CHEMICAL ENGINEERING

SECTION - A

ONE MARKS QUESTIONS (1-29)

For each of the following questions (1 to 29) four alternatives A, B, C and Dare provided. Indicate the correct answer by writing A, B, C or D, as appropriate, against the corresponding question number in the box in the answer book.

(Marks: 1 × 29 = 29)

1. A pair of fair dice is rolled simultaneously. The probability that the sum of the numbers from the dice equals six is
   a. $\frac{1}{6}$
   b. $\frac{7}{36}$
   c. $\frac{5}{36}$
   d. $\frac{1}{12}$

2. For an even function f(x),
   a. $\int_{-a}^{a} f(x)dx = 0$
   b. $\int_{-a}^{a} f(-x)dx = 0$
   c. $f(x) = -f(-x)$
   d. $f(x) = f(-x)$

3. The integrating factor for the differential equation $(\cos x)\frac{dy}{dx} + y = \tan x$, is
   a. [illegible]
   b. $\cos 2x$
   c. [illegible]
   d. $\sin 2x$

4. In a binary liquid solution of components A and B, if component A exhibits positive deviation from Raoult's law, then component B
   a. exhibits positive deviation from Raoult's law.
   b. exhibits negative deviation from Raoult's law.
   d. may exhibit either positive or negative deviation from Raoult's law.

5. Assume that benzene is insoluble in water. The normal boiling points of benzene and water are 80.1°C and 100°C, respectively. At a pressure of 1-atm, the boiling point of a mixture of benzene and water is
   a. 80.1 °C
   b. less than 80.1°C
   c. 100°C
   d. greater than 80.1°C but less than 100°C

6. On a P - V diagram of an ideal gas, suppose a reversible adiabatic line intersects a reversible isothermal line at point A. Then at point A, the slope of the reversible adiabatic line $\left(\frac{\partial P}{\partial V}\right)_S$ and the slope of the reversible isothermal line $\left(\frac{\partial P}{\partial V}\right)_T$ are related as (where $\gamma = \frac{C_p}{C_v}$)
   a. $\left(\frac{\partial P}{\partial V}\right)_S = \left(\frac{\partial P}{\partial V}\right)_T$
   b. $\left(\frac{\partial P}{\partial V}\right)_S = \left[\left(\frac{\partial P}{\partial V}\right)_T\right]^{\gamma}$
   c. $\left(\frac{\partial P}{\partial V}\right)_S = \gamma\left(\frac{\partial P}{\partial V}\right)_T$
   d. $\left(\frac{\partial P}{\partial V}\right)_S = \frac{1}{\gamma}\left(\frac{\partial P}{\partial V}\right)_T$

7. The molar composition of a gas is 10% H_2, 10% O_2, 30% CO_2 and balance H_2O. If 50% H_2O condenses, the final mole percent of H_2 in the gas on a dry basis will be
   a. 10%
   b. 5%
   c. 18.18%
   d. 20%

8. For a sphere falling in the constant drag coefficient regime, its terminal velocity depends on its diameter (d) as
   a. d
   b. $\sqrt{d}$
   c. d^2

9. In a fully turbulent flow ($Re > 10^5$) in a pipe of diameter d, for a constant pressure gradient, the dependence of volumetric flow rate of an incompressible fluid is
   a. d
   b. d^2
   c. $d^{2.5}$
   d. d^4

10. In the laminar boundary layer flow over a flat plate, the ratio (δ/x) varies as:
    a. Re
    b. $\sqrt{Re}$
    c. $\frac{1}{Re}$
    d. $Re^{-1/2}$

    where δ is the boundary layer thickness and x is the distance from the leading edge in the direction of flow.

11. For laminar flow of a shear-thinning liquid in a pipe, if the volumetric flow rate is doubled, the pressure gradient will increase by a factor of
    a. 2
    b. < 2
    c. > 2
    d. 1/2

12. The Grashof number is defined as the ratio of
    a. buoyancy to inertial forces.
    b. buoyancy to viscous forces.
    c. inertial to viscous forces.
    d. buoyancy to surface tension forces.

13. A sphere of radius, R_1 is enclosed in a sphere of radius, R_2. The view (or shape) factor for radiative heat transfer of the outer sphere with respect to the inner sphere is
    a. 0
    b. $\frac{R_2}{R_1 + R_2}$
    c. 1
    d. $\left(\frac{R_1}{R_2}\right)^2$

14. The absorption factor is defined as
    a. $\frac{L}{mG}$
    b. $\frac{G}{mL}$
    c. $\frac{mL}{G}$
    d. $\frac{LG}{m}$

    where L = liquid flow rate, G = gas flow rate and m = slope of the equilibrium line.

15. At 750 K and 1 atm. the approximate value of the Schmidt number for air is
    a. 0.01
    b. 0.1
    c. 1
    d. 10

16. For the n^{th} tray (counted from the bottom of a distillation column), the Murphree tray efficiency is given by
    a. $\frac{y_{n+1} - y_n}{y_n^* - y_{n+1}}$
    b. $\frac{y_n - y_{n-1}}{y_n^* - y_{n-1}}$
    c. $\frac{y_{n-1} - y_n}{y_{n+1} - y_n}$
    d. $\frac{y_n^* - y_{n-1}}{y_n^* - y_{n+1}}$

17. The McCabe ΔL law states that the
    a. molar heats of vaporization of components are nearly equal.
    b. linear crystal growth rate depends on the degree of super saturation.
    c. linear crystal growth rate does not depend on the crystal size.
    d. linear crystal growth rate depends on the crystal size.

18. The experimentally determined overall order for the reaction A + B → C + D is two. Then the
    a. reaction is elementary with a molecularity of 2.
    b. molecularity of the reaction is 2, but the reaction may not be elementary.
    c. reaction may be elementary with a molecularity of 2.
    d. reaction is elementary but the molecularity may not be 2.

19. The reaction A → B is conducted in an isothermal batch reactor. If the conversion of A increases linearly with holding time, then the order of the reaction is
    a. 0
    b. 1
    c. 1.5
    d. 2

20. For the liquid phase parallel reactions

$A \rightarrow R \quad r_R = k_1 C_A^2; \quad E_1 = 80\ kJ/mol$

$A \rightarrow S \quad r_S = k_2 C_A; \quad E_2 = 120\ kJ/mol$

the desired product is R. A higher selectivity of R will be achieved if the reaction is conducted at

a. low temperature in a CSTR.
b. high temperature in a CSTR.
c. low temperature in a PFR.
d. high temperature in a PFR.

21. In solid catalysed reactions the diffusional effects are more likely to affect the overall rate of reaction for
a. fast reactions in catalysts of small pore diameter.
b. fast reactions in catalysts of large pore diameter.
c. slow reactions in catalysts of small pore diameter.
d. slow reactions in catalysts of large pore diameter.

22. In petroleum refining, the process used for conversion of hydrocarbons to aromatics is
a. catalytic cracking
b. catalytic reforming
c. hydrotreating
d. alkylation.

23. Commercially, ethylene is produced from naphtha by
a. catalytic cracking
b. catalytic dehydrogenation.
c. pyrolysis
d. hydrocracking.

24. Triple super phosphate is manufactured by reacting
a. phosphate rock with phosphoric acid.
b. phosphate rock with sulphuric acid.
c. phosphate rock with nitric acid.
d. ammonium phosphate with phosphoric acid.

25. The unit step response of the transfer function $\frac{2s-1}{(3s+1)(4s+1)}$ reaches its final steady state asymptotically after
a. a monotonic increase.
b. a monotonic decrease.
c. initially increasing and then decreasing.
d. initially decreasing and then increasing.

26. The unit step response of the transfer
a. has a non-zero slope a
b. has a damped oscillatory
c. is overdamped.
d. is unstable.

27. Select the correct statement from the following:
a. The frequency response of a pure capacity process is unbounded.
b. The phase lag of a pure time delay system decreases with increasing frequency.
c. The amplitude ratio of a pure capacity process is inversely proportional to the frequency.
d. The amplitude ratio of a pure time delay system increases with frequency.

28. For a feedback control system to be stable, the
a. roots of the characteristic equation should be real.
b. poles of the closed loop transfer function should lie in the left half of the complex plane.
c. Bode plots of the corresponding open loop transfer function should monotonically decrease.
d. poles of the closed loop transfer function should lie in the right half of the complex plane.

29. For a typical project, the cumulative cash flow is zero at the
a. end of the project life.
b. break-even point.
c. start-up.
d. end of the design stage.

TWO MARKS QUESTIONS (30-53)

For each of the following questions (30 to 53), four alternatives — A, B, C, and D are provided. Indicate the correct answer by writing A, B, C, or D, as appropriate, against the corresponding question number in the answer book.

(Marks: 2 × 23 = 46)

30. The line integral of $\int_C \left\{ \frac{y}{x^2+y^2}dx - \frac{x}{x^2+y^2}dy \right\}$, where C is the unit circle around the origin traversed once in the counter—clockwise direction, is
a. -2π

d. π

31. The inverse of the matrix $\begin{bmatrix} 1 & -1 \\ -1 & -1 \end{bmatrix}$

a. Does not exist

b. is $\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$

c. is $\begin{bmatrix} 0.5 & -0.5 \\ -0.5 & -0.5 \end{bmatrix}$

d. $\begin{bmatrix} -0.5 & 0.5 \\ 0.5 & 0.5 \end{bmatrix}$

32. The complex conjugate of $\frac{1}{1+i}$ is

a. $\frac{1}{1-i}$

b. (1 – i)

c. 0.5(1- i)

d. in the first quadrant of the complex plane

33. The general solution of $\frac{d^4y}{dx^4}+2\frac{d^2y}{dx^2}+y=0$ is

a. $(C_1x+C_2)e^{x}+(C_3+C_4x)e^{-x}$

b. $C_1\cos x+C_2\sin x+C_3e^{x}+C_4e^{-x}$

c. $C_1e^{ix}+C_2e^{-ix}$

d. $(C_1+C_2x)\cos x+(C_3+C_4x)\sin x$

where C_1, C_2, C_3 *and* C_4 are constants

34. The thermal efficiency of a reversible heat engine operating between two given thermal reservoirs is 0.4. The device is used either as a refrigerator or as a hear pump between the same reservirs. Then the coefficient of performance as a refrigerator $(COP)_R$ and the coefficient of performance as a heat pump $(COP)_{HP}$ are

a. $(COP)_R = (COP)_{HP} = 0.6$

b. $(COP)_R = 2.5$, $(COP)_{HP} = 1.5$

c. $(COP)_R = 1.5$; $(COP)_{HP} = 2.5$

d. $(COP)_R = (COP)_{HP} = 2.5$

35. At a given temperature, K_1, K_2 and K_3 are the equilibrium constants for the following reactions 1, 2, 3 respectively:

$$CH_4(g)+H_2O \rightleftharpoons CO(g)+3H_2(g) \quad (1)$$

$$CO(g)+H_2O(g) \rightleftharpoons CO_2(g)+H_2(g) \quad (2)$$

$$CH_4(g)+2H_2O(g) \rightleftharpoons CO_2(g)+4H_2(g) \quad (3)$$

Then K_1, K_2 and K_3 are related as

a. $K_3 = K_1K_2$

c. $K_3 = \frac{(K_1K_2)}{2}$

d. $K_3 = (K_1K_2)^2$

36. The sphericity of a solid particle of cube shape is

a. π

b. $\left(\frac{\pi}{6}\right)^{\frac{1}{3}}$

c. $\left(\frac{\pi}{6}\right)^{\frac{1}{2}}$

d. $\frac{\pi}{3}$

37. A 30% (by volume) suspension of spherical sand particles in a viscous oil has hindered settling velocity of 4.44 µm/s. If the Richardso2-Zakl hindered setting index is 4.5, then the terminal velocity of a sand grain is

a. 0.[illegible] µm/s

b. [illegible] µm/s

c. 22.1 µm/s

d. 0.02 µm/s

38. A 1 m high bed made up of a mm particles is to be fluidlsed by an oil (density 900 kg/m^3; viscosity 0.01 Pa s). If at the point of incipient fluidization, the bed voltage is 39% and the pressure drop across the bed is 10 kPa, then the density of particles is

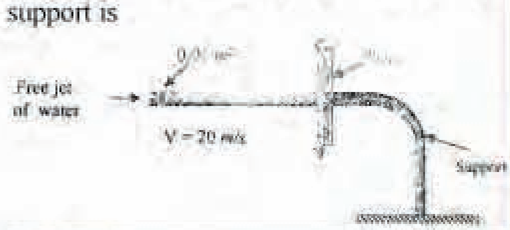
a. 2574 kg/m^3

b. 3514 kg/m^3

c. 4000 kg/m^3

d. 4350 kg/m^3

39. A free jet of water of cross-sectional area 0.02 m^2 and velocity of 20 m/s strikes a plate and then flows in the plane parallel to the plate as shown in the figure below. The horizontal component of the force on the support is



a. 200 N

b. 400 N

c. 2000 N

d. 4000 N

40. A steel sphere of radius 0.1 m at 400 K is

of the sphere reaches 350 K in 20 minutes, how long will it take for a 0.05 m radius steel sphere to teach the same temperature (at the centre) under identical conditions? Assume that the convective heat transfer coefficient is infinitely targe.

a. 5 min
b. 10 min
c. 20 min
d. 40 min

41. A composite flat wall of a mace is made of two materials A and B. The thermal conductivity of A is twice of that of material B, while the thickness of layer of A is half of that of B. If the temperatures at the two sides of the wall are 400 and 1200 K, then the temperature drop (in K) across the layer of material A is

a. 125
b. 133
c. 150
d. 160

42. For turbulent flow in a tube the heat transfer coefficient is obtained from the Dittus-Boelter correlation. If the tube diameter is halved and the flow rate is doubled, then the heat transfer coefficient will change by a factor of

a. 1
b. 1.74
c. 6.1
d. 37

43. The individual mass transfer coefficients (mol/m^2 s) for absorption of a solute from a gas mixture into a liquid solvent are k_L = 4.5 and k_G = 1.5. The slope of the equilibrium line is 3. Which of the following resistance(s) is (are) controlling?

a. liquid — side
b. gas — side
c. interfacial
d. both liquid — and gas — side.

44. In a laboratory test run, the rate of drying was found to be 0.5×10^{-3} kg/m^2 s when the moisture content reduced from 0.4 to 0.1 on a dry basis. The critical moisture content of the material is 0.08 on a dry basis. A tray drier is used to dry 100 kg (dry basis) of the same material under identical conditions. The surface area of the material is 0.04 m^2/kg of dry solid. The time required (in seconds) to reduce the moisture content of the solids from 0.3 to

a. 2000
b. 4000
c. 5000
d. 6000

45. The conversion for a first-order liquid phase reaction A → B in a CSTR is 50%. If another CSTR of the same volume is connected in series, then the % conversion at the exit of the second reactor will be

a. 60
b. 75
c. 90
d. 100

46. The following half-life data are available for the irreversible liquid phase reaction, $A \rightarrow$ products:

Initial concentration. (kmol/m³)	Half–life (min)
[illegible]	2
3	1

The overall order of the reaction is

a. 0.5
b. 1
c. 1.5
d. 2

47. The first order series reaction $A \xrightarrow{k_1} B \xrightarrow{k_2} C$ is conducted in a batch reactor. The initial concentrations of A, B, and C (C_{A0}, C_{B0}, C_{C0}, respectively) are all non-zero. The variation of C_B with reaction time will not show a maximum if

a. $k_2C_{B0} > k_1C_{A0}$
b. $k_1C_{A0} \geq k_2C_{B0}$
c. $C_{B0} > C_{A0}$
d. $C_{A0} > C_{B0}$

48. The reaction A → B is conducted in an adiabatic plug flow reactor (PFR). Pure A at a concentration of 2 $kmol/m^3$ is fed to the reactor at the rate of 0.01 m^3/s and at a temperature of 500 K. If the exit conversion is 20%, then the exit temperature (in K) is

a. 400
b. 500
c. 600
d. 1000

Data: Heat of reaction at 298 K = -50,000 kJ/kmol of A reacted

Heat capacities, $C_{PA} = C_{PB} = 100$ kJ/kmol K (may be assumed to be independent of temperature.)

49. The rate controlling step for the heterogeneous irreversible catalytic reaction

$$A(g) + B(g) \rightarrow C(g)$$

is the surface reaction of adsorbed A with adsorbed B to give adsorbed C. The rate expression for this reaction can then be written as

SECTION - B

FIVE MARKS QUESTIONS (54-70)

Answer Any Fifteen Questions

(Marks 5 × 15 = 75)

50. Find the directional derivative of u = xyz at the point (1, 2, 3) In the direction from (1, 2, 3) to (1, -1, -3).

51. Find whether or not the vectors (1,1,2), (1, 2, 1) and (0, 3, -3) are linearly independent.

52. Industrial grade methanol can be produced according to the reaction

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

For this reaction $\Delta G^\circ_{400} = -1.484$ kJ. If an equimolal mixture of CO and H_2 is fed to a reactor maintained at 400 K and 10 bar, determine the fraction of CO that is converted into CH_3OH at equilibrium. Assume that the reaction mixture behaves like an ideal gas.

53. In a binary mixture the activity coefficient γ_1 of component 1, in the entire range of composition, is given by

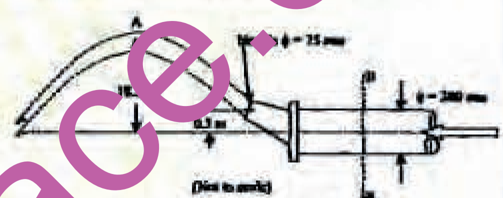
$$R \ln \gamma_1 = Ax_2^2 + Bx_2^3$$

where R, A and B are constants. Derive the expression for the activity coefficient of component 2.

54. A hydrocarbon oil (viscosity 0.025 Pa s and density 900 kg/m^3) is transported using a 0.6 m diameter, 10 km long pipe. The maximum allowable pressure drop across the pipe length is 1 MPa. Due to a ... long pipe to pump the same volumetric flow rate as in the first case. Estimate the pressure drop in the [illegible] m diameter pipe. Assume both pipes are hydrodynamically smooth and in the range of operating conditions, the Fanning friction factor is given by:

$$f = 0.079\,\mathrm{Re}^{-0.25}$$

55. A free jet of water is produced using a 75 mm diameter nozzle attached to a 200 mm diameter pipe, as shown in the figure. If the average velocity of water at plane B is 3.8 m/s, calculate the velocity of water at point A in the free jet. Neglect friction losses in the nozzle and pipe.



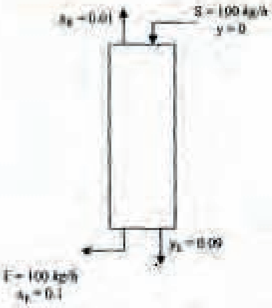
Obtain the equation for the q-line given that the operating lines are

$$y = \frac{L}{L+D}x + \frac{D}{L+D}x_D \quad \text{(enriching section)}$$

$$y = \frac{\bar{L}}{\bar{L}-B}x - \frac{B}{\bar{L}-B}x_B \quad \text{(stripping section)}$$

where L and $\bar{L}$ are the liquid flow rates in the enriching and stripping sections, D and B are the top and bottom product flow rates, and x_D and x_B are the mole fractions of top and bottom products, respectively.

56. A continuous — contact extraction column is used to extract a solute from an aqueous stream (F) using an organic solvent (S). The distribution coefficient (y/x) is 1.0, where x and y are the mass fractions of solute in raffinate and extract phases, respectively. The height of transfer unit based on the extract phase is 1.0m. The rest of the data are given in the figure. Assuming that the phase flow rates are constant, find the height of the tower.



57. Air at 1 atm is blown past the bulb of a mercury thermometer. The bulb is covered with a wick. The wick is immersed in an organic liquid (molecular weight = 58). The reading of the thermometer is 7.6 °C. At this temperature, the vapour pressure of the liquid is 5 kPa. Find the air temperature, given that the ratio of the heat transfer coefficients to the mass transfer coefficient (psychrometric ratio) is 2 kJ/kg K and the latent heat of vapourisation of the liquid is 360 kJ/kg. Assume that the air, which is blown, is free from the organic vapour.

58. A plant is designed to produce 1.2×10^8 kg/yr of an agrochemical. The estimated fixed capital investment is Rs 1.5×10^9. The working capital is Rs 2×10^8 and the start up cost (only in the first year of commissioning and to be accounted for in the first year) is Rs 1.5×10^8. The following cost data are available:

Raw materials: Rs 0.89/kg product

Labour and utilities, etc.: Rs 0.27/kg product

Selling price of product: Rs 10/kg

Other costs (on per year basis) including maintenance, insurance, etc. @10% of fixed capital.

Indirect costs of administration, R&D, marketing, etc. @20% of sale proceeds.

The plant will be fully depreciated over a period of 5 years using the straight-line method. The rate of income tax is 40%. Calculate

a. the net profit at the end of first year

b. the payout period.

59. The response of a thermocouple can be ... environment. If such a ... at 25°C is immersed suddenly ... 80°C and held there, it is found ... thermocouple reading (in °C) ... 63.2% of the final steady state value ... seconds. Find the time constant of the thermocouple.

60. A feedback control loop with a proportional controller has an open loop transfer function

$$G_L(s)=\frac{K_c}{s(5s+1)^2}$$

where time is in minutes. Obtain the crossover frequency and the ultimate controller gain.

61. Given the following block diagram,

a. Express the transfer function (Y/X) as a ratio of polynomials in s.

b. Calculate the offset in C due to a unit step change in the reference signal (set-point) R.

62. The elementary, second-order, liquid phase reaction A+B→C+D is conducted in an isothermal plug flow reactor of 1 m^3 capacity. The inlet volumetric flow rate is 10 m^3/h and C_{A0} = C_{B0} = 2 kmol/m^3. At these conditions, conversion of A is 50%. Now, if a stirred tank reactor of 2 m^3 capacity is installed in series, upstream of the plug flow reactor, then what conversion can be expected in the new system of reactors?

63. The following liquid phase reactions are carried out in a PFR:

$$A+C\rightarrow 2B+P; \qquad r_P=k_1C_AC_C$$
$$A\rightarrow D; \qquad r_D=k_2C_A$$

What is the ratio of moles of P formed to moles of D formed at the reactor exit if the conversion of C is 50%? No product is present in the feed.

Data:

64. Each of the products mentioned in the left-hand column requires one or more of the reactants mentioned in the right-hand column. March the products with the appropriate reactant(s).

(I) Phthalic anhydride
(II) Cumene

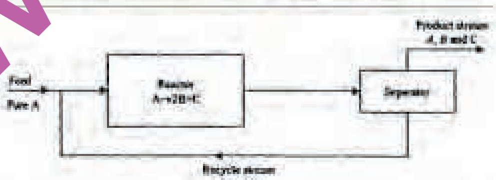
(A) Benzene
(B) Naphthalene
(C) Carbon monoxide
(D) Phenol
(E) Propylene
(F) Air
(G) Ethyl benzene
(H) Hydrogen

65. Synthesis gas is a mixture of

a. CO and H_2
b. N_2 and H_2
c. H_2, CH_4 and CO
d. CO_2 and H_2

66. The reaction $A \rightarrow 2B + C$ takes place in a catalytic reactor (see diagram below). The reactor effluent is sent to a separator. The overall conversion of A is 95%. The product stream from the separator consists of B, C and 0.5% of A entering the separator, while the recycle stream consists of the remainder of the unreacted A and 1% of B entering the separator. Calculate the

a. single pass conversion of A in the reactor
b. molar ratio of recycle to feed.



67. The outside surface temperature of a pipe (radius = 0.1 m) is 400 K. The pipe is W/m² K. To reduce the heat loss, the pipe is insulated by a 50mm thick layer of asbestos (k = 0.5 W/m K). Calculate the percentage reduction in the rate of heat loss.

68. In a 1—1 counter flow shell and tube heat exchanger, a process stream (C_p = 4.2 kJ/kg K) is cooled from 450 to 350 K using water (C_p = 4.2 kJ/kg K) at 300 K. The process stream flows on the shell side at a rate of 1 kg/s and the water on the tube-side at a rate of 5 kg/s. If heat transfer coefficients on the shell and tube sides are 1000 W/m² K and 1500 W/m² K, respectively, determine

a. the required heat transfer area.
b. by what factor will the required area change if the flow is cocurrent?

Neglect tube wall resistance and fouling resistances.

69. An aqueous solution of a solute is concentrated from 5% to 20% (mass basis) in a single-effect short-tube evaporator. The feed enters the evaporator at a rate of 10 kg/s and at a temperature of 300 K. Steam is available at a saturation pressure of 1.3 bar. The pressure in the vapour space of the evaporator is 0.13 bar and the corresponding saturation temperature of steam is 320 K. If the overall heat transfer coefficient is 5000 W/m² K, calculate the

a. steam economy
b. heat transfer surface area.

Data:

	Enthalpy (kJ/kg)	Heat of vaporization (kJ/kg)
Saturated steam (1.3 bar; 380 K)	—	2000
Saturated steam (0.13 bar; 320 K)	2200	—
Feed (5 %; 300 K)	80	—
Concentrated liquor (20 %; 325 K)	400	—

Boiling point elevation is 5 K.