Example 1.One face of a copper plate (k=379 w/mk), 3 cm thick is maintained at 400◦C, and the other face is maintained at 100◦C. How much heat is transferred through the plate?

Example 2. A cylindrical insulation for a steam pipe has an inside radius r_i = 6 cm, outside radius r_o = 8 cm and k = 0.5 W/(mC). The inside surface of the insulation is at a temperature T_i = 430°C and the outside surface is at T_o = 30°C

Determine:

1. heat loss per meter length of this insulation
2. temperature at mid-thickness of the insulation

Example 3. Determine the steady state heat transfer through a double pane window, 0.8 m high, 1.5 m wide, consisting of two 4 mm thick glass layers (k = 0.78 W/(mC)), separated by a 10 mm thick stagnant layer of air (k = 0.026 W/(mC)). Inside temperature of room air is maintained at 20°C with a convective heat transfer coefficient of h_a = 10 (W/mc). Outside air temperature is (-10°C) and the convective heat transfer coefficient on the outside is h_b = 40 W/(m^2C). Also, determine the overall heat transfer coefficient.

Example 4. Find the heat flow rate through the composite wall shown below, in the Figure. Assume one-dimensional conduction. Thermal conductivities of slabs A, B, C and D are 150, 30, 65 and 50 W/(mC), respectively. (Ans. 1.274 * 10^3 W)

Example 5. A composite wall consists of a 10 cm layer of building brick (k = 0.7 W/(mC)) and 3 cm thick plaster (k = 0.5 W/(mC)). An insulation material of k = 0.08 W/(mC) is to be added to reduce the heat transfer through the wall by 70%. Determine the thickness of the insulating layer. (Ans. 0.038 m)

Example 6. An exterior wall of a house may be approximated by a 4-in layer of common brick [*k* = 0.7 W/m◦C] followed by a 1.5-in layer of gypsum plaster [*k* =0.48 W/m◦C]. What thickness of loosely packed rock-wool insulation [*k* =0.065 W/m◦C] should be added to reduce the heat loss (or gain) through the wall by 80 percent? (Ans. 0.0584 m)

Example 7. A thick-walled tube of stainless steel [18% Cr, 8% Ni, *k* =19 W/m◦C] with 2-cm inner diameter (ID) and 4-cm outer diameter (OD) is covered with a 3-cm layer of asbestos insulation [*k* =0.2 W/m◦C]. If the inside wall temperature of the pipe is maintained at 600◦C, calculate the heat loss per meter of length. Also calculate the tube insulation interface temperature. (Ans. 680 W/m, 595.8◦C)

Example 8. A 10 cm OD pipe carrying saturated steam at a temperature of 195°C is lagged to 20 cm diameter with magnesia and further lagged with laminated asbestos to 25 cm diameter. The entire pipe is further protected by a layer of canvas. If the temperature under the canvas is 20°C, find the mass of steam condensed in 8 hrs on a 100 m length of pipe. Take thermal conductivity of magnesia as 0.07 W/(mK) and that of asbestos as

0.082 W/(mK). Neglect the thermal resistance of the pipe material. (take h_{fg} = 1951 kJ/kg latent heat of evaporation for steam at 195 C). (Ans. 128.581 kg)

Example 9. A metal (k= 45 W/(mC)) steam pipe of 5 cm ID and 6.5 cm OD is lagged with 2.75 cm radial thickness of high temperature insulation having thermal conductivity of 1.1 W/(mC). Convective heat transfer coefficients on the inside and outside surfaces are h_i = 4650 W/(m^2K) and h_o = 11.5 W/(m^2K), respectively. If the steam temperature is 200°C and the ambient temperature is 25°C, calculate: (1) heat loss per meter length of pipe (2) temperature at the interfaces, and (3) overall heat transfer coefficients referred to inside and outside surfaces (i.e. calculate U_i and U_o). (Ans. 544.046 W, 8.246 W/m^2C)

Example 10. A 3.3 cm OD steel pipe, outside surface of which is at 500 K, is surrounded by still air at 300 K. The heat transfer coefficient by natural convection is 10 W/(m^2K). It is proposed to reduce the heat loss to half by applying magnesia insulation (k = 0.07 W/mK) on the outside surface of the pipe. Determine the thickness of the insulation. Assume pipe surface temperature and convective heat transfer coefficients remain the same.(Ans. 0.05 m)

Example 11. Consider an aluminium hollow sphere of inside radius r_i = 2 cm, outside radius r_o = 6 cm and A: = 200 W/(mC). The inside surface is kept at an uniform temperature of T_i = 100°C and outside surface dissipates heat by convection with h = 80 W/(m^2C) into ambient air at a temperature of T_a = 20°C. Determine:
(i) outside surface temperature of the sphere in steady state. (ii) rate of heat transfer.
(iii) temperature within the aluminium sphere at a radius r = 3 cm. (Ans. 96.336 C, 276.268W, 98.168 C)

Example. Calculate the critical radius of insulation for asbestos [*k* =0.17 W/mC] surrounding a pipe and exposed to room air at 20°C with *h*=3.0 W/m^2C. Calculate the heat loss from a 200°C, 5.0-cm-diameter pipe when covered with the critical radius of insulation and without insulation.

Example 12. Heat is generated uniformly in a stainless steel plate having k = 20 W/(mK). The thickness of the plate is 1 cm and heat generation rate is 500 MW/m^3 If the two sides of the plate are maintained at 100 C and 200 C, respectively, calculate:

1. the temperature at the centre of the plate
2. the position and value of maximum temperature
3. heat transfer at the left and right faces

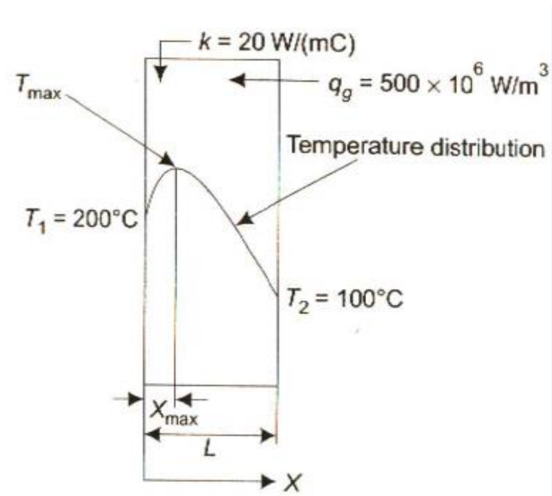


Figure example 12

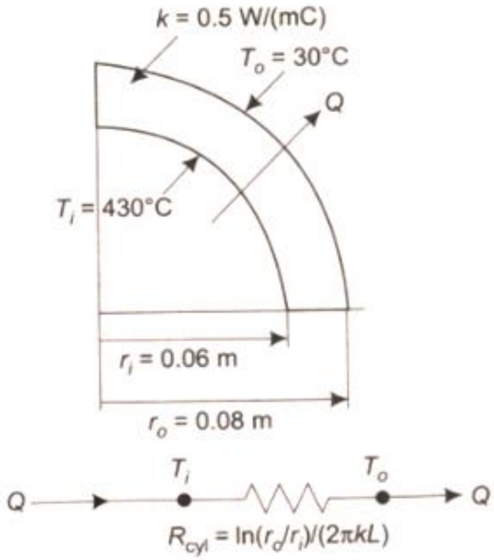


FIGURE Example **2**

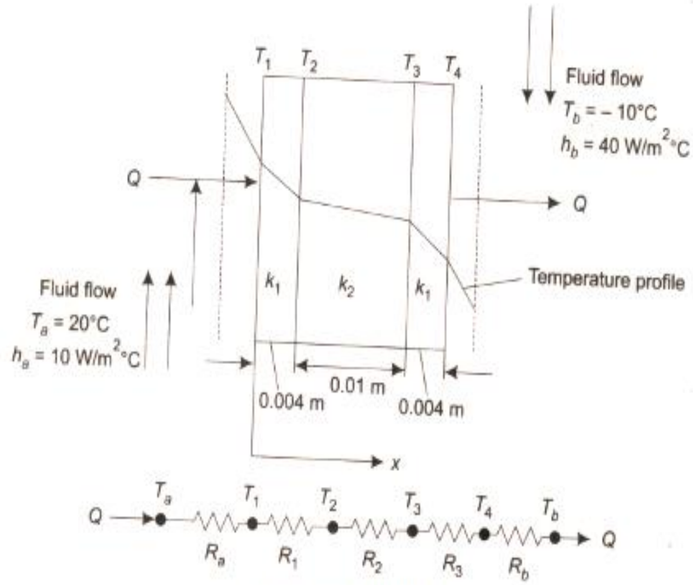


Figure example 3

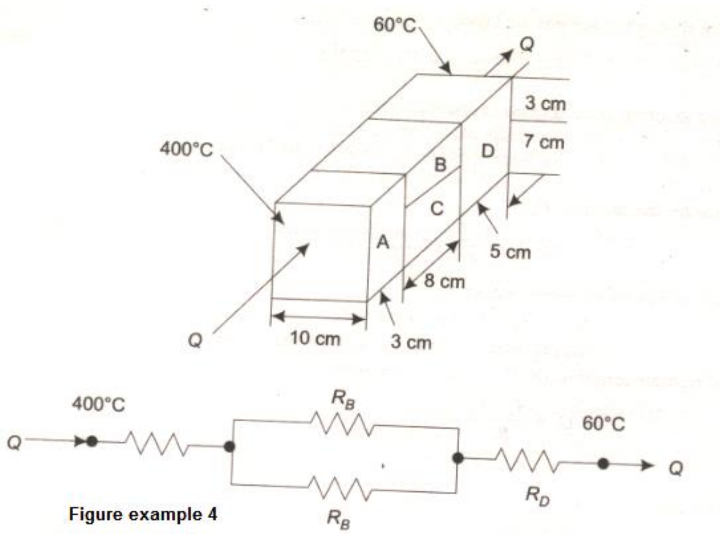


Figure example 4

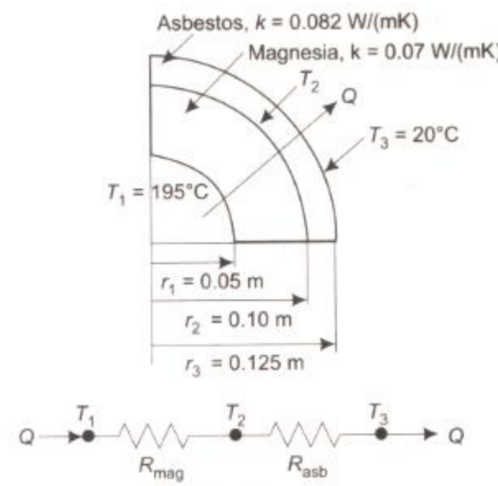


FIGURE Example **8**

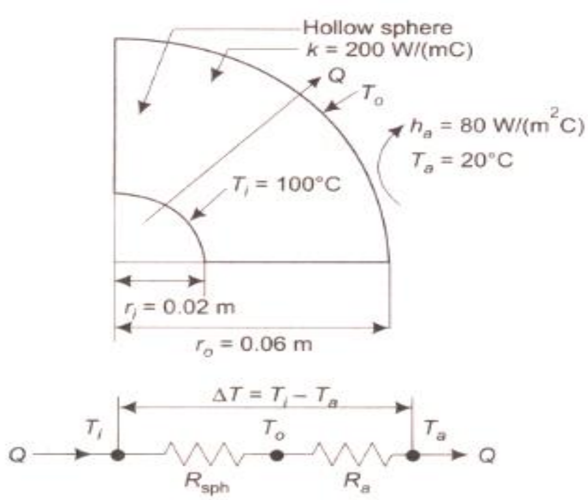


FIGURE Example **11**

Example 13. If in Example 12, the temperatures on either side of the plate are maintained at 100°C, calculate:

1. the temperature on the centre line
2. temperature at one-quarter of the thickness from the surface

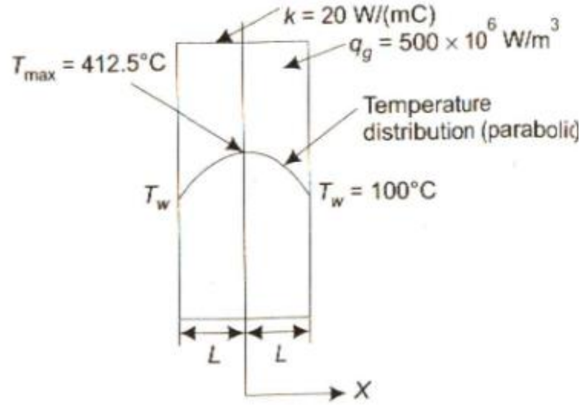


Figure example 13

Example 14. A 3.2 mm diameter stainless steel wire, 30 cm long has a electric power ($3.83 * 10^3$ W) on it. The outer surface temperature of the wire is maintained at 93C. Calculate the centre temperature of the wire. Take the thermal conductivity as 22.5 W/(mK).

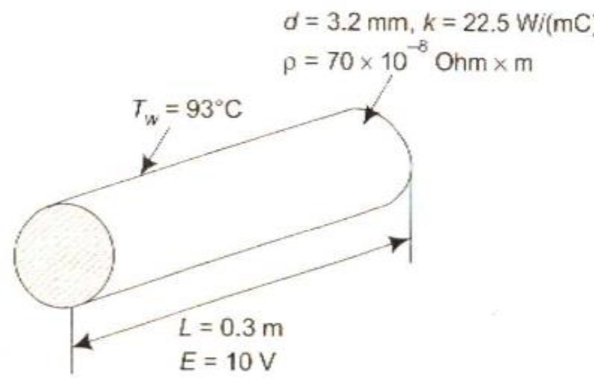


Figure example 14

Fins

Example1. (a) A very long, 25 mm diameter copper rod (k = 380 W/(mC)), extends horizontally from a plane heated wall at 150°C. Temperature of surrounding air is 30°C and heat transfer coefficient between the surface of the rod and the surroundings is 10 W/(m^2K).

(i) Determine the rate of heat loss from the rod

(ii) How long the rod should be to be considered as infinite?

(b) Compare the temperature distribution in the rod if the material were: (i) copper (k = 380 W/(mC), (ii) aluminium (k = 200 W/(mC) and, (iii) steel (k = 55 W/(mC)). Other data is the same as in part (a).

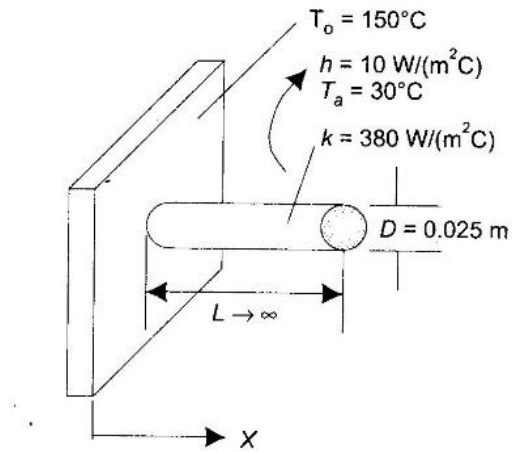


FIGURE Example 1 Fin of circular (round) cross section

Example 2. To determine the thermal conductivity of a long, solid 2.5 cm diameter rod, one half of the rod was. inserted to a furnace while the other half was projecting into air at 27°C. After steady state had been reached, the temperatures at two points 7.6 cm apart were measured and found to be 126°C and 91°C, respectively. The heat transfer coefficient over the surface of the rod exposed to air was estimated to be 22.7 W/(m^2K). What is the thermal conductivity of the rod?

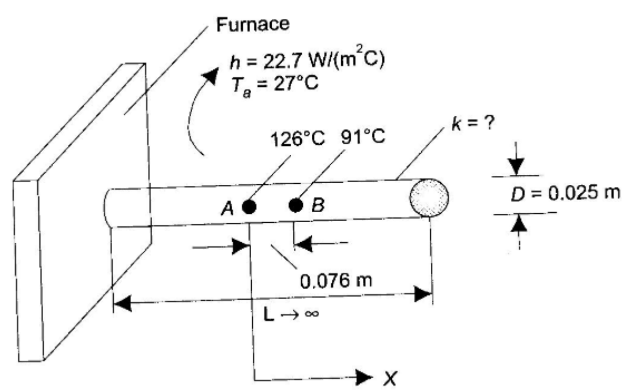


FIGURE Example 2 Very long fin of circular cross section

Example 3. Aluminum square fins (0.5 mm x 0.5 mm) of 1 cm length are provided on the surface of an electronic semiconductor device to carry 46 mW of energy generated by the electronic device and the temperature at the surface of the device should not exceed 80°C. The temperature of the surrounding medium is 40°C Thermal conductivity of aluminium =190 W/(mK) and heat transfer coefficient h = 12.5 W/(m^2K). Find number of fins required to canrry out the above duty- Neglect the heat loss from the end of the fin.

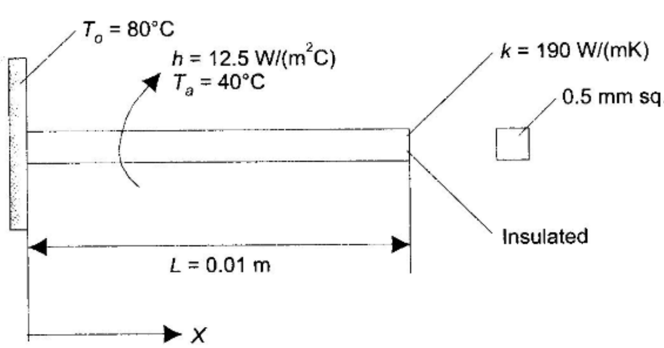


Figure Example 3 Finite fin insulated at its tip

Example 4. A cylinder 5 cm diameter and 50 cm long, is provided with 14 longitudinal straight fins of 1 mm thick and 2.5 mm height. Calculate the heat loss from the cylinder per second if the surface temperature of the cylinder is 200°C

Take h = 25W/(m^{2}K), k = 80 W/(mK), and T_a = 45°C.

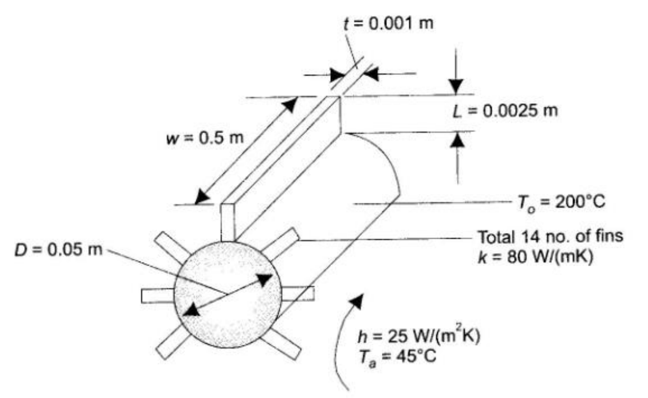


FIGURE Example 4 Longitudinal fins on a cylinder, losing heat from tip

Example 5. A steel rod (k = 30 W/(mC)), 10 mm in diameter and 50 mm long, with an insulated end is to be used as a spine. It is exposed to surroundings with a temperature of 65°C and a heat transfer coefficient of 50 W/(m^{2}C) temperature of the base is 98°C Determine: (i) fin efficiency (ii) temperature at the end of spine, and (iii) heat dissipation.

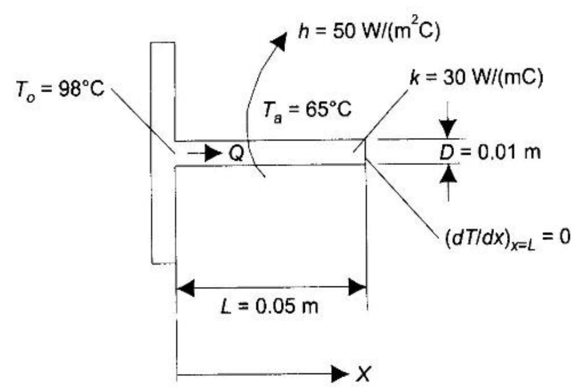


FIGURE Example 5 Fin of finite length, end insulated

Example 6. Circular aluminium fins of constant rectangular profile are attached to a tube of outside diameter D = 5cm. The fins have thickness t = 2 mm, height L = 15 mm, thermal conductivity k = 200 W/(mC), and spacing 8 mm (i.e. 125 fins per meter length of rube). The tube surface is maintained at a uniform temperature T_o = 180°C, and the fins dissipate heat by convection into the ambient air at T_a = 25°C, with a heat transfer coefficient h_a = 50 W/(m^{2}C). Determine the net

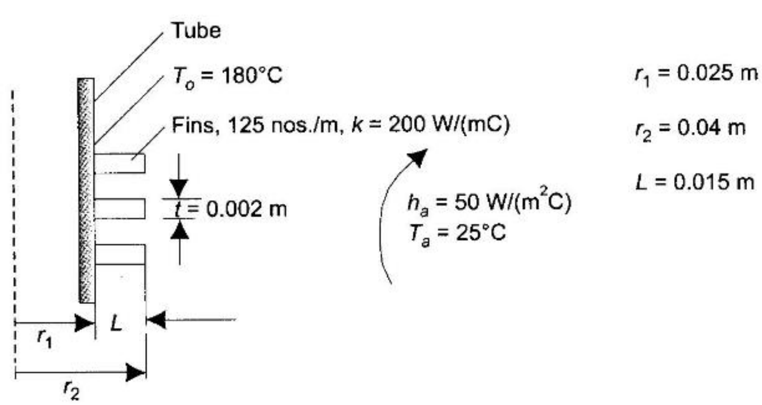


FIGURE Example 6 Circular fin of rectangular section heat transfer per meter length of tube.

Example 7. Aluminum fins 1.5 cm wide and 1.0mmthick are placed on a 2.5-cm-diameter tube to dissipate the heat. The tube surface temperature is 170◦C and the ambient-fluid temperature is 25◦C. Calculate the heat loss per fin for h=130 W/m^2◦C. Assume k =200 W/m◦C for aluminum.

Transient Heat Conduction Examples

Example 1. A steel ball of 5 cm diameter initially at a uniform temperature of 450°C is suddenly placed in an environment at 100°C. Heat transfer coefficient h, between the steel ball and the fluid is 10 W/(m^2K);. For steel $cp = 0.46(\text{kj/KgK})$ $\rho = 7800\ \text{kg/m}^3$, k = 35 W/(mK). Calculate the time required tor the ball to reach a temperature of 150°C.

Example 2. A 50 cm x 50 cm copper slab, 6 mm thick, at a uniform temperature of 350°C, suddenly has its surface temperature lowered to 30°C Find the time at which the slab temperature becomes 100°C. Given: $\rho = 9000\ \text{kg/m}^3$ cp=0. 38 kJ/(kgK), k = 370 W/(mK), h = 100 (W/m^2K).

Example 3. A carbon steel (AISI 1010) shaft of 0.2 m diameter is heat treated in a gas-fired furnace whose gases are at 1200 K and provide a convection coefficient of 80 W/(m^2K). If the shaft enters the furnace at 300 K, how long must it remain in the furnace to achieve a centre line temperature of 900 K? Given thermo physical properties of AISI 1010 carbon steel: ρ =7854 kg/m^3, k = 48.8 W/(mK), cp = 559 J/(kgK).

Example 4. A long, 15 cm diameter cylindrical shaft made of stainless steel 304 (k = 14.9 W/mC), ρ =7900 kg/m^3, Cp = 477 J/(kgC), and $\alpha =$ 3.95 x 10^{-6} m^2/s), comes out of an oven at an uniform temperature of 450°C. the shaft is then allowed to cool slowly in a chamber at 150°C with an average heat transfer coefficient of 85 w/(m^2C).

(i) Determine the temperature at the centre of the shaft 25 min ofter the start of the cooling process.
(ii) Determine the surface temperature at that time, and
(iii) Determine the heat transfer per unit length of the shaft during this time period.

Example 5. A steel plate ($= 1.2 * 10^{-5}$ m^2/s, k=43 W/(mC), of thickness 2L=10 cm, initially at uniform temperature of 250°C is suddenly immersed in an oil bath at T_a= 45 °C, h=700 w/(m^2c).

(i) How long will it take for the centre plane to cool to 100°C?
(ii) What fraction of the energy is removed during this time?

Example 6. An apple, which can be considered as a sphere of 8 cm diameter, is initially at a uniform temperature of 25°C it is put into a freezer at -15°C and the heat transfer coefficient between the surface of the apple and the surrounding in the freezer is 15

W/(m^2C). If the thermo physical properties of apple are given to be: ρ = 840 kg/m^3 Cp = 3.6 kj/(kgC), k=0.513 W/(mC), and α = 1.3 x 10^{-7} m^2/s, determine:
1- center temperature of the apple after 1 hour,
2- surface temperature of apple at that time, and
3- amount of heat transferred from the apple.

Example 7. A thick copper slab (α = 1.1 x 10^{-4} m^2/s, k = 380 W/(mC)) is Initially at a uniform temperature of 250°C. Suddenly, its surface temperature is lowered to 60°C.

(i) How long will it take the temperature at a depth of 3 cm to reach I00°C?
(ii) What is the heat flux at the surface at that time?
(iii) What is the total amount of heat removed from the slab per unit surface area till that time?

Example 8. In areas where ambient temperature drops to sub zero temperatures and remains so for prolonged period freezing of water in underground pipelines is a major concern. It is of interest to know at what depth the water buried so that the water does not freeze.

At a particular location, the soil is initially at a uniform temperature of I5°C and the soil is subjected to a sub zero temperature of -20°C continuously for 50 days.
What is the minimum burial depth required to ensure that the water in the pipes does not freeze?, i.e. pipe surface temperature should not fall below 0°C.
Properties of soil taken as: α = 0.138 x 10^{-6} m^2/s, ρ = 2050 kg/m^3, k = 0.52 w/(mK), Cp = 1840 J/kg.K.

Example9: A thermocouple junction is in the form of 8 mm diameter sphere. Properties of material are: c = 420 J/kg°C; ρ = 8000 kg/m^3 k = 40 W/m°C and h = 40 W/m^{2o}C.
This junction is initially at 40°C and inserted in a stream of hot air at 300°C. Find: (i) The thermocouple is taken out from the hot air after 10 seconds and kept in still air at 30°C. Assuming the heat transfer coefficient in air 10 W/m^{2o}C, find the temperature attained by the junction 20 seconds after removing from hot air.

Example 10: A very thin glass walled 3 mm diameter mercury thermometer is placed in a stream of air, where heat transfer coefficient is 55 W/m^2°C, for measuring the unsteady temperature of air. Consider cylindrical thermometer bulb to consist of mercury only for which k = 8.8 W/m°C and α = 0.0166 m^2/h. Calculate the time required for the temperature change to reach half of its distance.

Example11: An egg (assume spherical shape) with mean diameter of 40 mm and initially at 20°C is placed in a boiling water (100°C) pan for 4 minutes and found to be tasty for the consumer. For how long should a similar egg for same consumer to be boiled when taken from a refrigerator at 5°C.
Properties for egg: k= 10 W/m°C, ρ = 1200 kg/m3 Cp= 2000 J/kg°C and h=100 W/m2°C.

Example12: A person is found dead at 5 PM in a room at 20°C temperature. The temperature of the body surface is measured to be 25°C when found, and the heat transfer coefficient is estimated to be h = 8 W/m2°C. Modeling the body as a 30-cm-diameter, 1.70-m-long cylinder. Estimate the time of death of that person.
The average human body is 72 percent water by mass, and thus we can assume the body to have the properties of water: k = 0.617 W/m°C, ρ=996 kg/m3, and Cp = 4178 J/kg°C, Take the live human body temperature as 37°C.

Example 1. Dry air at atmospheric pressure and 20°C is flowing with a velocity of 3 m/s along the length of a long, flat plate 0.3 m length, maintained at 100°C
Calculate the following quantities at x = 0.3 m:
(i) boundary layer thickness (ii) local and average friction coefficient (iii) shear stress (iv) thickness of thermal boundary layer (v) local convection heat transfer coefficient (vi) average heat transfer coefficient (vii) rate of heat transfer from the plate between x = 0 and x = x, by convection, and (viii)total drag force on the plate between x = 0 and x = 0.3 m.
Also, find out the value of xc (i.e. the distance along the length at which the flow turns turbulent, $Re_c = 5 \times 10^5$).
properties of air at 60°C is: ρ= 1.025 kg/m^3 Cp = 1017 J/(kgK) μ = 19.907 10^{-6} kg/(ms) k = 0.0279 W/(mK) Pr = 0.71

Example 2. Dry air at atmospheric pressure and 20°C is flowing with a velocity of 3 m/s along the length of a flat plate, (size: 0.5 m x 0.25 m), maintained at 100°C. Using the exact solution, calculate the heat transfer rate from: (i) the first half of the plate (ii) full plate, and (iii) next half of plate.
properties of air at 60°C is: ρ= 1.025 kg/m^3 Cp = 1017 J/(kgK) μ = 19.907 10^{-6} kg/(ms) k = 0.0279 W/(mK) Pr = 0.71

Example 3. A refrigerated truck is moving at a speed of 85 km/h where ambient temperature is 50°C The truck is of rectangular shape of size 10 m (L) x 4 m(W) x 3 m(H). Assume the boundary layer is turbulent surface temperature is at 10°C. Neglect heat transfer from vertical front and backside of truck and flow of air is parallel to 10 m long side. Calculate heat loss from the four surfaces.
For turbulent flow over flat surfaces: $Nu = 0.036\, Re^{0.8}\, Pr^{0.33}$
properties of air at 30°C: ρ = 1.165 kg/m^3 Cp = 1.005 kJ/kgK, $v = 16*10^{-6}$ m^2/s, Pr = 0.701

Example 4. Air at 1 bar and 20°C flows across a bank of tubes 10 rows high and 4 rows deep; air velocity is 8 m/s, measured at the entry to the tube bank. Diameter of the tubes is 25 mm and surface temperature of the tubes is maintained at 80°C. Tubes are arranged in an in - line manner. Sn = Sp = 37.5 mm. Calculate the total heat transfer per unit length of the tube bank, and also the exit air temperature. Also, find out the pressure drop.
properties of air at 20°C: ρ = 1.164 kg/m^3, Cp = 1012 J/(kgK), k = 0.0251 W/(mK), v = 15.7 x 10^{-6} m^2/s, Pr = 0.71

Example 5. Water at 20°C flows through a 2.5 cm ID, l m long pipe, whose surface is maintained at a constant temperature of 50°C, at velocity of 5 cm/s. Determine the outlet temperature of water, assuming fully developed hydrodynamic boundary layer. Properties of water at Tb = 30°C: ρ := 996.0 kg/m^3, μ :=0.798 x 10^{-3} kg/(ms) Cp := 4178 J/(kgC) k := 0.615 W/(mC) Pr := 5.42

And Properties of water at Tb = 22.5°C: ρ := 997.5 kg/m^3, μ :=0.95 x 10^{-3} kg/(ms) Cp := 4181 J/(kgC) k := 0.602 W/(mC) Pr := 6.575

Example 6. Air at 1 bar and 20°C flows through a 6 mm ID, 1 m long smooth pipe, whose surface is maintained at a constant heat flux, with velocity of 3 m/s. Determine the heat transfer coefficient if the exit bulk temperature of air is 80°C determine the exit wall temperature and the value of h at the exit.
properties of air at Tb = 50°C: ρ := 1.093 kg/m^3 μ := 19.61 x 10^{-6} kg/(ms) Cp ;= 1005 J/(kgC) k := 0.02826 W/(mC) Pr := 0.698

Example 7. Water is heated in the annular section of a double pipe heat exchanger by electrical heating of the inner pipe. Outer pipe is insulated. Mean bulk temperature of water is 60°C. For the annulus, Di = 2.5 cm and Do = 5 cm. Determine the convection coefficient and pressure drop/meter length for flow rate of 0.5 kg/s
properties of water at average temperature of 60°C: ρ := 983.3 kg/m^3 μ = 0.467 x 10^{-3} kg/(ms) Cp := 4185 J/(kgC) k := 0.654 W/(mC) Pr := 2.99

Example 8. Water (under pressure) is heated in an economizer from a temperature of 30°C to 150°C. Tube wall is maintained at a constant temperature of 350°C. If the water "flows at a velocity of 1.5 m/s and the tube diameter is 50 mm, determine the length of tube required.
Properties of water at Tb = 90°C:
ρ := 965.3 kg/m^3 μ := 0-315 x 10^{-3} kg/(m/s) Cp := 4206 J/(kgC) k := 0.675 W/(mC)
Pr := 1.96

Example 9. In a long annulus (3.125 cm ID, 5 cm OD), air is heated by maintaining the temperature of outer surface of the inner tube at 50°C. The air enters at 16°C and leaves at 32°C and its flow velocity is 30 m/s. Estimate the heat transfer coefficient between the air and the inner tube. Use Dittus - Boelter equation, viz. $Nu = 0.023.Re_D^{0.8}.Pr^{0.4}$;
Average properties of air at 24°C are:
ρ = 1.614 kg/m^3, Cp = 1007 J/(kgC), k = 0.0263 W/(mC), Pr = 0.7 v = 15.9 x 10^{-6} m^2/s

Example 10. Water at 20°C flows through a tube, 4 cm diameter 9 m length, tube surface being maintained at 90°C Temperature of water increases from 20°C to 60°C. Find the mass flow rate. Use Dittus-Boelter equation, viz. $Nu = 0.023.Re_D^{0.8}.Pr^{0.4}$; Take properties of water at mean bulk temperature of 40°C as: ρ = 993 kg/m^3, Cp = 4170 J/kgC), k = 0.64 W/(mC), v= 0.65 x 10^{-6} m^2/s

Example 11. 180 kg/h of air at one atm. pressure is cooled from 100°C to 20°C while passing through a 3 cm ID pipe coil bent into a helix of 0.7 m diameter. Calculate the air side heat transfer coefficient.
Properties of air at Tb = 60°C: := 1.06 kg/m^3 μ := 20.10 x 10^{-6} kg/(ms) Cp := 1005 J/(KgC) k := 0.02896 W/(mC) Pr := 0.696

Example 12/ 3.8 kg of oil per second is heated from 20° C to 40°C by passing through a circular annulus with a velocity of 0.3 m/s. The inner tube (100 mm diameter) is a heater its surface temperature is maintained at 250°C. find the length of the pipe required for the above heat transfer process
Take the following properties of oil at mean temperature :
ρ =800 kg/m^3 cp =3350 J/kg K
ν =8*10^{-6} m^2/s k =0.2 W/m°C
Example 13/ A horizontal tubular condenser is used to condense saturated steam at 80°C. The condenser is a shell and tube with brass tubes (k = 110 W/m°C) of 1.59 cm OD and 1.34 cm ID. Steam is outside tubes and cooling water enters the tubes at 20°C with a velocity of 1.4 m/s and leaves at 40°C. If the rate of cooling water supply is 55000 kg/h.

1. The number of tubes,
2. The length of each tube.

For calculating the tube side heat transfer coefficient use the Dittus-Boelter equation and for
the shell side heat transfer coefficient, the average value may be taken as 10760 W/m^2 K.
Data : Properties of water at 30° C.
k = 0.659 W/m°C ρ = 979.8 kg/m^3
cp = 4.180 kJ/kg K μ = 0.4044 * 10^{-3}

Example 14/ An aeroplane flies with a speed of450 km/h at a height where the surrounding
air has a temperature of 1°C and pressure of 0.866 bar. The aeroplane wing idealised as a flat
plate 6m long. 1.2 m wide is maintained at 19°C. If the flow is made parallel to the 1.2 m width. Calculate Heat loss from the wing
pr=0.705 cp =3350 J/kg K
ν =14.16*10^{-6} m^2/s k =0.025 W/m°C

CONDENSATION

Example 1. Saturated steam at atmospheric pressure condenses on a vertical plate (size: 30 cm x 30 cm) maintained at 60°C. Determine heat transfer rate and the mass of steam condensed per hour. (b) If the plate is tilted at an angle of 30 deg. to the vertical, what is the value of condensation rate?.

Properties of liquid at T = 80°C:

ρ_L= 971.8 kg/m^3 C_{pL} := 4197 J/kg.C μ_L= 0.355 x 10^{-3} kg/(ms) k_L := 0.67 W/(mC) g = 9.81 m/s^2

Properties of saturation vapours at 100°C:

h_{fg} = 2257 x 10^3 J/kg ρ_V = 0.5978 kg/m^3

Example 2. Saturated steam at a temperature of 65°C condenses on a vertical surface at 55°C Determine the thickness of the condensate film at locations 0.2 m from top. Also, calculate the condensate flow rate, local and average heat transfer coefficients at these locations.

Properties of water at the mean temperature are:

ρ_L := 983.3 kg/m^3 k_L := 0.654 W/(mK) μ_L := 4.67 x 10^{-4} kg/(ms) Cp := 485 J/(kgC)

h_{fg} := 2346 x 10^3 J/kg T_{sat} := 65°C T_s = 55°C g := 9.81 m/s^2 b = lm (width, assumed)

Example 3. Dry, saturated steam at atmospheric pressure condenses on a horizontal tube of diameter 5 cm and length 1 m; surface of the tube is maintained at 60°C. Determine heat transfer rate and the mass of steam condensed per hour. Assume laminar film condensation. (b) If the tube is vertical, what is the condensation rate?

Properties of liquid at T = 80°C:

ρ_L= 971.8 kg/m^3 C_{pL} := 4197 J/kgC μ_L = 0.355 x 10^{-3} kg/(ms) k_L= 0.67 W/(mC)

Properties of saturated vapour at 100°C:

h_{fg} = 2257 x 10^3 J/kg

ρ_V = 0.5978 kg/m^3

Example 4. Dry, saturated steam at atmospheric pressure condenses on a vertical tube of diameter = 5 cm and length L = 1.5 m; surface of the tube is maintained at 80°C. Determine the heat transfer rate and the mass of steam condensed per hour.

Properties of liquid at 90°C

ρ_L = 965.3 kg/m^3 C_{pL}= J/kgC μ_L := 0.315 x 10^{-3} kg/(ms) k_L := 0.675 W/(mC) Pr, := 1.96

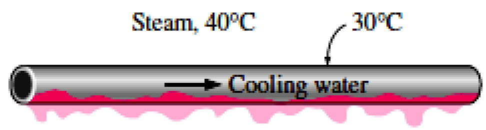
Properties of saturated vapour at 100°C:

h_{fg} := 2257 x 10^3 J/kg

ρ_V:= 0.5978 kg/m^3

Example 5. A steam condenser consists of a square array of 400 horizontal tubes, each 6 mm in diameter. The tubes are exposed to exhaust steam arriving from the turbine at a pressure of 0.1 bar. If the tube surface temperature is maintained at a temperature of 25°C by circulating cold water through the tubes, determine the heat transfer coefficient and the rate at which the steam is condensed per unit length of tubes for the entire array. Assume laminar film condensate and that there are no condensable gases mixed with

steam.
Properties of liquid at T= 35.4°C:
ρ_L := 994.04 kg/m3 C_{pL}:=4178 J/kgC μ_L := 0.720 x 10^{-3} kg/(ms) k_L := 0.623 W/(mC)
P_{rL} := 4.83
Properties of saturated vapour at 45.8°C:
h_{fg} := 2393 x 101 J/kg
ρ_V= 0.068 kg/m^3

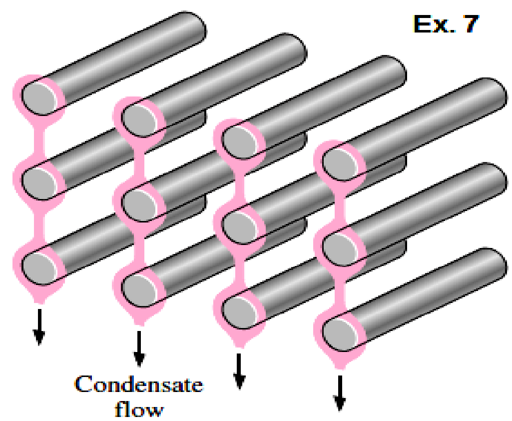


Schematic for Example 6

Example 6
The condenser of a steam power plant operates at a pressure of 7.38 kPa. Steam at this pressure condenses on the outer surfaces of horizontal pipes through which cooling water circulates. The outer diameter of the pipes is 3 cm, and the outer surfaces of the pipes are maintained at 30°C. Determine
(*a*) the rate of heat transfer to the cooling water circulating in the pipes
(*b*) the rate of condensation of steam per unit length of a horizontal pipe.

The Properties of saturation vapours of 40°C corresponding to 7.38 kPa are h_{fg} = 2407 * 10^3 J/kg and ρ_V =0.05 kg/m^3.
The properties of liquid water at the film temperature of T_f=35°C are ρ_L = 994 kg/m^3 C_{pL} = 4178 J/kg · °Cμ_L= 0.720*10^{-3} kg/m · s k_L= 0.623 W/m · °C

Example 7
Repeat the proceeding example problem for the case of 12 horizontal tubes arranged in a rectangular array of 3 tubes high and 4 tubes wide, as shown in the figure.

Ex. 7


BOILING

Example 8. Water is boiling at 8 arm. on the surface of a horizontal tube, whose wall temperature is maintained at 8°C above the boiling point of water. Calculate the nucleate boiling heat transfer coefficient
(b) What is the change in the value of heat transfer coefficient when (i) temperature difference is increased to 16°C at the pressure of 8 atm., and (ii) pressure is raised to 16 atm. with ΔTe = 8°C.

Example 9. Water at 8 atm. flows inside a vertical tube of 2.5 cm diameter under flow boiling conditions. Tube wall temperature is maintained at 8 C above the saturation temperature. Determine the heat transfer for one metre length of tube

Example 10. Water at 5 atm flows inside a tube of 1-in [2.54-cm] diameter under local boiling conditions where the tube wall temperature is 10◦C above the saturation temperature. Estimate the heat transfer in a 1.0-m length of tube.

Example1. Water at a mean temperature of T_m = 90°C and a mean velocity of u_m = 0.10 m/s flows inside a 2.5 cm ID, thin-walled copper tube. Outer surface of the tube dissipates heat to atmospheric air at Ta = 20°C, by free convection. Calculate the tube wall temperature, overall heat transfer coefficient and heat loss per metre length of tube. Use following simplified expression for air to determine heat transfer coefficient by free convection:

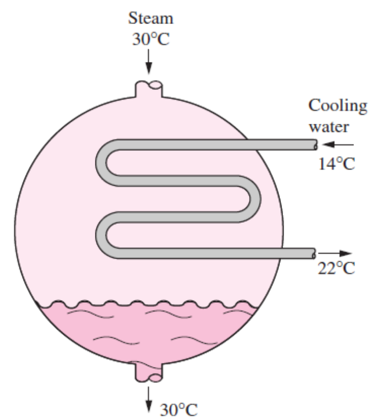
$$h_a = 1.32.\left(\frac{T_s - T_a}{D}\right)$$

Properties of water at mean temperature of 90°C:	Properties of air at 55°C:
ρ =965.3 kg/m^3 $k = 0.675\ W/(mC)$ $\mu = 0.315\ x\ 10^{-3}\ kg/(ms)$ Pr = 2.22	ρ =1.076 kg/m^3 $k = 0.0283\ W/(mC)$ $\mu = 1.99\ x\ 10^{-5}\ kg/(ms)$ Pr = 0.708

Example2. In Example 1, if we desire to increase the value of overall heat transfer coefficient U, the obvious choice is to focus on the air-side, since the air side heat transfer coefficient is the lower of the inside and outside heat transfer coefficients. Let us increase the area on the air side by providing 8 numbers of radial fins of rectangular cross section, 2 mm thick and 20 mm height. Material of fins is the same as that of the tube, i.e. copper (k = 380 W/(mK)). Then, determine the overall heat transfer coefficient and the rate of heat transfer.

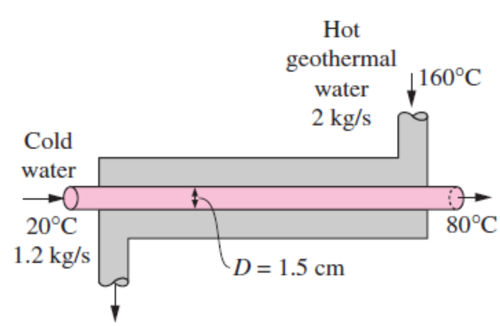
Example3. A shell and tube counter-flow heat exchanger uses copper tubes (k = 380 W/(mC)), 20 mm ID and 23 mm OD. Inside and outside film coefficients are 5000 and 1500 W/(m^{2}C), respectively. Fouling factors on the inside and outside may be taken as 0.0004 and 0.001 m^{2}C/W respectively. Calculate the overall heat transfer coefficient based on: (i) outside surface, and (ii) inside surface.

Example4.Steam in the condenser of a power plant is to be condensed at a temperature of 30°C with cooling water from a nearby lake, which enters the tubes of the condenser at 14°C and leaves at 22°C. The surface area of the tubes is 45 m^2, and the overall heat transfer coefficient is 2100 W/m^2°C. Determine the mass flow rate of the cooling water needed.



Schematic for Example 4

Example5. A counter-flow double-pipe heat exchanger is to heat water from 20°C to 80°C at a rate of 1.2 kg/s. The heating is to be accomplished by geothermal water available at 160°C at a mass flow rate of 2 kg/s. The inner tube is thin-walled and has a diameter of 1.5 cm. If the overall heat transfer coefficient of the heat exchanger is 640 W/m^2°C, determine the length of the heat exchanger required to achieve the desired heating.



Schematic for Example 5

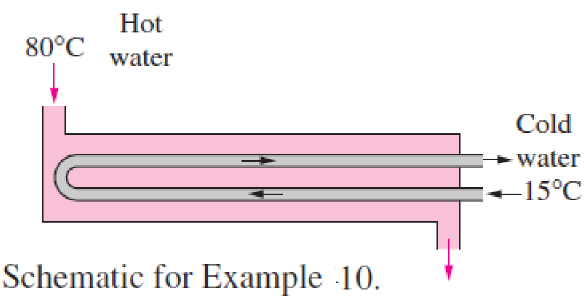
Example6. A one shell pass, two tube pass heat exchanger, has water flowing through the tubes and oil flowing on the shell side. Water flow rate is 1.2 kg/s and its temperatures at inlet and exit are 25°C and 75°C, respectively. Engine oil enters at 110°C and leaves at 75°C Overall U = 300 W/(m^{2}K). Take C_p for water as 4.18 kJ/(kgK) and calculate the heat transfer area required.

Example7. In a shell and tube HX, 50 kg/min of oil is heated from 10 to 90°C. Steam at 120°C flows through the shell and oil flows inside the tube. Tube size: 1.65 cm ID and 1.9 cm OD. Heat transfer coefficient on oil and steam sides are: 85 and 7420 W/(m^{2}K), respectively. Find the number of passes and number of tubes in each pass if the length of HX is limited to 2.85 m. Velocity of oil is limited to 5 cm/s. Density and specific heat of oil are 900 kg/m^3 and 1970 J/(kg.K), respectively.

Example8. Consider a heat exchanger for cooling oil which enters at 180°C and cooling water enters at 25°C. Mass flow rates of oil and water are: 2.5 and 1.2 kg/s, respectively. Area for heat transfer = 16 m^2. Specific heat data for oil and water and overall U are given: Cp_{oil} = 1900 J/kgK; Cp_{water} = 4184 J/kgK; U = 285 W/m^{2}K. Calculate outlet temperatures of oil and water for parallel and counter-flow.

Example9. A steam condenser, condensing at 70°C has to have a capacity of 100 kW. Water at 20°C is used and the outlet water temperature is limited to 45°C. If the overall heat transfer coefficient is 3100 W/m^{2}K, determine the area required.
(b) If the inlet water temperature is increased to 30°C, determine the increased flow rate of water to maintain the same outlet temperature.

Example10. Installing a Heat Exchanger to Save Energy and Money
In a dairy plant, milk is pasteurized by hot water supplied by a natural gas furnace. The hot water is then discharged to an open floor drain at 80°C at a rate of 15 kg/min. The plant operates 24 h a day and 365 days a year. The furnace has an efficiency of 80 percent, and the cost of the natural gas is $0.40 per therm (1 therm _ 1055*10^5 J). The average temperature of the cold water entering the furnace throughout the year is 15°C. The drained hot water cannot be returned to the furnace and recirculated, because it is polluted during the process.
In order to save energy, installation of a water-to-water heat exchanger to preheat the incoming cold water by the drained hot water is proposed. Assuming that the heat exchanger will recover 75 percent of the available heat in the hot water, determine the heat transfer rating of the heat exchanger that needs to be purchased and suggest a suitable type. Also, determine the amount of money this heat exchanger will save the company per year from natural gas savings.



Schematic for Example 10.