively, when using backward feed. The feed enters at 15 °C while saturated steam at 120°C is used to heat the first effect. An absolute pressure of 115 mm Hg is to be maintained in the second effect. Assume that the specific heat of all solutions is equal to 4.187 J/g-C° and units are to have equal areas.

18. What is the heat transfer surface area in m2 of the second effect?
    a. 3.56
    b. 4.34
    c. 5.88
    d. 6.74

19. What is the steam consumption in kg/h?
    a. 478
    b. 748
    c. 874
    d. 784

20. What is the steam economy of the multi-effect system?
    a. 1.56
    b. 1.79
    c. 1.32
    d. 0.84

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