



Ranjan e-institute

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Gate Solution

20 year

Heat Transfer Operation

Quick link: year wise

2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	2010
2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	
Answer Key										

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1)

Ratio of momentum diffusivity to thermal diffusivity is

Reynolds number

Prandtl number

Nusselt number

Peclet number

Solution

2)

Leidenfrost phenomenon refers to

the condensation of vapour on a cold surface

the exchange of heat between two solids

the melting of frost

film boiling and evaporation of liquid droplets falling on a very hot surface

Solution

3)

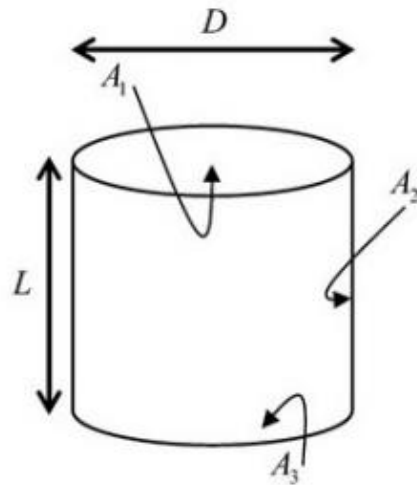
An aqueous suspension at 60 °C is fed to the first effect of a double effect forward feed evaporator with a mass flow rate of 1.25 kg s⁻¹. The sum of the rates of water evaporated from the first and second effects is 1.0 kg s⁻¹.

Temperatures of the exit streams from the first and the second effects are 100 °C, and 60 °C, respectively. Consider the specific heat of the aqueous suspension, and the latent heat of phase change for water to be 4 kJ kg⁻¹ K⁻¹ and 2200 kJ kg⁻¹, respectively, over this temperature range. The steam economy (in kg per kg) is _____ (round off to 2 decimal places).

Solution

4)

A hollow cylinder of equal length and inner diameter (i.e., $L = D$) is sealed at both ends with flat plate, as shown in the figure. Its inner surfaces, A_1 , A_2 , and A_3 radiate energy.



F_{ij} denotes the fraction of radiation energy leaving the surface A_i which reaches the surface A_j . It is also known that $F_{13} = 3 - 2\sqrt{2}$. Which one of the following is correct?

$$F_{21} = \sqrt{2} - 1$$

$$F_{21} = \frac{\sqrt{2} - 1}{2}$$

$$F_{21} = \frac{\sqrt{2} - 1}{4}$$

$$F_{21} = \frac{\sqrt{2} - 1}{8}$$

Solution

1)

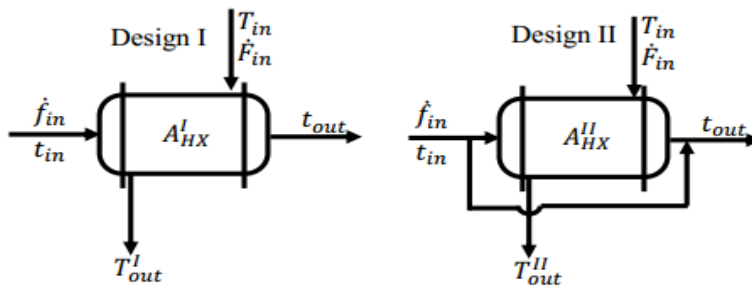
Prandtl number signifies the ratio of

- (A) $\frac{\text{Momentum Diffusivity}}{\text{Thermal Diffusivity}}$ (B) $\frac{\text{Mass Diffusivity}}{\text{Thermal Diffusivity}}$
- (C) $\frac{\text{Thermal Diffusivity}}{\text{Momentum Diffusivity}}$ (D) $\frac{\text{Thermal Diffusivity}}{\text{Mass Diffusivity}}$

Solution

2)

Consider the two countercurrent heat exchanger designs for heating a cold stream from t_{in} to t_{out} , as shown in figure. The hot process stream is available at T_{in} . The inlet stream conditions and overall heat transfer coefficients are identical in both the designs. The heat transfer area in Design I and Design II are respectively A_{HX}^I and A_{HX}^{II}



If heat losses are neglected, and if both the designs are feasible, which of the following statements holds true:

- (A) $A_{HX}^I > A_{HX}^{II}$ $T_{out}^I < T_{out}^{II}$
- (B) $A_{HX}^I = A_{HX}^{II}$ $T_{out}^I = T_{out}^{II}$
- (C) $A_{HX}^I < A_{HX}^{II}$ $T_{out}^I > T_{out}^{II}$
- (D) $A_{HX}^I < A_{HX}^{II}$ $T_{out}^I = T_{out}^{II}$

Solution

3)

A solid sphere of radius 1 cm and initial temperature of 25 °C is exposed to a gas stream at 100 °C. For the solid sphere, the density is 10^4 kg/m^3 and the specific heat capacity is 500 J/(kg K). The density of the gas is 0.6 kg/m^3 and its specific heat capacity is 10^3 J/(kg K) . The solid sphere is approximated as a lumped system (Biot number $\ll 1$) and all specific heats are constant. If the heat transfer coefficient between the solid and gas is $50 \text{ W/(m}^2 \text{ K)}$, the time (in seconds) needed for the sphere to reach 95 °C is _____ (rounded off to the nearest integer)

Solution

4)

Stream A with specific heat capacity $C_{pA} = 2000 \text{ J/(kg K)}$ is cooled from $90 \text{ }^\circ\text{C}$ to $45 \text{ }^\circ\text{C}$ in a concentric double pipe counter current heat exchanger having a heat transfer area of 8 m^2 . The cold stream B of specific heat capacity $C_{pB} = 1000 \text{ J/(kg K)}$ enters the exchanger at a flow rate 1 kg/s and $40 \text{ }^\circ\text{C}$. The overall heat transfer coefficient $U = 250 \text{ W/(m}^2 \text{ K)}$. Assume that the mean driving force is based on the arithmetic mean temperature difference, that is,

$[\Delta T]_{AMTD} = \left(\frac{T_{A,in} + T_{A,out}}{2} \right) - \left(\frac{T_{B,in} + T_{B,out}}{2} \right)$ where $T_{i,in}$ and $T_{i,out}$ refer to the temperature of the i^{th} stream ($i = A, B$) at the inlet and exit, respectively. The mass flow rate of stream A (in kg/s), is _____ (rounded off to two decimal places).

Solution

5)

A 20 cm diameter cylindrical solid pellet of a nuclear fuel with density 6000 kg/m^3 and conductivity of 300 W/(m K) generates heat by nuclear fission at a spatially uniform rate of 10^4 W/kg . The heat from the fuel pellet is transferred to the surrounding coolant by convection such that the pellet wall temperature remains constant at $300 \text{ }^\circ\text{C}$. Neglecting the axial and azimuthal dependence, the maximum temperature (in $^\circ\text{C}$) in the pellet at steady state is _____ (rounded off to the nearest integer).

Solution

G - 2018

1)

Economy of evaporators used for concentrating sugarcane juice is

- (A) $\frac{\text{kg of concentrated juice produced}}{\text{kg of steam supplied}}$
- (B) $\frac{\text{kg of steam supplied}}{\text{kg of sugarcane juice fed}}$
- (C) $\frac{\text{kg of water vaporized}}{\text{kg of steam supplied}}$
- (D) $\frac{\text{kg of sugarcane juice fed}}{\text{kg of water vaporized}}$

Solution

2)

Segmental baffles in a 2-4 shell and tube heat exchanger

- (A) change the flow pattern of the tube side fluid and increase the overall heat transfer coefficient
- (B) increase the heat transfer coefficient in the shell side and support the tubes
- (C) help to reduce the thermal expansion of the tubes and increase the heat transfer coefficient in the tube side
- (D) increase the number of passes in the shell side and increase the heat transfer coefficient in the tube side

Solution

3)

An insulated storage tank contains 1000 kg liquid of specific heat $10 \text{ kJ kg}^{-1} \text{ K}^{-1}$. The liquid is heated by saturated steam, condensing in a helical coil at a temperature of $180 \text{ }^\circ\text{C}$. The heat transfer area of the coil is 0.1 m^2 . If the overall heat transfer coefficient is constant at $1000 \text{ W m}^{-2} \text{ K}^{-1}$, then the time (in hours) required to raise the temperature of the liquid in the tank from $20 \text{ }^\circ\text{C}$ to $80 \text{ }^\circ\text{C}$ is _____ (rounded off to second decimal place).

Solution

4)

The wall of a pipe of radius 1 m is at a uniform temperature of $200 \text{ }^\circ\text{C}$, and is covered by insulation of thickness 0.1 m. The ambient air outside the insulated pipe is at $20 \text{ }^\circ\text{C}$ and has heat transfer coefficient of $10 \text{ W m}^{-2} \text{ K}^{-1}$. The thermal conductivity of the insulation material is $0.05 \text{ W m}^{-1} \text{ K}^{-1}$. If the heat transfer occurs at steady state, the temperature (in $^\circ\text{C}$) of the outer surface of insulation is _____ (rounded off to second decimal place).

Solution

5)

Vapour bubbles are formed in the nucleate boiling regime at a frequency of 10 bubbles per second per nucleation site. There are 100 nucleation sites per m^2 of heating area. The latent heat of vapourization and the density of vapour under the operating condition are 1000 kJ/kg and 1 kg/m^3 respectively. The diameter of each bubble is 10^{-3} m . Assume that the entire heat supplied is used for vapour generation. The heat flux (in Watt per m^2 of heating area) is _____ (rounded off to third decimal place).

Solution

6)

A hot liquid is to be cooled in a 1-1 shell and tube heat exchanger from $80 \text{ }^\circ\text{C}$ to $50 \text{ }^\circ\text{C}$. Cooling water enters the tube side at $30 \text{ }^\circ\text{C}$, and exits at $45 \text{ }^\circ\text{C}$. The properties of the liquids are constant. Also, the overall heat transfer coefficient is same for counter-current and co-current modes. The percentage saving in heat transfer area for counter-current option with respect to the area of co-current option is _____ (rounded off to third decimal place).

Solution

1)

The one-dimensional unsteady heat conduction equation is

$$\rho C_p \frac{\partial T}{\partial t} = \frac{1}{r^n} \frac{\partial}{\partial r} \left(r^n k \frac{\partial T}{\partial r} \right)$$

where T – temperature, t – time, r – radial position, k – thermal conductivity, ρ – density, and C_p – specific heat.

For the cylindrical coordinate system, the value of n in the above equation is

- (A) 0 (B) 1 (C) 2 (D) 3

Solution

2)

In a heat exchanger, the inner diameter of a tube is 25 mm and its outer diameter is 30 mm. The overall heat transfer coefficient based on the inner area is $360 \text{ W/m}^2 \cdot ^\circ\text{C}$. Then, the overall heat transfer coefficient based on the outer area, rounded to the nearest integer, is _____ $\text{W/m}^2 \cdot ^\circ\text{C}$.

Solution

3)

Let $I_{b\lambda}$ be the spectral blackbody radiation intensity per unit wavelength about the wavelength λ . The blackbody radiation intensity emitted by a blackbody over all wavelengths is

- (A) $\frac{dI_{b\lambda}}{d\lambda}$ (B) $\frac{d^2 I_{b\lambda}}{d\lambda^2}$
 (C) $\int_0^\infty I_{b\lambda} d\lambda$ (D) $\int_0^\infty \lambda I_{b\lambda} d\lambda$

Solution

4)

A fluid flows over a heated horizontal plate maintained at temperature T_w . The bulk temperature of the fluid is T_∞ . The temperature profile in the thermal boundary layer is given by:

$$T = T_w + (T_w - T_\infty) \left[\frac{1}{2} \left(\frac{y}{\delta_t} \right)^3 - \frac{3}{2} \left(\frac{y}{\delta_t} \right) \right], \quad 0 \leq y \leq \delta_t$$

Here, y is the vertical distance from the plate, δ_t is the thickness of the thermal boundary layer and k is the thermal conductivity of the fluid.

The local heat transfer coefficient is given by

- (A) $\frac{k}{2\delta_t}$ (B) $\frac{k}{\delta_t}$ (C) $\frac{3}{2} \frac{k}{\delta_t}$ (D) $2 \frac{k}{\delta_t}$

Solution

5)

In nucleate boiling, the pressure inside a bubble is higher than the pressure of the surrounding liquid. Assuming that both the liquid and vapour are saturated, the temperature of the liquid will ALWAYS be

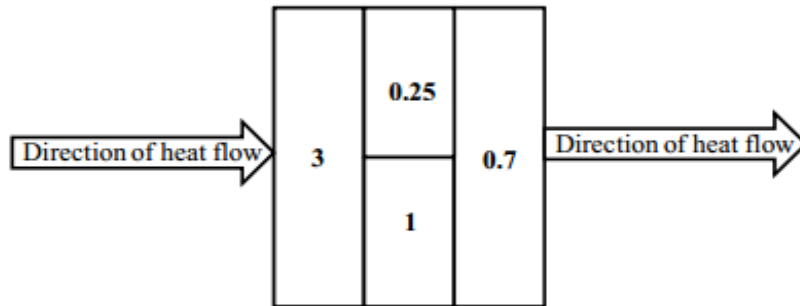
- (A) at 100 °C
(B) lower than the temperature of the vapour
(C) equal to the temperature of the vapour
(D) higher than the temperature of the vapour

Solution

G - 2016

1)

A composite wall is made of four different materials of construction in the fashion shown below. The resistance (in K/W) of each of the sections of the wall is indicated in the diagram.



The overall resistance (in K/W, rounded off to the first decimal place) of the composite wall, in the direction of heat flow, is _____

Solution

2)

Steam at 100°C is condensing on a vertical steel plate. The condensate flow is laminar. The average Nusselt numbers are Nu_1 and Nu_2 , when the plate temperatures are 10°C and 55°C, respectively. Assume the physical properties of the fluid and steel to remain constant within the temperature range of interest. Using Nusselt equations for film-type condensation, what is the value of the ratio $\frac{Nu_2}{Nu_1}$?

- (A) 0.5 (B) 0.84 (C) 1.19 (D) 1.41

solution

3)

Match the dimensionless numbers in **Group-1** with the ratios in **Group-2**.

Group-1

- P Biot number
Q Schmidt number
R Grashof number

Group-2

- I $\frac{\text{buoyancy force}}{\text{viscous force}}$
II $\frac{\text{internal thermal resistance of a solid}}{\text{boundary layer thermal resistance}}$
III $\frac{\text{momentum diffusivity}}{\text{mass diffusivity}}$

- (A) P-II, Q-I, R-III (B) P-I, Q-III, R-II
(C) P-III, Q-I, R-II (D) P-II, Q-III, R-I

solution

4)

The space between two hollow concentric spheres of radii 0.1 m and 0.2 m is under vacuum. Exchange of radiation (uniform in all directions) occurs only between the outer surface (S_1) of the smaller sphere and the inner surface (S_2) of the larger sphere. The fraction (rounded off to the second decimal place) of the radiation energy leaving S_2 , which reaches S_1 is _____

solution

5)

A jacketed stirred tank with a provision for heat removal is used to mix sulphuric acid and water in a steady state flow process. $\text{H}_2\text{SO}_4 (l)$ enters at a rate of 4 kg/h at 25°C and $\text{H}_2\text{O} (l)$ enters at a rate of 6 kg/h at 10°C . The following data are available:

Specific heat capacity of water = $4.2 \text{ kJ kg}^{-1}\text{K}^{-1}$.

Specific heat capacity of aqueous solution of 40 mass% $\text{H}_2\text{SO}_4 = 2.8 \text{ kJ (kg solution)}^{-1} \text{ K}^{-1}$.

Assume the specific heat capacities to be independent of temperature.

Based on reference states of $\text{H}_2\text{SO}_4 (l)$ and $\text{H}_2\text{O} (l)$ at 25°C , the heat of mixing for aqueous solution of 40 mass% $\text{H}_2\text{SO}_4 = -650 \text{ kJ (kg H}_2\text{SO}_4)^{-1}$.

If the mixed stream leaves at 40°C , what is the rate of heat removal (in kJ/h)?

- (A) 1802 (B) 2558 (C) 5702 (D) 6458

solution

6)

In a 1-1 pass shell and tube exchanger, steam is condensing in the shell side at a temperature (T_s) of 135°C and the cold fluid is heated from a temperature (T_1) of 20°C to a temperature (T_2) of 90°C . The energy balance equation for this heat exchanger is

$$\ln \frac{T_s - T_1}{T_s - T_2} = \frac{UA}{\dot{m}c_p}$$

where U is the overall heat transfer coefficient, A is the heat transfer area, \dot{m} is the mass flow rate of the cold fluid and c_p is its specific heat. Tube side fluid is in a turbulent flow and the heat transfer coefficient can be estimated from the following equation:

$$\text{Nu} = 0.023 (\text{Re})^{0.8} (\text{Pr})^{1/3}$$

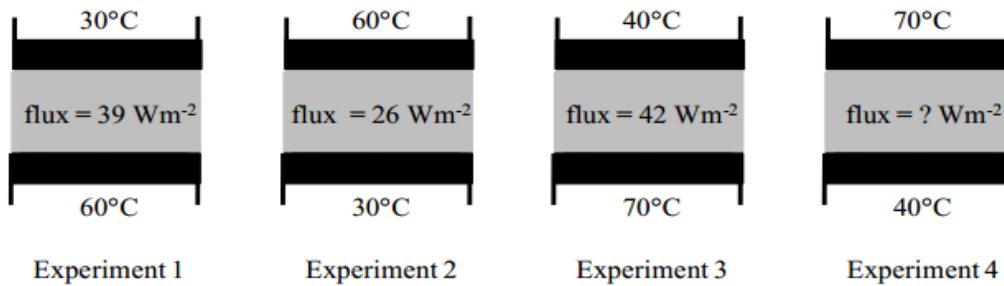
where Nu is the Nusselt number, Re is the Reynolds number and Pr is the Prandtl number. The condensing heat transfer coefficient in the shell side is significantly higher than the tube side heat transfer coefficient. The resistance of the wall to heat transfer is negligible. If only the mass flow rate of the cold fluid is doubled, what is the outlet temperature (in $^\circ\text{C}$) of the cold fluid at steady state?

- (A) 80.2 (B) 84.2 (C) 87.4 (D) 88.6

solution

7)

In an experimental setup, mineral oil is filled in between the narrow gap of two horizontal smooth plates. The setup has arrangements to maintain the plates at desired uniform temperatures. At these temperatures, ONLY the radiative heat flux is negligible. The thermal conductivity of the oil does not vary perceptibly in this temperature range. Consider four experiments at steady state under different experimental conditions, as shown in the figure below. The figure shows plate temperatures and the heat fluxes in the vertical direction.



What is the steady state heat flux (in $W\ m^{-2}$) with the top plate at $70^\circ C$ and the bottom plate at $40^\circ C$?

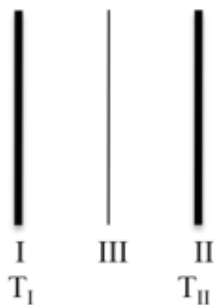
- (A) 26 (B) 39 (C) 42 (D) 63

solution

G-2015

1)

Two infinitely large parallel plates (I and II) are held at temperatures T_I and T_{II} ($T_I > T_{II}$) respectively, and placed at a distance $2d$ apart in vacuum. An infinitely large flat radiation shield (III) is placed in parallel in between I and II. The emissivities of all the plates are equal. The ratio of the steady state radiative heat fluxes with and without the shield is:



- (A) 0.5 (B) 0.75 (C) 0.25 (D) 0

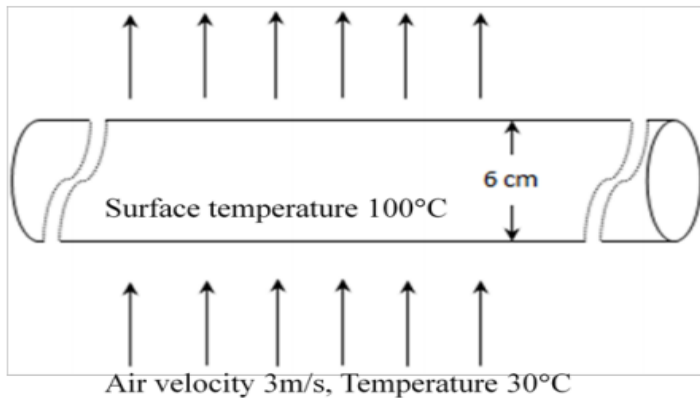
solution

2)

Air is flowing at a velocity of 3 m/s perpendicular to a long pipe as shown in the figure below. The outer diameter of the pipe is $d = 6$ cm and temperature at the outside surface of the pipe is maintained at 100°C . The temperature of the air far from the tube is 30°C .

Data for air: Kinematic viscosity, $\nu = 18 \times 10^{-6} \text{ m}^2/\text{s}$; Thermal conductivity, $k = 0.03 \text{ W}/(\text{m}\cdot\text{K})$

Using the Nusselt number correlation: $Nu = \frac{hd}{k} = 0.024 \times Re^{0.8}$, the rate of heat loss per unit length (W/m) from the pipe to air (up to one decimal place) is _____.



solution

3)

A heated solid copper sphere (of surface area A and volume V) is immersed in a large body of cold fluid. Assume the resistance to heat transfer inside the sphere to be negligible and heat transfer coefficient (h), density (ρ), heat capacity (C), and thermal conductivity (k) to be constant. Then, at time t , the temperature difference between the sphere and the fluid is proportional to:

- (A) $\exp\left[-\frac{hA}{\rho V C} t\right]$ (B) $\exp\left[-\frac{\rho V C}{hA} t\right]$
 (C) $\exp\left[-\frac{4\pi k}{\rho CA} t\right]$ (D) $\exp\left[-\frac{\rho CA}{4\pi k} t\right]$

solution

4)

In the figure below, the temperature profiles of cold and hot fluids in counter current double pipe heat exchangers (in different modes of operation) are shown on the left. For each case, match the heat exchange process for the fluid *represented by the bold curve* with the options given on the right.

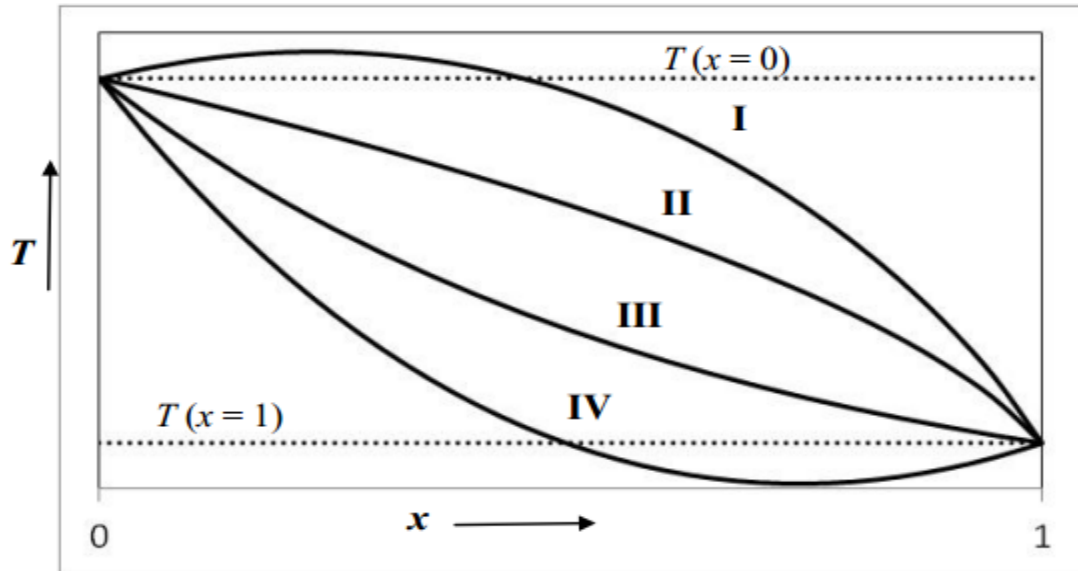
<p>(I)</p> <p>Temperature</p> <p>Distance</p>	<p>(P) Heating of sub-cooled feed to super heated vapour .</p>
<p>(II)</p> <p>Temperature</p> <p>Distance</p>	<p>(Q) Condensation of super heated vapour</p>
<p>(III)</p> <p>Temperature</p> <p>Distance</p>	<p>(R) Boiling of sub-cooled liquid.</p>
<p>(IV)</p> <p>Temperature</p> <p>Distance</p>	<p>(S) Condensation of saturated vapour followed by sub-cooling</p>

- (A) I-P, II-Q, III-R, IV-S
 (B) I-P, II-Q, III-S, IV-R
 (C) I-Q, II-P, III-S, IV-R
 (D) I-Q, II-S, III-P, IV-R

solution

5)

Consider a solid block of unit thickness for which the thermal conductivity decreases with an increase in temperature. The opposite faces of the block are maintained at constant but different temperatures: $T(x = 0) > T(x = 1)$. Heat transfer is by steady state conduction in x -direction only. There is no source or sink of heat inside the block. In the figure below, identify the correct temperature profile in the block.



- (A) I (B) II (C) III (D) IV

solution

G - 2014

1)

In a completely opaque medium, if 50% of the incident monochromatic radiation is absorbed, then which of the following statements are **CORRECT**?

- P. 50% of the incident radiation is reflected
- Q. 25% of the incident radiation is reflected
- R. 25% of the incident radiation is transmitted
- S. No incident radiation is transmitted

- (A) P and S only (B) Q and R only (C) P and Q only (D) R and S only

solution

2)

Steam economy of a multiple effect evaporator system is defined as

- (A) kilogram of steam used per hour
- (B) kilogram of steam consumed in all the effects for each kilogram of steam fed
- (C) kilogram of steam used in all the effects for each kilogram of water vaporized per hour
- (D) kilogram of water vaporized from all the effects for each kilogram of steam fed to the first effect

solution

3)

A brick wall of 20 cm thickness has thermal conductivity of $0.7 \text{ W m}^{-1} \text{ K}^{-1}$. An insulation of thermal conductivity $0.2 \text{ W m}^{-1} \text{ K}^{-1}$ is to be applied on one side of the wall, so that the heat transfer through the wall is reduced by 75%. The same temperature difference is maintained across the wall before and after applying the insulation. The required thickness (in cm) of the insulation is _____

solution

4)

An oil with a flow rate of 1000 kg/h is to be cooled using water in a double-pipe counter-flow heat exchanger from a temperature of 70°C to 40°C . Water enters the exchanger at 25°C and leaves at 40°C . The specific heats of oil and water are $2 \text{ kJ kg}^{-1} \text{ K}^{-1}$ and $4.2 \text{ kJ kg}^{-1} \text{ K}^{-1}$, respectively. The overall heat transfer coefficient is $0.2 \text{ kW m}^{-2} \text{ K}^{-1}$. The minimum heat exchanger area (in m^2) required for this operation is _____

solution

5)

The bottom face of a horizontal slab of thickness 6 mm is maintained at 300°C . The top face is exposed to a flowing gas at 30°C . The thermal conductivity of the slab is $1.5 \text{ W m}^{-1} \text{ K}^{-1}$ and the convective heat transfer coefficient is $30 \text{ W m}^{-2} \text{ K}^{-1}$. At steady state, the temperature (in $^\circ\text{C}$) of the top face is _____

solution

1)

The effectiveness of a heat exchanger in the ϵ -NTU method is defined as

- (A) $\frac{\text{increase in temperature of the cold fluid}}{\text{decrease in temperature of the hot fluid}}$
- (B) $\frac{\text{actual exit temperature attained by the cold fluid}}{\text{maximum exit temperature attainable by the cold fluid}}$
- (C) $\frac{\text{actual exit temperature attained by the hot fluid}}{\text{minimum exit temperature attainable by the hot fluid}}$
- (D) $\frac{\text{actual heat transfer rate}}{\text{maximum possible heat transfer rate from hot fluid to cold fluid}}$

solution

2)

In a pool boiling experiment, the following phenomena were observed.

- P. Natural convection
- Q. Film boiling
- R. Transition boiling
- S. Nucleate boiling

What was the CORRECT sequence of their occurrence?

- (A) P, Q, R, S (B) S, R, Q, P (C) Q, R, P, S (D) P, S, R, Q

solution

3)

A hole of area 1 cm^2 is opened on the surface of a large spherical cavity whose inside temperature is maintained at $727 \text{ }^\circ\text{C}$. The value of Stefan-Boltzmann constant is $5.67 \times 10^{-8} \text{ W/m}^2\text{-K}^4$. Assuming black body radiation, the rate at which the energy is emitted (in W) by the cavity through the hole, up to 3 digits after the decimal point, is _____

solution

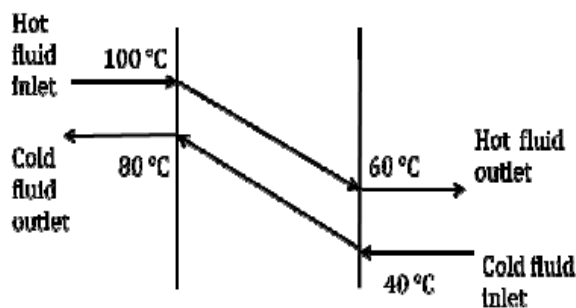
4)

Calculate the heat required (in kJ, up to 1 digit after the decimal point) to raise the temperature of 1 mole of a solid material from 100 °C to 1000 °C. The specific heat (C_p) of the material (in J/mol-K) is expressed as $C_p = 20 + 0.005T$, where T is in K. Assume no phase change. _____

solution

5)

In a double pipe counter-current heat exchanger, the temperature profiles shown in the figure were observed. During operation, due to fouling inside the pipe, the heat transfer rate reduces to half of the original value. Assuming that the flow rates and the physical properties of the fluids do not change, the LMTD (in °C) in the new situation is



(A) 0

(B) 20

(C) 40

(D) indeterminate

solution

G - 2012

1)

For heat transfer across a solid-fluid interface, which one of the following statements is **NOT** true when the Biot number is very small compared to 1?

- (A) Conduction resistance in the solid is very small compared to convection resistance in the fluid
- (B) Temperature profile within the solid is nearly uniform
- (C) Temperature drop in the fluid is significant
- (D) Temperature drop in the solid is significant

solution

2)

A solid sphere with an initial temperature T_i is immersed in a large thermal reservoir of temperature T_o . The sphere reaches a steady temperature after a certain time t_1 . If the radius of the sphere is doubled, the time required to reach steady-state will be

- (A) $t_1/4$ (B) $t_1/2$ (C) $2t_1$ (D) $4t_1$

solution

3)

If the Nusselt number (Nu) for heat transfer in a pipe varies with Reynolds number (Re) as $Nu \propto Re^{0.8}$, then for constant average velocity in the pipe, the heat transfer coefficient varies with the pipe diameter D as

- (A) $D^{-1.8}$ (B) $D^{-0.2}$ (C) $D^{0.2}$ (D) $D^{1.8}$

solution

4)

The one - dimensional unsteady state heat conduction equation in a hollow cylinder with a constant heat source q is

$$\frac{\partial T}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial T}{\partial r} \right) + q$$

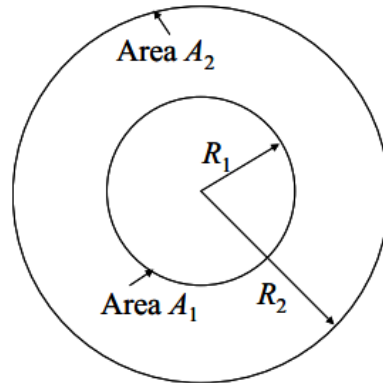
If A and B are arbitrary constants, then the steady state solution to the above equation is

- (A) $T(r) = -\frac{qr^2}{2} + \frac{A}{r} + B$
(B) $T(r) = -\frac{qr^2}{4} + A \ln r + B$
(C) $T(r) = A \ln r + B$
(D) $T(r) = \frac{qr^2}{4} + A \ln r + B$

solution

5)

For the enclosure formed between two concentric spheres as shown below ($R_2 = 2R_1$), the fraction of radiation leaving the surface area A_2 that strikes itself is



- (A) 1/4 (B) 1/2 (C) $1/\sqrt{2}$ (D) 3/4

solution

6)

Heat is generated at a steady rate of 100 W due to resistance heating in a long wire (length = 5 m, diameter = 2 mm). This wire is wrapped with an insulation of thickness 1 mm that has a thermal conductivity of 0.1 W/m.K. The insulated wire is exposed to air at 30°C. The convective heat transfer between the wire and surrounding air is characterized by a heat transfer coefficient of 10 W/m².K. The temperature (in °C) at the interface between the wire and the insulation is

- (A) 211.2 (B) 242.1 (C) 311.2 (D) 484.2

solution

7)

In a counter-flow double pipe heat exchanger, oil ($\dot{m} = 2$ kg/s, $C_p = 2.1$ kJ/kg.°C) is cooled from 90 °C to 40 °C by water ($\dot{m} = 1$ kg/s, $C_p = 4.2$ kJ/kg.°C) which enters the inner tube at 10 °C. The radius of the inner tube is 3 cm and its length is 5 m. Neglecting the wall resistance, the overall heat transfer coefficient based on the inner radius, in kW/ m².K, is

- (A) 0.743 (B) 7.43 (C) 74.3 (D) 2475

solution

1)

Consider two black bodies with surfaces S_1 (area = 1 m^2) and S_2 (area = 4 m^2). They exchange heat only by radiation. 40% of the energy emitted by S_1 is received by S_2 . The fraction of energy emitted by S_2 that is received by S_1 is

- (A) 0.05 (B) 0.1 (C) 0.4 (D) 0.6

solution

2)

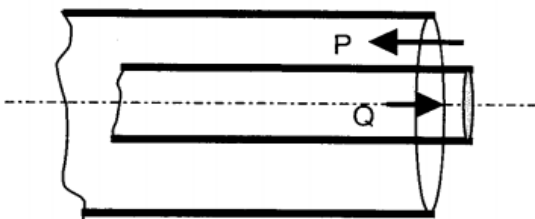
In film type condensation over a vertical tube, local heat transfer coefficient is

- (A) inversely proportional to local film thickness
 (B) directly proportional to local film thickness
 (C) equal to local film thickness
 (D) independent of local film thickness

solution

3)

Two liquids (P and Q) having same viscosity are flowing through a double pipe heat exchanger as shown in the schematic below.



Densities of P and Q are 1000 and 800 kg/m^3 respectively. The average velocities of the liquids P and Q are 1 and 2.5 m/s respectively. The inner diameters of the pipes are 0.31 and 0.1 m . Both pipes are 5 mm thick. The ratio of the Reynolds numbers Re_P to Re_Q is

- (A) 2.5 (B) 1.55 (C) 1 (D) 4

solution

4)

Oil at 120 °C is used to heat water at 30 °C in a 1–1 co-current shell and tube heat exchanger. The available heat exchange area is S_1 . The exit temperatures of the oil and the water streams are 90 °C and 60 °C respectively. The co-current heat exchanger is replaced by a 1–1 counter-current heat exchanger having heat exchange area S_2 . If the exit temperatures and the overall heat transfer coefficients are same, the ratio of S_1 to S_2 is

- (A) ∞ (B) 1.1 (C) 0.91 (D) 0

solution

5)

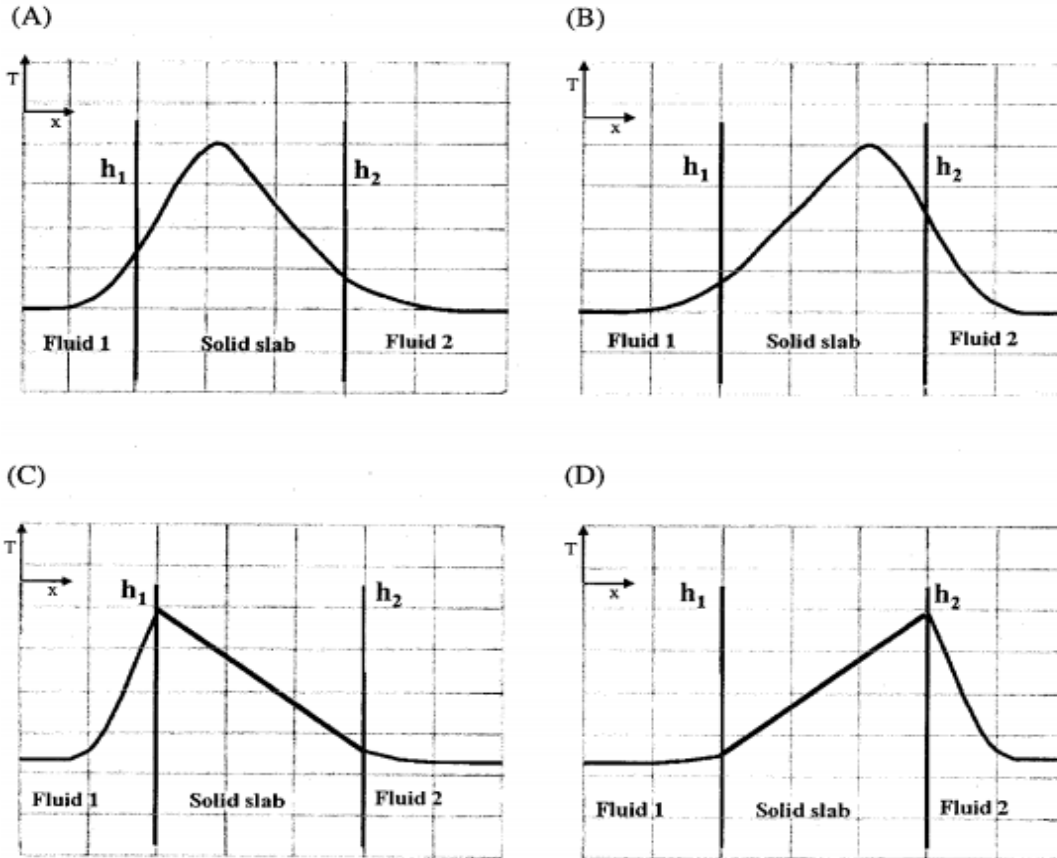
An aqueous sodium chloride solution (10 wt %) is fed into a single effect evaporator at a rate of 10000 kg/hr. It is concentrated to a 20 wt % sodium chloride solution. The rate of consumption of steam in the evaporator is 8000 kg/hr. The evaporator capacity (kg/hr) and economy are

- (A) 5000, 0.625 (B) 10000, 0.625 (C) 5000, 1.6 (D) 10000, 1.6

solution

6)

Heat is generated uniformly within a solid slab. The slab separates fluid 1 from fluid 2. The heat transfer coefficients between the solid slab and the fluids are h_1 and h_2 ($h_2 > h_1$) respectively. The steady state temperature profile (T vs. x) for one-dimensional heat transfer is **CORRECTLY** shown by



solution

G - 2010

1)

The ratio of Nusselt number to Biot number is

- (A) conductive resistance of fluid / conductive resistance of solid
- (B) conductive resistance of fluid / convective resistance of fluid
- (C) conductive resistance of solid / conductive resistance of fluid
- (D) unity

solution

2)

The ratio of the thermal boundary layer thickness to the concentration boundary layer thickness is proportional to

- (A) Nu (B) Le (C) Sh (D) Pr

solution

3)

Which **ONE** of the following statements about baffles in a shell and tube heat exchanger is **FALSE**? Baffles

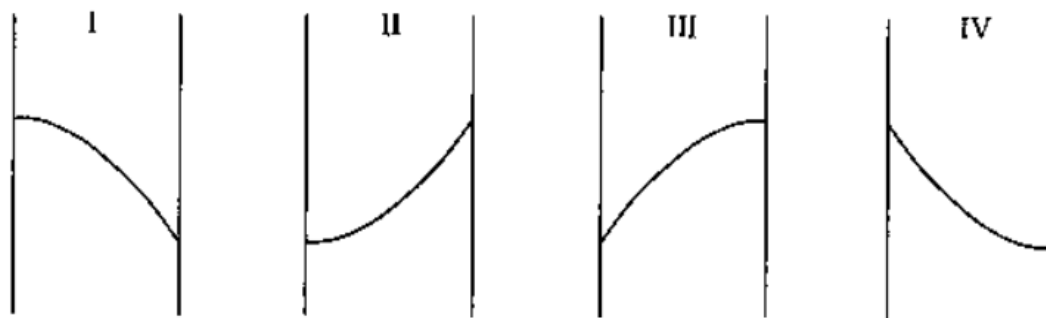
- (A) act as a support to the tube bundle
 (B) reduce the pressure drop on the shell-side
 (C) alter the shell-side flow pattern
 (D) help in increasing the shell-side heat transfer coefficient

solution

4)

The figure below shows steady state temperature profiles for one dimensional heat transfer within a solid slab for the following cases:

- P: uniform heat generation with left surface perfectly insulated
 Q: uniform heat generation with right surface perfectly insulated
 R: uniform heat consumption with left surface perfectly insulated
 S: uniform heat consumption with right surface perfectly insulated



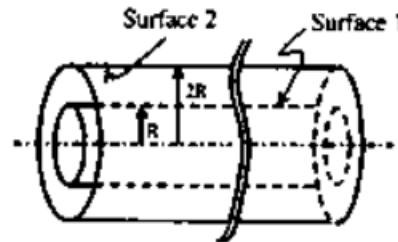
Match the profiles with appropriate cases.

- (A) P – I, Q – III, R – II, S – IV (B) P – II, Q – III, R – I, S – IV
 (C) P – I, Q – IV, R – II, S – III (D) P – II, Q – IV, R – I, S – III

solution

5)

The view factor matrix for two infinitely long co-axial cylinders, shown in the figure below, is



(A) $\begin{bmatrix} 0 & 1 \\ 0.5 & 0.5 \end{bmatrix}$

(B) $\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$

(C) $\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$

(D) $\begin{bmatrix} 0.5 & 0.5 \\ 0 & 1 \end{bmatrix}$

solution

6)

Common Data for Questions 48 and 49:

Hot oil at 150°C is used to preheat a cold fluid at 30°C in a 1 : 1 shell and tube heat exchanger. The exit temperature of the hot oil is 110°C. Heat capacities (product of mass flow rate and specific heat capacity) of both the streams are equal. The heat duty is 2 kW.

Q.48 Under co-current flow conditions, the overall heat transfer resistance ($1/UA$) is

(A) 0.4 °C/W

(B) 0.04 °C/W

(C) 0.36 °C/W

(D) 0.036 °C/W

Q.49 Under counter-current flow conditions, the overall heat transfer resistance ($1/UA$) is

(A) 0.4 °C/W

(B) 0.04 °C/W

(C) 0.36 °C/W

(D) 0.036 °C/W

solution

G - 2009

1)

During the transient convective cooling of a solid object, Biot number $\rightarrow 0$ indicates

- (A) uniform temperature throughout the object
- (B) negligible convection at the surface of the object
- (C) significant thermal resistance within the object
- (D) significant temperature gradient within the object

solution

2)

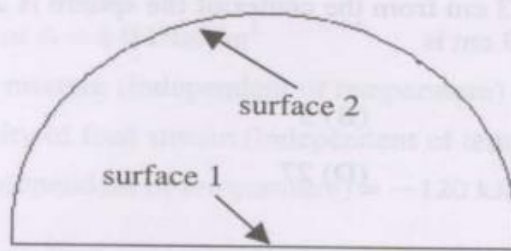
The Prandtl number of a fluid is the ratio of

- (A) thermal diffusivity to momentum diffusivity
- (B) momentum diffusivity to thermal diffusivity
- (C) conductive resistance to convective resistance
- (D) thermal diffusivity to kinematic viscosity

solution

3)

A well-insulated hemispherical furnace (radius = 1 m) is shown below:



The self-view factor of radiation for the curved surface 2 is

- (A) 1/4
- (B) 1/2
- (C) 2/3
- (D) 3/4

solution

4)

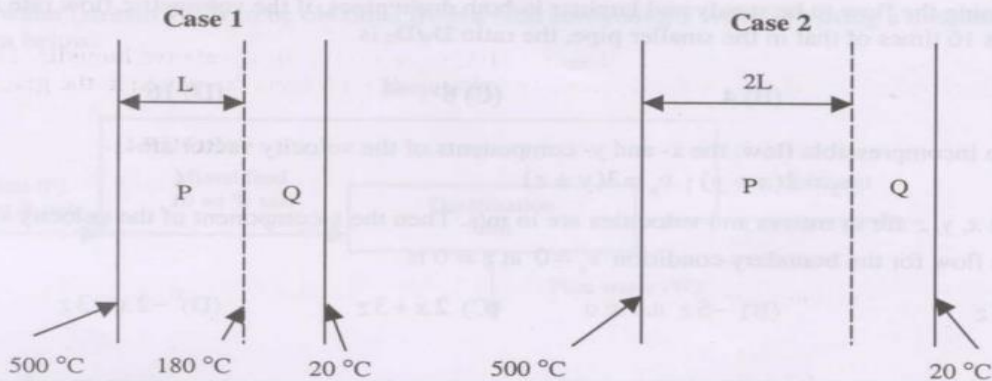
A double-pipe heat exchanger is to be designed to heat 4 kg/s of a cold feed from 20 to 40 °C using a hot stream available at 160 °C and a flow rate of 1 kg/s. The two streams have equal specific heat capacities and the overall heat transfer coefficient of the heat exchanger is 640 W/m². K. Then the ratio of the heat transfer areas required for the co-current to counter-current modes of operation is

- (A) 0.73 (B) 0.92
(C) 1.085 (D) 1.25

solution

5)

For the composite wall shown below (Case 1), the steady state interface temperature is 180 °C. If the thickness of layer P is doubled (Case 2), then the rate of heat transfer (assuming 1-D conduction) is reduced by



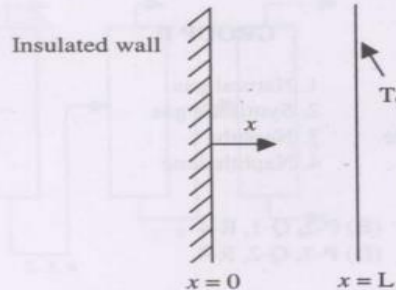
- (A) 20% (B) 40%
(C) 50% (D) 70%

solution

6)

Common Data for Questions 53 and 54:

A slab of thickness L with one side ($x = 0$) insulated and the other side ($x = L$) maintained at a constant temperature T_0 is shown below.



A uniformly distributed internal heat source produces heat in the slab at the rate of $S \text{ W/m}^3$. Assume the heat conduction to be steady and 1-D along the x -direction.

Q.53 The maximum temperature in the slab occurs at x equal to

- (A) 0 (B) $L/4$ (C) $L/2$ (D) L

Q.54 The heat flux at $x = L$ is

- (A) 0 (B) $S L/4$ (C) $S L/2$ (D) $S L$

solution

G - 2008

1)

Transient three-dimensional heat conduction is governed by ONE of the following differential equations (α - thermal diffusivity, k - thermal conductivity and ψ - volumetric rate of heat generation)

(A) $\frac{1}{\alpha} \frac{\partial T}{\partial t} = \nabla T + \psi k$

(B) $\frac{1}{\alpha} \frac{\partial T}{\partial t} = \nabla T + \frac{\psi}{k}$

(C) $\frac{1}{\alpha} \frac{\partial T}{\partial t} = \nabla^2 T + \psi k$

(D) $\frac{1}{\alpha} \frac{\partial T}{\partial t} = \nabla^2 T + \frac{\psi}{k}$

solution

2)

Two plates of equal thickness (t) and cross-sectional area, are joined together to form a composite as shown in the figure. If the thermal conductivities of the plates are k and $2k$ then, the effective thermal conductivity of the composite is

A) $3k/2$ (B) $4k/3$ (C) $3k/4$ (D) $2k/3$

solution

3)

Hot liquid is flowing at a velocity of 2 m/s through a metallic pipe having an inner diameter of 3.5 cm and length 20 m. The temperature at the inlet of the pipe is 90°C . Following data is given for liquid at 90°C

Density = 950 kg/m^3 ;
 Specific heat = $4.23 \text{ kJ/kg } ^\circ\text{C}$;
 Viscosity = $2.55 \times 10^{-4} \text{ kg/m.s}$;
 Thermal conductivity = $0.685 \text{ W/m } ^\circ\text{C}$

The heat transfer coefficient (in $\text{W/m}^2 \text{ } ^\circ\text{C}$) inside the tube is

(A) 222.22 (B) 111.11 (C) 22.22 (D) 11.11

solution

4)

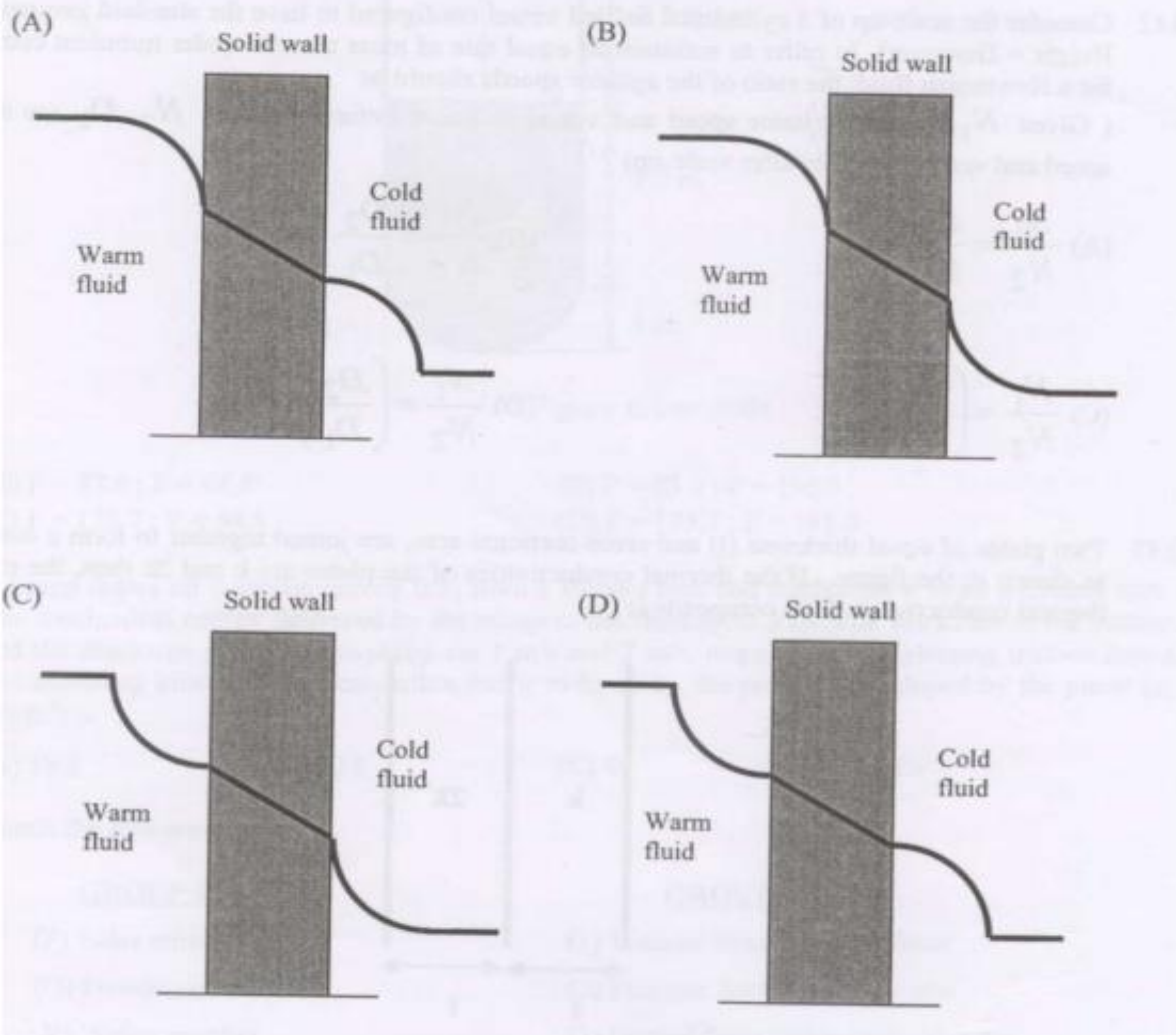
A metallic ball ($\rho = 2700 \text{ kg/m}^3$ and $C_p = 0.9 \text{ kJ/kg } ^\circ\text{C}$) of diameter 7.5 cm is allowed to cool in air at 25°C . When the temperature of the ball is 125°C , it is found to cool at the rate of 4°C per minute. If thermal gradients inside the ball are neglected, the heat transfer coefficient (in $\text{W/m}^2 \text{ } ^\circ\text{C}$) is

- (A) 2.034 (B) 20.34 (C) 81.36 (D) 203.4

solution

5)

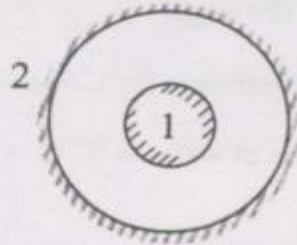
The temperature profile for heat transfer from one fluid to another separated by a solid wall is



solution

1)

For the two long concentric cylinders with surface areas A_1 and A_2 , the view factor F_{22} is given by



- (A) 0 (B) 1 (C) $1 - A_1/A_2$ (D) A_1/A_2

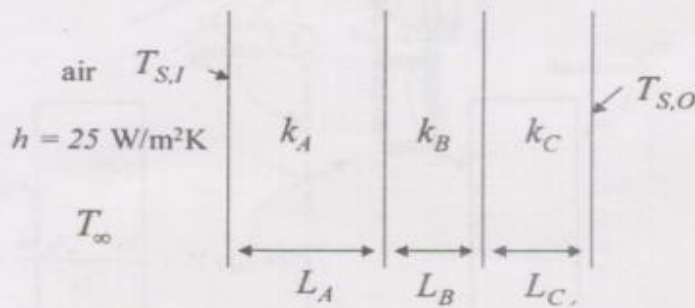
solution

2)

The composite wall of an oven consists of three materials A, B and C. Under steady state operating conditions, the outer surface temperature $T_{s,o}$ is 20°C , the inner surface temperature $T_{s,i}$ is 600°C and the oven air temperature is $T_\infty = 800^\circ\text{C}$. For the following data

thermal conductivities $k_A = 20 \text{ W/(m K)}$ and $k_C = 50 \text{ W/(m K)}$,
 thickness $L_A = 0.3\text{m}$, $L_B = 0.15\text{m}$ and $L_C = 0.15\text{m}$,
 inner-wall heat transfer coefficient $h = 25 \text{ W/(m}^2\text{ K)}$,

the thermal conductivity k_B (W/(mK) of the material B, is calculated as



- (A) 35 (B) 1.53 (C) 0.66 (D) 0.03

solution

3)

Water enters a thin walled tube ($L=1$ m, $D=3$ mm) at an inlet temperature of 97°C and mass flow rate 0.015 kg/s. The tube wall is maintained at a constant temperature of 27°C . Given the following data for water

Density, $\rho = 1000$ kg/m³

Viscosity, $\mu = 489 \cdot 10^{-6}$ Ns/m²

Specific heat $C_p = 4184$ J/kg/k

Inside heat transfer coefficient $h = 12978$ W/(m² K),

the outlet temperature of water in $^\circ\text{C}$ is,

(A) 28

(B) 37

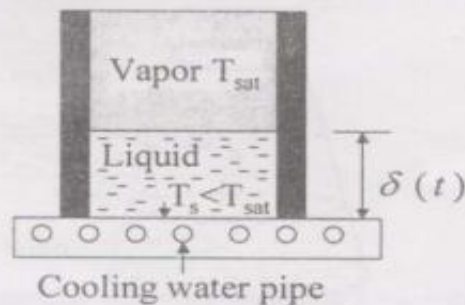
(C) 62

(D) 96

solution

4)

Consider a liquid stored in a container exposed to its saturated vapor at constant temperature T_{sat} . The bottom surface of the container is maintained at a constant temperature $T_s < T_{\text{sat}}$ while its side walls are insulated. The thermal conductivity k_l of the liquid, its latent heat of vaporisation λ and density ρ_l are known. Assuming a linear temperature distribution in the liquid, the expression for the growth of the liquid layer δ as a function of time t is given by



(A) $\delta(t) = \left[\frac{4k_l(T_{\text{sat}} - T_s)t}{\rho_l\lambda} \right]^{1/2}$

(B) $\delta(t) = \left[\frac{k_l(T_{\text{sat}} - T_s)t}{2\rho_l\lambda} \right]^{1/2}$

(C) $\delta(t) = \left[\frac{2k_l(T_{\text{sat}} - T_s)t}{\rho_l\lambda} \right]^{1/2}$

(D) $\delta(t) = \left[\frac{k_l(T_{\text{sat}} - T_s)t}{\rho_l\lambda} \right]^{1/2}$

solution

5)

The following list of options P, Q, R and S are some of the important considerations in the design of a shell and tube heat exchanger.

- P) square pitch permits the use of more tubes in a given shell diameter
- Q) the tube side clearance should not be less than one fourth of the tube diameter
- R) baffle spacing is not greater than the diameter of the shell or less than one-fifth of the shell diameter
- S) The pressure drop on the tube side is less than 10 psi

Pick out the correct combination of 'TRUE' statements from the following:

- (A) P, Q and R
- (B) Q, R and S
- (C) R, S and P
- (D) P, Q, R and S

solution

7)

A hot fluid entering a well-stirred vessel is cooled by feeding cold water through a jacket around the vessel. Assume the jacket is well-mixed. For the following data,

- mass flowrates of the hot fluid = 0.25 kg/s,
- mass flow rate of cold water = 0.4 kg/s,
- specific heats of oil = 6000 J/kgK
- specific heat of cold water = 4184 J/kgK
- the inlet and exit temperature of the hot fluid is 150 °C and 100 °C respectively.
- inlet temperature of cold water = 20 °C
- the overall heat transfer coefficient is 500 W/m²K.

the heat transfer area in m², is

- (A) 1.82
- (B) 2.1
- (C) 3
- (D) 4.26

solution

8)

The Grashof Number is

- (A) thermal diffusivity/mass diffusivity
- (B) inertial force/surface tension force
- (C) sensible heat/latent heat
- (D) buoyancy force/viscous force

solution

G - 2006

1. A stagnant liquid film of 0.4 mm thickness is held between two parallel plates. The top plate is maintained at 40°C and the bottom plate is maintained at 30°C. If the thermal conductivity of the liquid is 0.14 W/(m K), then the steady state heat flux (in W/m²) assuming one-dimensional heat transfer is

- (A) 3.5 (B) 350 (C) 3500 (D) 7000

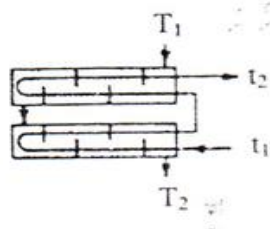
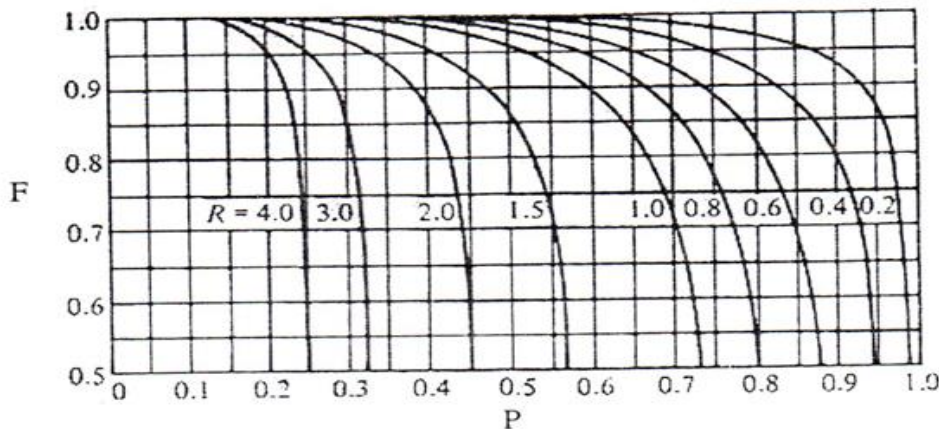
Solution

2. An insulated cylindrical pipe of 0.2 m diameter has a surface temperature of 45°C. It is exposed to black body surroundings at 25°C. The emissivity and absorptivity of the insulation surface are 0.96 and 0.93, respectively. The convective heat transfer coefficient outside the insulation surface is 3.25 W/(m²K). The Stefan-Boltzmann constant is 5.67 x 10⁻⁸ W/m²K⁴). The surrounding fluid may be assumed to be transparent. Find the percentage contribution from, radiation to the total heat transfer rate to the surroundings.

- (A) 30.9 (B) 50.0 (C) 57.6 (D) 68.4

Solution

3. A process fluid has to be cooled from 22°C to 2°C using brine in a 2-4 shell and tube heat exchanger shown below. The brine enters at -3°C and leaves at 7°C. The overall heat transfer coefficient is 500 W/m² K). The design heat load is 30 kW. The brine flows on the tube side and the process fluid on the shell side. The heat transfer area in m² is



$$P = \frac{t_2 - t_1}{T_1 - t_1}$$

$$R = \frac{T_1 - T_2}{t_2 - t_1}$$

(A) 1.1

(B) 5.77

(C) 6.59

(D) 7.53

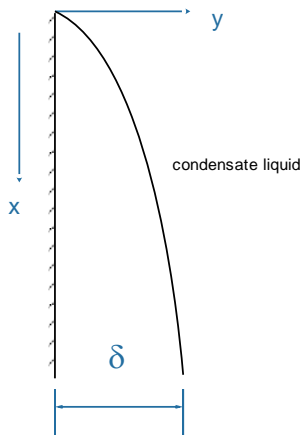
Solution

Statement for Linked Answer Questions 6 (I , II):

In film condensation on a vertical plane surface, the x directional velocity distribution is given by

$$u(y) = \frac{g(\rho_l - \rho_v)}{\mu_l} \left(\delta y - \frac{1}{2} y^2 \right)$$

Where δ is the film thickness at any x,



I. The mass flow rate of the condensate $m(x)$ through any axial position x per unit width of the plate is given by

$$(A) m(x) = \frac{g\rho_l(\rho_l - \rho_v)\delta^3}{3\mu_l}$$

$$(B) m(x) = \frac{g(\rho_l - \rho_v)\delta^2}{3\mu_l}$$

$$(C) m(x) = \frac{g\rho_v^2\delta^3}{\mu_l}$$

$$(D) m(x) = \frac{g\rho_l\rho_v\delta^3}{3\mu_l}$$

Solution

II. Differentiate $m(x)$ with respect to δ to get the differential increase in condensate mass dm with film thickness i.e., $dm/d\delta$. Then obtain dm/dx assuming heat flux through the film to be due to conduction based on a linear temperature profile between the vapor and wall. Hence determine $d\delta/dx$. Here μ_l is liquid viscosity, k_l is thermal conductivity, and λ is latent heat of condensation. T_v is the vapor temperature and T_w is the wall temperature.

$$(A) \frac{d\delta}{dx} = \frac{\mu_l k_l (T_v - T_w)}{g\rho_l(\rho_l - \rho_v)\lambda} \frac{1}{\delta^2}$$

$$(B) \frac{d\delta}{dx} = \frac{\mu_l k_l (T_v - T_w)}{g\rho_v(\rho_l - \rho_v)\lambda} \frac{1}{\delta^3}$$

$$(C) \frac{d\delta}{dx} = \frac{\mu_l (T_v - T_w)}{g\rho_l k_l (\rho_l - \rho_v)\lambda} \frac{1}{\delta^2}$$

$$(D) \frac{d\delta}{dx} = \frac{\mu_l k_l (T_v - T_w)}{g\rho_l(\rho_l - \rho_v)\lambda} \frac{1}{\delta^3}$$

Solution



G - 2005

1. The thermal boundary layer is significantly thicker than the hydrodynamic boundary layer for

- (a) Newtonian liquids
- (b) polymeric liquids
- (c) liquid metals
- (d) gases

Solution

2. An electrically heated element is submerged in a pool of water at its saturation temperature. As the temperature of the element increases, the maximum heat transfer coefficient is observed

- (a) in the free convection regime
- (b) between the nucleate boiling and partial nucleate boiling mixed with unstable film boiling regimes
- (c) in the incipient nucleate boiling regime
- (d) in the stable film boiling regime without significant radiation effects.

Solution

3. Baffles are used in heat exchangers in order to

- (a) increase the tube side fluid's heat transfer coefficient
- (b) promote vibration in the heat exchanger
- (c) promote cross flow and turbulence in the shell side fluid
- (d) prevent shell expansion due to thermal effects.

Solution

4. In film type condensation of liquid along a vertical tube, the thickness of the condensate layer increases towards the bottom. This implies that the local heat transfer coefficient.

- (a) increases from top to bottom
- (b) decreases from top to bottom
- (c) remains constant from top to bottom
- (d) first increases and then decreases from top to bottom

Solution



(c) t

(d) $t^{3/2}$

Solution

9. A countercurrent flow double pipe heat exchanger is used to heat water flowing at 1 kg/s from 40°C to 80°C. Oil is used for heating and its temperature changes from 100°C to 70°C. The overall heat transfer coefficient is 300 W/(m² °C). If it is replaced by a 1-2 shell and tube heat exchanger with countercurrent flow configuration with water flowing in shell and oil flowing in the tube, what is the excess area required with respect to the double pipe heat exchanger? The correction factor, F_t for LMTD (log mean temperature difference) based on the above double pipe heat exchanger is 0.5. The heat transfer coefficient remains unchanged, and the same inlet and outlet conditions are maintained.

$$C_{P, \text{water}} = 4180 \text{ J/kg } ^\circ\text{C}, C_{P, \text{oil}} = 2000 \text{ J/kg } ^\circ\text{C},$$

(a) 0 m²

(b) - 20.15 m²

(c) 22.6 m²

(d) 9.69 m²

Solution

10. Fluid flows in an annulus of inner diameter 0.8 m and outer diameter 1 m. Heat is transferred to the fluid from, inner tube surface of the annulus. What is the equivalent diameter for heat transfer in meter?

(a) 0.45

(b) 0.20

(c) 1.64

(d) 0.90

Solution

Statement for Linked Answer Questions 11a & 11b

A liquid of mass 7 kg and specific heat 4 kJ/(kg °C) is contained in a cylindrical heater of diameter 0.15 m and height 0.40 m. The cylindrical surface of the heater is exposed to air at 25°C while the end caps are insulated, so that heat transfer takes place only through the cylindrical surface.

The thickness of the wall of the heater = 2 mm

The wall thermal conductivity = 10 W/ (m K)

The heat transfer coefficient in the liquid = 100 W/(m²K)

The heat transfer coefficient in air = 10 W/(m²K)

The liquid is initially maintained at a temperature of 75°C. AT time $t = 0$, the heater is switched off, and the temperature of the liquid in the heater decreases due to heat loss across the cylindrical surface.

11a. What is the overall heat transfer coefficient in W/m² K)?

(a) 1

(b) 4.04

(c) 9.07

(d) 10

Solution



11b. What is the time required for the temperature of the liquid to reduce to 50°C after the heater is switched off, assuming lumped system analysis is valid ?

- (a) $7.874 \times 10^3 \text{ s}$ (b) $11.346 \times 10^3 \text{ s}$
(c) $16.828 \times 10^3 \text{ s}$ (d) $23.213 \times 10^3 \text{ s}$

Solution

G - 2004

1. for an ideal black body

- (A) Absorptivity = 1 (B) reflectivity = 1
(C) Emissivity = 0 (D) transmissivity = 1

Solution

2. The left face of a one dimensional slab of thickness 0.2 m is maintained at 80°C and the right face is exposed to air at 30°C . The thermal conductivity of the slab is $1.2 \text{ W}/(\text{m K})$ and the heat transfer coefficient from the right face is $10 \text{ W}/(\text{m}^2 \text{ K})$. At steady state, the temperature of the right face in $^{\circ}\text{C}$ is

- (A) 77.2 (B) 71.2 (C) 63.8 (D) 48.7

Solution

3. A metal ball of radius 0.1 m at a uniform temperature of 90°C is left in air at 30°C . The density and the specific heat capacity of the metal are $3000 \text{ kg}/\text{m}^3$ and $0.4 \text{ kJ}/(\text{kg K})$, respectively. The heat transfer coefficient is $50 \text{ W}/\text{m}^2 \text{ K}$. Neglecting the temperature gradients inside the ball, the time taken (in hours) for the ball to cool to 60°C is

- (A) 555 (B) 55.5 (C) 0.55 (D) 0.15

Solution

4. It is desired to concentrate a 20% salt solution (20 kg of salt in 100 kg of solution) to a 30% salt solution in an evaporator. Consider a feed of $300 \text{ kg}/\text{min}$ at 30°C . The boiling point of the solution is 110°C , the latent heat of vaporization is $2100 \text{ kJ}/\text{kg}$, and the specific heat of



the solution is 4 kJ/(kg K). The rate at which heat has to be supplied (in kJ/min) to the evaporator is

- (A) 3.06×10^5 (B) 6.12×10^5
(C) 7.24×10^5 (D) 9.08×10^5

Solution

5. Hot water ($0.01 \text{ m}^3/\text{min}$) enters the tube side of a cocurrent shell and tube heat exchanger at 80°C and leaves at 50°C . Cold oil ($0.05 \text{ m}^3/\text{min}$) of density 800 kg/m^3 and specific heat of $2 \text{ kJ}/(\text{kg K})$ enters at 20°C . The log mean temperature difference in $^\circ\text{C}$ is approximately.

- (A) 32 (B) 37 (C) 45 (D) 50

Solution

G - 2003

1. A dilute aqueous solution is to be concentrated in an evaporator system. High pressure steam is available. Multiple effect evaporator system is employed because –

- a) total heat transfer area of all the effects is less than that in a single effect evaporator system
b) total amount of vapour produced per kg of feed steam in a multieffect system is much higher than in a single effect
c) boiling point elevation in a single effect system is much higher than that in any effect in a multieffect system
d) heat transfer coefficient in a single effect is much lower than that in any effect in a multieffect system

Solution

2. The units of resistance to heat transfer are –

- a) $\text{J m}^{-2} \text{K}^{-1}$ b) $\text{J m}^{-1} \text{K}^{-1}$ c) $\text{W m}^{-2} \text{K}^{-1}$ d) $\text{W}^{-1} \text{m}^2 \text{K}^1$



Solution

3. A process stream of dilute aqueous solution flowing at the rate of 10 kg s^{-1} is to be heated. Steam condensate at 95°C is available for heating purpose, also at a rate of 10 kg s^{-1} . A 1–1 shell and tube heat exchanger is available. The best arrangement is

- a) counter flow with process stream on shell side
- b) counter flow with process stream on tube side
- c) parallel flow with process stream on shell side
- d) parallel flow with process stream on tube side

Solution

4. The inner wall of a furnace is at a temperature of 700°C . The composite wall is made of two substances, 10 and 20 cm thick with thermal conductivities of 0.05 and $0.1 \text{ W m}^{-1} \text{ }^\circ\text{C}^{-1}$ respectively. The ambient air is at 30°C and the heat transfer coefficient between the outer surface of wall and air is $20 \text{ W m}^{-2} \text{ }^\circ\text{C}^{-1}$. The rate of heat loss from the outer surface in W m^{-2} is

- a) 165.4
- b) 167.5
- c) 172.8
- d) 175

Solution

5. Steam is to be condensed in a shell and tube heat exchanger which is 5 m long with a shell diameter of 1 m. Cooling water is to be used for removing the heat. Heat transfer coefficient for the cooling water, whether on shell side or tube side is same. The best arrangement is

- a) vertical heat exchanger with steam on tube side
- b) vertical heat exchanger with steam on shell side
- c) horizontal heat exchanger with steam on tube side
- d) horizontal heat exchanger with steam on shell side

Solution



6. A fluid is flowing inside the inner tube of a double pipe heat exchanger with diameter 'd'. For a fixed mass flow rate, the tube side heat transfer coefficient for turbulent flow conditions is proportional to

- a) $d^{0.8}$ b) $d^{-0.2}$ c) d^{-1} d) $d^{-1.8}$

Solution

7. Air is to be heated by condensing steam. Two heat exchangers are available : (i) a shell and tube heat exchanger, and (ii) a finned tube heat exchanger. Tube side heat transfer area is equal in both cases. The recommended arrangement is

- a) finned tube heat exchanger with air inside and steam outside
b) finned tube heat exchanger with air outside and steam inside
c) shell and tube heat exchanger with air inside tubes and steam shell side
d) shell and tube heat exchanger with air on shell side and steam inside tubes

Solution

8. For a given ambient air temperature with increase in the thickness of insulation of a hot cylindrical pipe, the rate of heat loss from the surface would

- a) decrease c) first decrease and then increase
b) increase d) first increase and then decrease

Solution

G - 2002

1. If the baffle spacing in a shell and tube heat exchanger increases, then the Reynolds number of the shell side fluid

- A) Remains unchanged B) Increases
C) Increases or decreases depending on No. of shell passes D) Decreases

Solution

2. A 10 cm diameter steam pipe, carrying steam at 180°C , is covered with an insulation (conductivity = $0.6 \text{ W/m}^{\circ}\text{C}$). It loses heat to the surroundings at 30°C . Assume a heat transfer coefficient of $8.0 \text{ W/m}^2^{\circ}\text{C}$ for heat transfer from surface to the surroundings. Neglect wall resistance of the pipe and film resistance of steam. If the insulation thickness is 2 cm, the rate of heat loss from this insulated pipe will be

- A) greater than that of the un-insulated steam pipe
- B) less than that of the un-insulated steam pipe
- C) equal to that of the un-insulated steam pipe
- D) less than the steam pipe with 5 cm insulation

Solution

3. 1000 kg of liquid at 30°C in a well-stirred vessel has to be heated to 120°C , using immersed coils carrying condensing steam at 150°C . The area of the steam coils is 1.2 m^2 and overall heat transfer coefficient to the liquid is $1500 \text{ W/m}^2^{\circ}\text{C}$. Assuming negligible heat loss to surrounding and specific heat capacity of the liquid to be $4 \text{ kJ/kg}^{\circ}\text{C}$, the time taken for the liquid to reach desired temperature will be

- A) 15 min
- B) 22 min
- C) 44 min
- D) 51 min

Solution

4. A composite wall consists of two plates A and B placed in series normal to the flow of heat. The thermal conductivities are k_A and k_B and the specific heat capacities are C_{pA} and C_{pB} , for plates A and B respectively. Plate B has twice the thickness of plate A. At steady state, the temperature difference across plate A is greater than that across plate B when

- A) $C_{pA} > C_{pB}$
- B) $C_p < C_{pB}$
- C) $k_A < 0.5 k_B$
- D) $k_A > 2 k_B$

Solution

5. A double pipe countercurrent heat exchanger is designed to cool 3500 kg/hr of benzene flowing in the inner pipe from 80°C to 35°C. Water enters at 20°C and exits at 37°C in the annular space. The inside pipe has an inner diameter of 3.5 cm and wall thickness of 3.56 mm. The outer pipe has an inner diameter of 5.25 cm and is insulated. Neglecting the wall resistance to heat transfer from the inner pipe, and assuming the individual film heat transfer coefficient for water to be 6600 W/m² °C, calculate :
- (a) the individual heat transfer coefficient for benzene flowing in the inner pipe.
 - (b) the overall heat transfer coefficient based on inside diameter of inner pipe.
 - (c) the total length required for the heat exchanger.

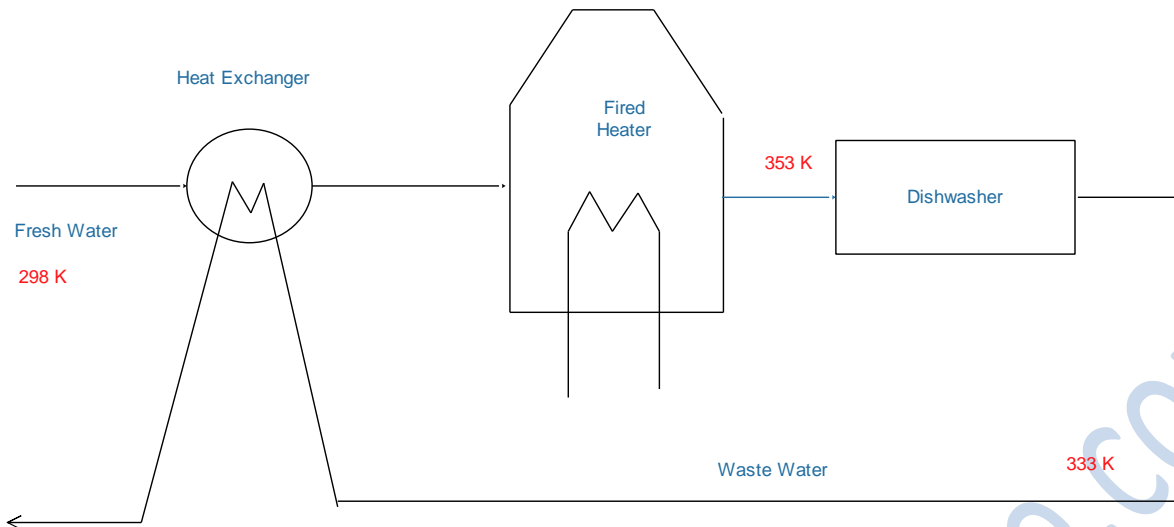
$$Nu = 0.023 (Re)^{0.8} (Pr)^{0.3}$$

Where Nu is the Nusselt Number and Pr is the Prandtl Number.

Average properties of benzene : viscosity = 4×10^{-4} kg/m s, thermal conductivity = 0.147 W/m°C, specific heat capacity = 1880 J/kg°C, density = 837 kg/m³.

Solution

6. A canteen requires hot water for its dish-washing. For this purpose, the canteen draws 0.4 kg/s of water at 298 K and heats it to 353 K in a fired-heater. The wastewater leaving the dishwasher is at 333 K. In order to save energy, it is proposed to recover heat from the wastewater to partially heat up the incoming water in a counter-current exchanger as shown schematically below:



Assume that there is no loss of water in the dishwasher and a minimum approach temperature of 10 K should be maintained in the exchanger.

- Determine the maximum temperature to which the incoming water can be heated in the exchanger.
- If the overall heat transfer coefficient in the exchanger is $1200 \text{ W/m}^2 \text{ K}$ and the specific heat capacity of water is 4186 J/kg K , compute the area of the heat exchanger.
- If the cost of the exchanger in 1982 was $2 \times A^{0.41}$ (in lakh rupees), where A is the exchanger area in m^2 and the Marshall and Swift cost indices in 1982 and 2000 are 315 and 400 respectively, determine the cost of the exchanger in the year 2000.

Solution

7. Air flows through a smooth tube, 2.5 cm diameter and 10 m long, at 37°C . If the pressure drop through the tube is 10000 Pa, estimate

- the air velocity through the tube and the friction factor
- the heat transfer coefficient using Colburn Analogy $[j_H = (St)(Pr)^{0.67}]$, where St is the Stanton Number and Pr is the Prandtl Number.



Gas constant, $R = 82.06 \text{ cm}^3 \text{ atm/mol K}$. Darcy friction factor, $f = 0.184 / \text{Re}^{0.2}$. Other relevant properties of air under the given conditions : viscosity = $1.8 \times 10^{-5} \text{ kg/m s}$, density = 1.134 kg/m^3 , specific heat capacity, $C_p = 1.046 \text{ kJ/kg } ^\circ\text{C}$, thermal conductivity = $0.028 \text{ W/m } ^\circ\text{C}$.

solution

G - 2001

1. The heat transfer by radiation from a mild steel surface is to be reduced by reducing the emissivity of the surface. This can be best achieved by –

- A) painting the surface black B) painting the surface white
C) giving the surface a mirror finish D) roughening the surface

Solution

2. Heat transfer by natural convection is enhanced in systems with

- A) high viscosity B) high coefficient of thermal expansion
C) low temperature gradients D) low density change with temperature

Solution

3. The Sieder-Tate correlation for heat transfer in turbulent flow in a pipe gives $\text{Nu} \propto \text{Re}^{0.8}$, where Nu is the Nusselt number and Re is the Reynolds number for the flow. Assuming that this relation is valid, the heat transfer coefficient varies with pipe diameter (D) as

- A) $D^{-1.8}$ B) $D^{-0.2}$ C) $D^{0.2}$ D) $D^{1.8}$

solution

4. The overall heat transfer coefficient for a shell and tube heat exchanger for clean surfaces is $U_0 = 400 \text{ W/m}^2\text{K}$. The fouling factor after one year of operation is found to be $h_{do} = 2000 \text{ W/m}^2\text{K}$. The overall heat transfer coefficient at this time is

- A) $1200 \text{ W/m}^2\text{K}$ B) $894 \text{ W/m}^2\text{K}$



C) 333 W/m²K

D) 287 W/m²K

Solution

5. The heat flux (from outside to inside) across an insulating wall with thermal conductivity $k = 0.04$ W/m K and thickness 0.16 m is 10 W/m^2 . The temperature of the inside wall is -5°C . The outside wall temperature is

A) 25°C , B) 30°C C) 35°C D) 40°C

Solution

6. A 200 W heater has a spherical casing of diameter 0.2 m. The heat transfer coefficient for conduction and convection from the casing to the ambient air is obtained from $\text{Nu} = 2 + 0.6 \text{Re}^{1/2} \text{Pr}^{1/3}$, with $\text{Re} = 10^4$ and $\text{Pr} = 0.69$. The temperature of the ambient air is 30°C and the thermal conductivity of air is $k = 0.02 \text{ W/m K}$.

(a) Find the heat flux from the surface at steady state

(b) Find the steady state surface temperature of the casing

(c) Find the temperature of the casing at steady state for stagnant air. Why is this situation physically infeasible?

Solution

7. A 1-2 shell and tube heat exchanger has liquid (specific heat C_p) flowing at a mass flow rate m in the tubes and saturated steam (temperature T_s) condensing on the shell side.

(a) Carry out a differential energy balance on a single tube to show that

$$\frac{m}{N} C_p \frac{dT}{dz} = \pi D U (T_s - T)$$

where T is the temperature of the liquid N is the number of tube in a pass, z is the distance along the tube, D is the inner diameter of the tubes and U is the overall heat transfer coefficient based on the inside surface area.



(b) Obtain an expression for the temperature of the liquid at the exit of the heat exchanger, T_2 . The length of the tubes is L and liquid enters the heat exchanger at temperature T_0 .

Solution

G - 2000

1. 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,

Solution

2. 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) $\left[\frac{R_1}{R_2}\right]^2$

Solution

3. A steel sphere of radius 0.1 m at 400K is immersed in an oil at 300K. If the centre of the sphere reaches 350K in 20 minutes, how long will it take for a 0.05m radius steel sphere to reach the same temperature (at the centre) under identical conditions? Assume that the convective heat transfer coefficient is infinitely large.

- A) 5 min, B) 10 min, C) 20 min, D) 40 min,

Solution

4. A composite flat wall of a furnace 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

Solution

5. 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,

Solution

6. The outside surface temperature of a pipe (radius = 0.1 m) is 400 K. The pipe is losing heat to atmosphere, which is at 300 K. The film heat transfer coefficient is $10 \text{ W/m}^2 \text{ K}$. To reduce the rate of heat loss, the pipe is insulated by a 50 mm thick layer of asbestos ($k = 0.5 \text{ W/m K}$). Calculate the percentage reduction in the rate of heat loss.

Solution

7. In a 1 – 1 counter flow shell and tube heat exchanger, process stream ($C_p = 4.2 \text{ kJ/kg K}$) is cooled from 450 to 350 K using water ($C_p = 4.2 \text{ kJ/kg K}$) 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 $1000 \text{ W/m}^2 \text{ K}$ and $1500 \text{ W/m}^2 \text{ K}$, 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.



8. 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

- steam economy,
- 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.



Answer Key

	Question No										
	1	2	3	4	5	6	7	8	9	10	11
00	B	D	A	D	C	32.32	a) 8.36 b) 1.123	a) 60.72 b) 0.898			
01	C	B	B	C	C	a) 1591.5 b) 319.27 c) 7987.7	-----				
02	D	A	D	C	a) 1428.37 b) 1210 c) 23.24	a) 323 b) 3.48 c) 4.23	a) $V=47.34$ $f= 0.0194$ b) 178.2				
03	B	D	B	A	B	D	B	D			
04	A	D	D	A	A						
05	C	B	C	B	D	B	C	A	C	A	C B
06	C	D	D	A D							
07	C	B	B	C	B	D	D				
08	D	D	D	D	B						
09	A	B	B	C	B	A D					
10	A	B	B	A	A	D B					
11	B	A	C	B	A	A					
12	D	C	B	B	D	C	A				
13	D	D	5.67	21.7	C						
14	A	D	17.14	3.85	271.071						
15	A	250.5	A	C	C						
16	3.9	C	D	0.25	A	B	A				
17	B	300	C	C	B						
18	C	B	13	28.2	0.52	27.27					
19	A	D	902	0.30	800						
20	B	D	1.8	B							