Indian Institute of Technology Kharagpur

Department of Mechanical Engineering

Heat Transfer ME30005

Tutorial 1 Date: 27/07/2010

1. What is the thickness required of a masonry wall having thermal conductivity 0.75 W/m-K if the heat rate is to be 80% of the heat rate through a composite structure wall having a thermal conductivity of 0.25 W/m-K and a thickness of 100mm? Both walls are subjected to the same surface temperature difference? (Ans: 375 mm)

2. Consider steady heat transfer between two large parallel plates at constant temperatures of $T1$=290 K and $T2$=150 K that are L=2 cm apart. Assuming the surfaces to be black (Emissivity =1, there are no Convection currents in the air space between the plates), determine the rate of heat transfer between the plates per unit surface area Assuming the gap between the plates is **(*a*)** Filled with atmospheric air(k=0.01979 W/m ^{o}C)**(*b*)** Evacuated, **(*c*)** Filled with fibreglass (k=0.036 W/m ^{o}C)insulation, and **(*d*)** Filled with super insulation having an apparent thermal conductivity of 0.00015 W/m °C. (Ans: 511W, 372W, 252W, 1.05W)

3. An electric resistance heater is embedded in a long cylinder of diameter 30 mm. When water with a temperature of 25 ^{o}C and velocity of 1 m/s flows crosswise over the cylinder ,the power per unit length required to maintain the surface at a uniform temperature of 90 ^{o}C is 28 kW/m .When air ,also at 25^{o}C , but with a velocity of 10 m/s is flowing , the power per unit length required to maintain the same surface temperature is 400W/m. Calculate and compare the convection has coefficients for the flows of water and air.(Ans: 4,570 W/m^2 K, 65 W/m^2 K)

4. The roof of a car in a parking lot absorbs a solar radiant flux of 800W/m^2, while the underside is perfectly insulated. The convection coefficient between the roof and the ambient air is 12 W/m^2-K. **(a)** Neglecting radiation exchange with the surroundings, calculate the temperature of the roof under steady-state conditions if the ambient air temperature is 20˚C. (Ans: 86.7˚C) **(b)** If the surrounding temperature is also 20˚C, calculate the temperature of the roof if its surface emissivity is 0.8. (Ans: 47˚C)

5. A surface of area 0.5 m^2, emissivity 0.8, and temperature 150^{o}C is placed in a large evacuated chamber whose walls are maintained at 25^{o}C.What is the rate at which radiation is emitted by the surface? What is the net rate at which radiation is exchanged between the surface and chamber walls? (Ans: 726W, 547W)

6. In an orbiting space, an electronic package is housed in a comportment having a surface area A_S=1 m^2, which is exposed to space. Under normal operating conditions, the electronics dissipate 1kW, all of which must be transferred from the exposed surface to space. If the surface emissivity is 1.0 and the surface is not exposed to the sun, what is its steady state temperature? If the surface is exposed to a solar flux of 750 W/m^2 and absorptivity to solar radiation is 0.25, what is the steady state temperature? (Ans: 364K, 380K)

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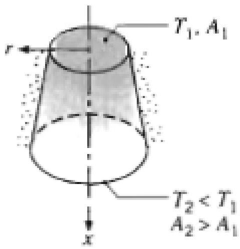
Tutorial 2 Date: 03/08/2010

1. A solid, truncated cone serves as a support for a system that maintains the top (truncated) face of the cone at a temperature T_1, while the base of the cone is at a temperature $T_2 < T_1$. The thermal conductivity of the solid depends on temperature according to the relation $k = k_o - aT$, where a is a positive constant, and the sides of the cone are well insulated. Do the following quantities increase, decrease, or remain the same with increasing x: the heat transfer rate q_x, the heat flux q_x'', the thermal conductivity k, and the temperature gradient dT/dx?



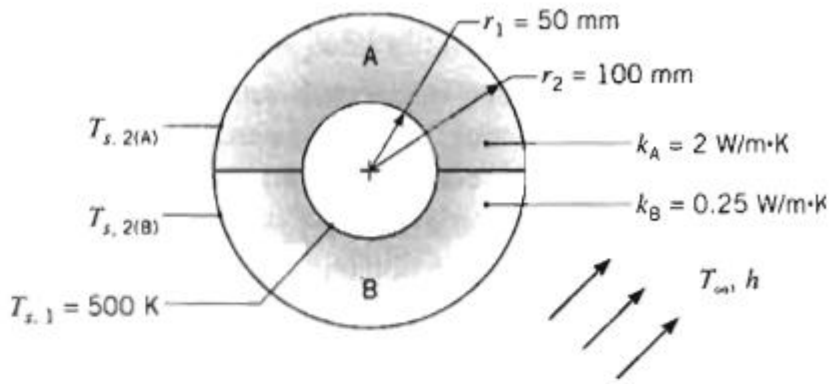
2. In the design of buildings, energy conservation requirements dictate that the exterior surface area, A_S be minimized. This requirement implies that, for a desired floor space, there may be optimum values associated with the number of floors and horizontal dimensions of the building. Consider a design for which the total floor space, A_f, and the vertical distance between floors, H_f, are prescribed.

(a) If the building has a square cross section of width W on a side, obtain an expression for the value of W that would minimize heat loss to the surroundings. Heat loss may be assumed to occur from the four vertical side walls and from a flat roof. Express your result in terms of A_f and H_f. (Ans: $W_{op} = (2A_fH_f)^{1/3}$)

(b) If $A_f = 32{,}768\ m^2$ and $H_f = 4$ m, for what values of Wand N_f (the number of floors) is the heat loss minimized? If the average overall heat transfer coefficient is $U = 1 W/m^2 \cdot K$ and the difference between the inside and ambient air temperatures is 25°C, what is the corresponding heat loss? What is the percent reduction in heat loss compared with a building for $N_f = 2$? (Ans:64 m, 8, 307200 W, 40%)

3. Steam flowing through a long, thin-walled pipe maintains the pipe wall at a uniform temperature of 500 K. The pipe is covered with an insulation blanket comprised of two different materials, A and B. The interface between the two materials may be assumed to have an infinite contact resistance, and the entire outer surface is exposed to air for which $T_\infty = 300$ K and $h = 25\ W/m^2 \cdot K$. (a) Sketch the thermal circuit of the system. Label (using the above symbols) all pertinent nodes and resistances.

(b) For the prescribed conditions, what is the total heat loss from the pipe? What are the outer surface temperatures $T_{S,2(A)}$ and $T_{S.2(B)}$? (Ans: 1040 W/m., 407K, 325K)



4. A spherical, cryosurgical probe may be imbedded in diseased tissue for the purpose of freezing, and thereby destroying, the tissue. Consider a probe of 3-mm diameter whose surface is maintained at – 30^{o}C when imbedded in tissue that is at 37^{o}C. A spherical layer of Frozen tissue forms around the probe, with a temperature of 0^{o}C existing at the phase front (interface) between the frozen and normal tissue. If the thermal conductivity of frozen tissue is approximately 1.5 W/m. K and heat transfer at the phase front may be characterized by an effective convection coefficient of 50 W/m2 • K, what is the thickness of the layer of frozen tissue (assuming negligible perfusion)? (Ans: 5.34mm)

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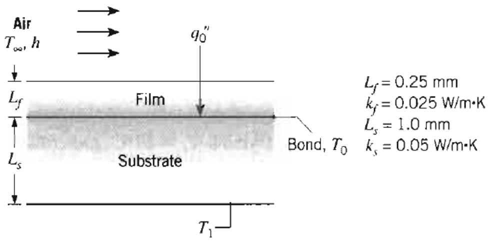
Tutorial 3 Date: 10/08/10

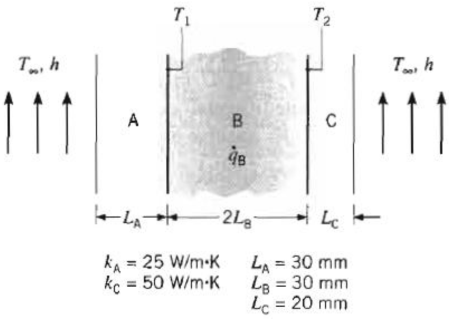
1. In a manufacturing process, a transparent film is being bonded to a substrate as shown in the figure. To cure the bond at temperature T_0, a radiant source is used to provide a heat flux q_0'',(W/m^2), all of which is absorbed at the bonded surface. The back of the substrate is maintained at T_1 while the free surface of the film is exposed to air at T_∞ and a convection heat transfer co-efficient h.
   (a) Show the thermal circuit representing the steady-state heat transfer situation. Be sure to label all elements, nodes and heat rates. Leave in symbolic form.
   (b) Assume the following conditions: $T_\infty=20^0$C, h=50 W/m^2-K, $T_1=30^0$C.
   Calculate the heat flux that is required to maintain the bonded surface at $T_0=60^0$C. (Ans: 2833W/m^2)



2. Consider a person standing in a room at 20°C with an exposed surface area of 1.7 m^2. The deep body temperature of the human body is 37°C, and the thermal conductivity of the human tissue near the skin is about 0.3 W/m · °C. The body is losing heat at a rate of 150 W by natural convection and radiation to the surroundings. Taking the body temperature 0.5 cm beneath the skin to be 37°C, determine the skin temperature of the person. (Ans: 35.5°C)

3. Consider 1D conduction in a plane composite wall. The outer surface is exposed to a fluid at 25^0C and a convection co-efficient 1000 W/m^2-K. The middle wall B experiences uniform heat generation, while there is no generation in walls A and C. The temperature at interfaces are $T_1=261^0$C and $T_2=211^0$C.

   (a) Assuming negligible contact resistance at the interfaces, determine volumetric heat generation in material B and thermal conductivity of B.
   (Ans: 4.00x10^6 W/ m^3, 15.3 W/ m K)
   (b) Plot the temperature distribution showing important features.



4. A homeowner, whose water pipes have frozen during a period of cold weather, decides to melt ice by passing an electric current I through the pipe wall. The inner and outer radii of the wall are r_1 and r_2 respectively, and its electrical resistance per unit length is R_e (ohm/m). The pipe is well insulated on the outside, and at a constant temperature T_∞ associated with melting process.

(a) Assuming steady-state conditions are reached shortly after application of the current; determine the form of the steady-state temperature distribution T(r) in the pipe wall during the melting process.

(b) Develop an expression for the time t_m required to completely melt the ice. Calculate this time for I=100 A, R_e=0.30 ohm/m and r_1=50mm.
You may use the following data:
Ice (273K): $\rho = 920$ kg/m^3; Latent heat of fusion, hsf = 3.34×10^5 J/kg.
(Ans: 804 sec)

5. Unique characteristics of biologically active materials such as fruits, vegetables and other products require special care in handling. Following harvest and separation from producing plants, glucose is catabolized to produce carbon dioxide, water vapour and heat, with attendant internal energy generation. Consider a carton of apples, each of 80 mm diameter, which is ventilated with air at 5^0C and a velocity of 0.5 m/s. Velocity (in m/s) and heat transfer co-efficient (in W/m^{2}K) can be co-related as $h=10.1xV^{0.425}$ (in the range 0.1 m/s<V<1 m/s). Within each apple thermal energy is uniformly generated at a total rate of 4000 J/kg-day. The density and thermal conductivity of apple are 840 kg/m^3 and 0.5 W/m-K, respectively.
Determine the apple centre and surface temperature.
(Ans: $T_{centre}=5.26^0$C, $T_{surface} = 5.14^0$C)

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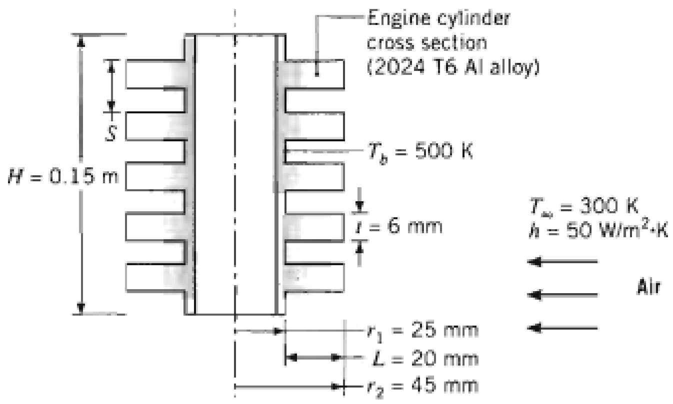
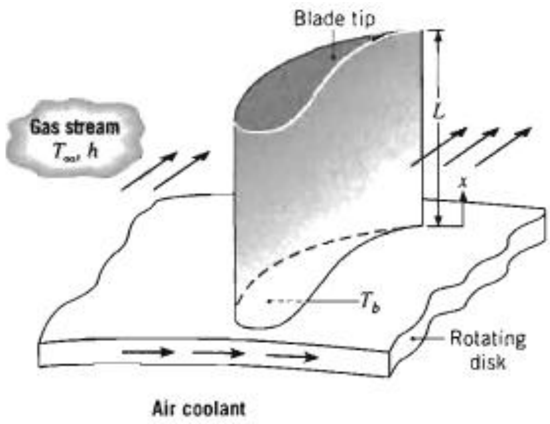
Tutorial 4 Date: 24/08/10

1. The engine cylinder of a motorcycle is constructed of 2024-T6 aluminium alloy and is of height H = 0.15 m and outside diameter D = 50 mm. Under typical operating conditions the outer surface of the cylinder is at a temperature of 500 K and is exposed to ambient air at 300 K, with a convection coefficient of 50 W/m^2 K. Annular fins are integrally cast with the cylinder to increase heat transfer to the surroundings. Consider five such fins, which are of thickness t = 6 mm, length L = 20 mm, and equally spaced. What is the increase in heat transfer due to use of the fins (η_f =0.95 k=186 W/m-K)? (Ans. 454 W)



2. Turbine blades mounted to a rotating disc in a gas turbine engine are exposed to a gas stream that is at T_∞ = 1200°C and maintains a convection coefficient of h = 250 W/m^2 K over the blade. The blades, which are fabricated from lnconel, k = 20 W/m K, have a length of L = 50 mm. The blade profile has a uniform cross-sectional area of $A_C = 6 \text{ X } 10^{-4} \text{ m}^2$ and a perimeter of P = 110 mm. A proposed blade-cooling scheme, which involves routing air through the supporting disc, is able to maintain the base of each blade at a temperature of T_b = 300°C. (a) If the maximum allowable blade temperature is 1050°C and the blade tip may be assumed to be adiabatic, is the proposed cooling scheme satisfactory?

(b) For the proposed cooling scheme, what is the rate at which heat is transferred from each blade to the coolant? (Ans. 508 W)

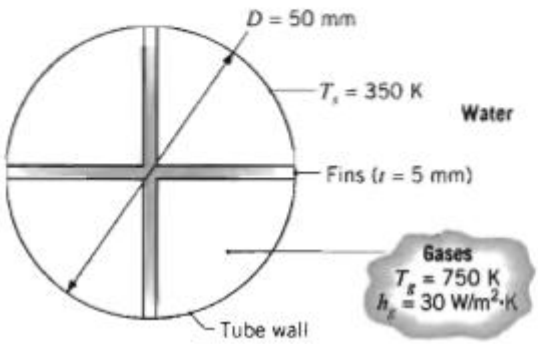


3. Aluminium fins of triangular profile are attached to a plane wall whose surface temperature is 250 ^oC, Thermal Conductivity of aluminium is k=250 W/m K. The fin base thickness is 2 mm, and its length is 6 mm. The system is in ambient air at a temperature of 20^oC, and the surface convection coefficient is 40 W/m^2 K. Efficiency of fin is η_f=0.99.

(a) What is effectiveness? (Ans. 6.02)

(b) What is the heat dissipated per unit width by a single fin? (Ans. 110.8 W/m)

4. Water is heated by submerging 50-mm diameter, thin walled copper tubes in a tank and passing hot combustion gases (T_g = 750 K) through the tubes. To enhance heat transfer to the water, four straight fins of uniform cross section, which form a cross, are inserted in each tube. The fins are 5 mm thick and are also made of copper (k = 400 W/m K). If the tube surface temperature is T_s = 350 K and the gas-side convection coefficient is h_g = 30 W/m^2 K, what is the rate of heat transfer to the water per meter of pipe length? (Ans. 4025 W/m)



5. A straight fin fabricated from 2024 aluminium alloy (k = 185 W/m K) has a base thickness of 1 = 3 mm and a length of L = 15 mm. Its base temperature is T_b, = 100°C, and it is exposed to a fluid for which T_∞ = 20°C and h = 50 W/m^2 K. For the foregoing conditions and a fin of unit width, compare the fin heat transfer rate, And volume for rectangular (η_f =0.982), triangular (η_f=0.978.), and parabolic profiles (η_f=0.963)

(Ans: Rectangular 129.6W/ m, 4.5x10^{-5}m^2 Triangular, 117.3W/ m, 2.25x10^{-5}m^2 parabolic 115.6W/ m, 1.5x10^{-5}m^2)

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Tutorial - 5 Date: 31/08/10

1. A two-dimensional rectangular plate is subjected to prescribed boundary conditions as shown below. 1. Calculate the temperature at the midpoint (1, 0.5) by considering the first five nonzero terms of the infinite series that must be evaluated. **(Ans:94.5°C)**
   2. If the plate has a thermal conductivity of 50 W/m.K, derive an expression for the heat transfer rate per unit thickness from the plate along the lower surface (0 <= *x* <=2, *y* = 0). Find the heat transfer rate considering the first five nonzero terms of the infinite series. **(Ans: 5.611 kW/m)** .

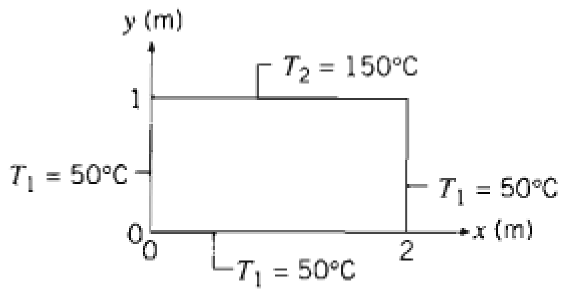


Figure1.1

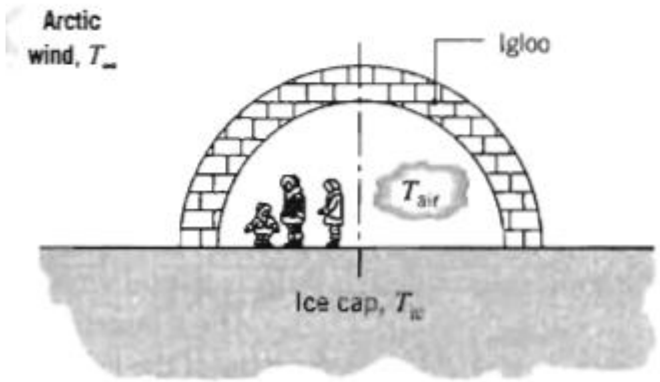
2. A pipeline, used for the transport of crude oil, is buried in the earth such that its centre line is a distance of 1.5 m below the surface. The pipe has an outer diameter of 0.5 m and is insulated with a layer of cellular glass 100 mm thick. What is the heat loss per unit length of pipe under conditions for which heated oil at 120°C flows through the pipe and the surface of the earth is at a temperature of 0°C? **(Ans: 84 W/m)**
   PROPERTIES: Soil (300K): k = 0.52 W/m K; Cellular glass (365K): = 0.069 W/m K.

3. Pressurized steam at 450 K flows through a long, thin walled pipe of 0.5-m diameter. The pipe is enclosed in a concrete casing that is of square cross section and 1.5 m on a side. The axis of the pipe is centered in the casing, and the outer surfaces of the casing are maintained at 300 K. What is the heat loss per unit length of pipe? **PROPERTIES:** Concrete (300K): k = 1.4 W/m K. **(Ans:1122W/m)**

4. A cubical glass melting furnace has exterior dimensions of width W = 5 m on a side and is constructed from refractory brick of thickness L = 0.35 m and thermal conductivity k = 1.4 W/m .K. The sides and top of the furnace are exposed to ambient air at 25°C, with free convection characterized by an average coefficient of h = 5 W/m^2 K. The bottom of the furnace rests on a framed platform for which much of the surface is exposed to the ambient air, and a convection coefficient of h = 5 W/m^2 K may be assumed as a first approximation. Under operating conditions for which

combustion gases maintain the inner surfaces of the furnace at 1100°C, what is the heat loss from the furnace? **(Ans: 316 kW)**

5. An igloo is built in the shape of a hemisphere, with an inner radius of 1.8 m and walls of compacted snow that are 0.5 m thick. On the inside of the igloo the surface heat transfer coefficient is 6 W/m^2 K; on the outside, under normal wind conditions, it is 15 W/m^2 K. The thermal conductivity of compacted snow is 0.15 W/m K. The temperature of the ice cap on which the igloo sits is -20°C and has the same thermal conductivity as the compacted snow.



Assuming that the occupants' body heat provides a continuous source of 320 W within the igloo, calculate the inside air temperature when the outside air temperature is $T\infty$ = –40°C. Be sure to consider heat losses through the floor of the igloo. **(Ans: 1.2°C)**

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Department of Mechanical Engineering

Heat Transfer ME30005

Tutorial - 6 Date: 07/09/10

1) Air at 27°C and 1 atm flows over a flat plate at a speed of 2 m/s. Calculate the boundary layer thickness at distances of 20 and 40 cm from the leading edge of the plate. Calculate the mass flow which enters the boundary layer between x = 20 cm and x = 40 cm. The viscosity of air at 27°C is 1.85 x 10^{-5} kg/m s. Assume unit depth in the z direction. For the flow system if the plate is heated over its entire length to a temperature of 60°C. Calculate the heat transferred in (i) the first 20 cm of the plate and (ii) the first 40 cm of the plate. Compute the drag force exerted on the first 40 cm of the plate using the analogy between fluid friction and heat transfer.
(**Ans.:** 0.00559m, 0.0079m, 3.399x10^{-3}kg/s, 81.18W, 114.8W, 5.44x10^{-3}N)

2) The forming section of a plastics plant puts out a continuous sheet of plastic that is 1.2 m wide and 2 mm thick at a rate of 15 m/min. The temperature of the plastic sheet is 90°C when it is exposed to the surrounding air, and the sheet is subjected to air flow at 30°C at a velocity of 3 m/s on both sides along its surfaces normal to the direction of motion of the sheet. The width of the air cooling section is such that a fixed point on the plastic sheet passes through that section in 2 s. Determine the rate of heat transfer from the plastic sheet to the air. (**Ans.:** 437W)

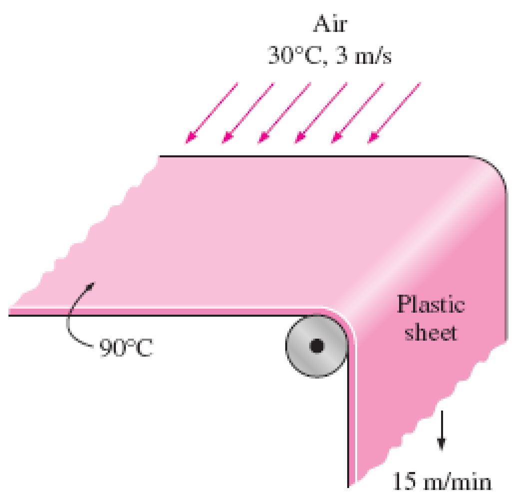


FIGURE P7–21

3). The 3 mm gap between two infinitely large, horizontal parallel plates is filled with engine oil. The bottom plate is stationery while the top plate moves with a speed of 10 m/s in the horizontal direction. The temperature of the stationary and moving plates are $T_O = 10^OC$ and $T_L = 30^OC$, respectively. Calculate the heat flux to each of the plate and determine the maximum temperature in the oil? (Engine oil density=888.2 kg/m^3, k=0.145 W/m K, viscosity =0.799 Ns/m^2)

(**Ans.:** -14.3 kW/m^2, 12.3 kW/m^2, 89.3^{O}C).

4). A heavy lubricating oil μ=0.8 Ns/m^2 k=0.15 W/Mk flows in the clearance between a shaft and its bearing .If the bearing and the shaft are kept at 10^{o}C and 30 ^{o}C respectively and the clearance between them is 2mm, determine the maximum temperature rise and the heat flux to the plates for a velocity U=6 m/s. (**Ans.:** -8.7 kW/m^2, 5.7kW/m^2, 45.02^{o}C).

5). Consider a lightly loaded journal bearing using oil having the proprieties ρ = 800 kg/m^3, υ= 10^{-5} m^2/s, k=0.13 W/m K. The journal diameter is 75 mm, the clearance is 0.25 mm and bearing operates 3600 rpm

a) Determine the temperature distribution in the oil film assuming there is no heat transfer into journal and that the bearing surface is maintained at 75 ^{o}C

b) What is the rate of heat transfer from bearing, and how much power is needed to rotate the journal? (**Ans:** T= T0 + **[**($\mu U^{2)}$/k [(y/L)-(1/2) (y/L)]], -1507.5 W/m ,1507.5W/m)

6). A thermal sensor is to be located 2m from the leading edge of a plate along which 10^{o}C glycerin flows at 19 m/s. The pressure is atmosphere. In order to calibrate the sensor the velocity components, u and v must be known. At y=4.5 cm determine the velocity components.

Given, ρ = 1270 m^3/kg, υ = 2.79×10^{-3} m^2/s. (**Ans.:** 14.73m/s, 0.078m/s)

7). Atmospheric air is in parallel flow (u_∞ = 15 m/s, T_∞ = 15°C) over a flat heater surface that is to be maintained at a temperature of 140°C. The heater surface area is 0.25 m^2, and the airflow is known to induce a drag force of 0.25 N on the heater. What is the electrical power needed to maintain the prescribed surface temperature? (**Ans.:** 2.66 kW.)

PROPERTIES: Air (T_f = 350K, 1atm): ρ = 0.995 kg/m^3, cp = 1009 J/kg K, Pr =0.700).

Indian Institute of Technology Kharagpur

Department of Mechanical Engineering

Heat Transfer ME30005

Tutorial - 7

Date: 21/09/10

1. Water at **25^oC** flows over a flat plate with a uniform velocity of 2 m/s. The plate is maintained at a temperature of 85^oC. Determine the following:

a) The thermal boundary layer thickness at a distance of 8 cm from the leading edge

b) The heat flux at this location

c) The total heat transfer from the first 8 cm of the plate

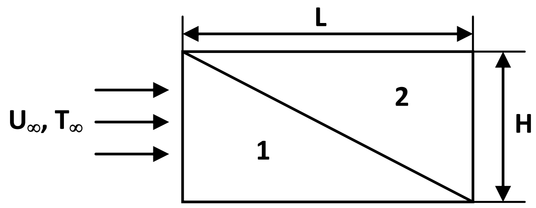
d) Whether Polhausen solution can be used to find the heat flux at a distance of 80 cm from the leading edge.

Properties of water at **55^oC:**

μ = 0.0005042 kg/m.s, k_f = 0.636 W/m.K, Pr=3.315, ρ = 985.7 kg/m^3, η_t at Pr =3.3 $\approx$ 3.0

Ans.: a) **δ_t = 0.0006437 m** b) **$q_{x=0.08\ m}$ = 132064 W/m^2** c) **$Q_{0\ to\ 0.08\ m}$ = 2.113 kW** d) **No** (flow is not laminar)

2. Consider two identical triangles drawn on the surface of a flat plate as shown. The plate, which is maintained at a uniform surface temperature, is cooled by laminar forced convection. Determine the ratio of heat transfer rates from the two triangles 1 and 2, Q_1/Q_2.



Top view

3. Engine oil at 22^oC flows over a flat plate with a free stream velocity of 27.5 m/s. Determine the heat transfer rate from unit width of the plate from the first 16 cm. The temperature of the plate surface is 132^oC and the properties of engine oil at the film temperature of 77^oC are: ν = 0.0000417 m^2/s, k_f = 0.138 W/m.K, Pr=546, c_p = 2.119 kJ/kg.K. (**Ans.**: **$Q_{0\ to\ 0.16\ m}$ = 26761 W)**

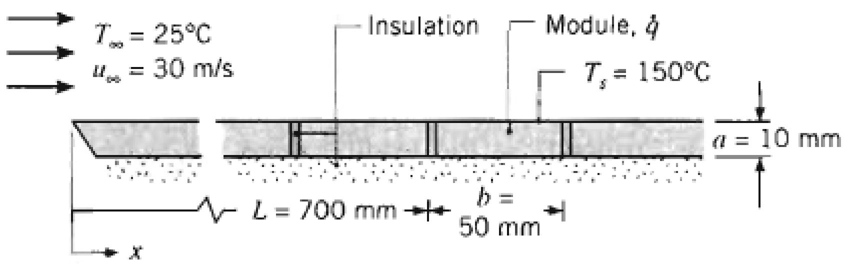
4. A flat plate of width 1 m is maintained at a uniform surface temperature of 150^oC by using independently controlled, heat generating rectangular modules of thickness a = 10 mm and length b = 50 mm. Each module is insulated from its neighbours, as well as on its back sides. Atmospheric air at 25^oC flows over the plate at a velocity of 30m/s.

The thermophysical properties of the module are k = 5.2W/m-K, c_p = 320 J/kg-K and ρ = 2300 kg/m^3.

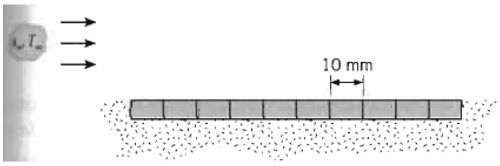
The properties of air at film temperature of 87^oC are: k_f=0.0308 W/m.K, ν = 22.02 X 10^{-6} m^2/s, Pr=0.698

a) Find the required power generation, q (W/m^3), in a module positioned at a distance **200 mm** from the leading edge. (**Ans.: q_g=2.79 X 10^5 W/m^3**)

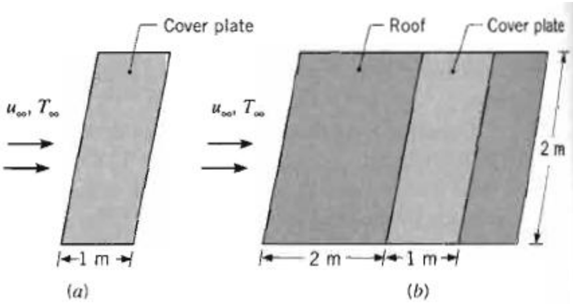
b) Find the maximum temperature T_{max} in the heat-generating module. **(Ans.: T_{max}=152.7^{o}C**)



5. An array of 10 silicon chips, each of length L = 10 mm on a side, is insulated on one surface and cooled on the opposite surface by atmospheric air in parallel flow with $T_\infty = 24^oC$ and $U_\infty = 40$ m/s. When in use, the same electrical power is dissipated in each chip, maintaining a uniform heat flux over the entire cooled surface. If the temperature of each chip may not exceed 80°C, what is the maximum allowable power per chip? Would it be preferable to orient the array normal, instead of parallel, to the airflow? Take the properties of air as: k_f=0.02735 W/m.K, $\nu = 18.03X10^{-6}$ m^2/s, Pr=0.722, ρ =1.089 kg/m^3
(Ans: 0.30 W)



6. The cover plate of a flat-plate solar collector is at 15°C while ambient air at 10°C is in parallel flow over the plate, with u_∞ = 2 m/s. a)What is the rate of convective heat loss from the plate? (b) If the plate is installed 2 m from the leading edge of a roof and flushes with the roof surface, what is the rate of convective heat loss? (Ans: 55 W, 39 W)



Correlations:

$$Nu_X = \frac{0.332 Re_X^{1/2} Pr^{1/3}}{\left[1-(\xi/x)^{3/4}\right]^{1/3}}$$ unheated starting length, ξ

$$\overline{Nu}_L = 0.664 Re_L^{1/2} Pr^{1/3}$$ laminar flow, uniform wall temperature

$$Nu_x = 0.453 Re_x^{0.5} Pr^{1/3}$$ laminar flow, uniform wall heat flux

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Heat Transfer ME30005

Tutorial -9 Date: 5/10/2010

1. Air at $4e^{-4}$ kg/s and 27^oC enters a triangular duct that is 20 mm on each side and 2 m long. The duct surface is maintained at 100^oC. Assuming fully developed flow throughout the duct, determine the air outlet temperature. (Ans: 88^oC)
(Assume for air: Cp=1008 J/kg-K, μ=196.4e^{-7} N-s/m^2, k=0.0282 W/m-K, Pr=0.707)

2. A device that recovers heat from high temperature combustion products involves passing the combustion gas between parallel plates, each of which is maintained at 350K by water flow on the opposite surface. The plate separation is 40 mm, and the gas flow is fully developed. The gas may be assumed to have the properties of atmospheric air, and its mean temperature and velocity are 1000 K and 60 m/s, respectively.

    a. What is the heat flux at plate surface? (Ans: 53700 W/m^2)
    b. If a third plate of 20 mm thickness is suspended midway between the original plates, what is the surface heat flux for the original plates? (ans:123400 W/m^2)

    (For part b assume the temperature and flow rate of the gas to be unchanged and radiation effects to be negligible.) (Assume for gas: ν=15.71e^{-6} m^2/s)

3. A fan that can provide air speed up to 50 m/s is to be used in a low-speed wind tunnel with atmospheric air at 25^oC. If one wishes to use the wind tunnel to study flat-plate boundary layer behaviour up to Re_x = $10e^8$, what is the minimum plate length that should be used? At what distance from the leading edge would transition occur if Critical Reynolds Number = $5e^5$. (Ans: L=31.4m, x_c=0.157m)
(Assume for air: k=0.0667 W/m-K, μ=424.4e^{-7} N-s/m^2, ρ=0.348 kg/m^3, Pr=0.726)

4. A 6-cm-diameter shaft rotates at 3000 rpm in a 20-cm long bearing with a uniform clearance of 0.2 mm. At steady operating conditions, both the bearing and the shaft in the vicinity of the oil gap are at 50°C, and the viscosity and thermal conductivity of lubricating oil are 0.05 N-s/m^2 and 0.17 W/m-K. By simplifying and solving the continuity, momentum and energy equations, determine
(*a*) The maximum temperature of oil.
(*b*) The rates of heat transfer to the bearing and the shaft.
(*c*) The mechanical power wasted by the viscous dissipation in the oil.
(Ans: (*a*) 53.3°C, (*b*) 419 W, (*c*) 838 W) (Assume for oil: k=0.17 W/m-K, μ=0.05 N-s/m^2)

5. Engine oil at 100 ^oC and a velocity of 0.1 m/s flows over both surfaces of a 1-m long flat plate maintained at 20 ^oC. Determine
1. The velocity and thermal boundary layer thicknesses at the trailing edge?
2. The local heat flux and surface shear stress at the trailing edge?
3. The local drag force and heat transfer per unit width of the plate?
(Ans: (a) 0.147 m , 0.0143m (b) -1300 W/m^2 , 0.0842 N/m^2 (c) 0.337 N/m)

    Properties: For Engine Oil

    $\rho = 864$ kg/m^3, $\nu = 86.1 \times 10^{-6}$ m^2/s, k = 0.140 , Pr = 1081.

6. Consider steady , parallel flow of atmospheric air over a flat plate . The air has a temperature and free stream velocity of 300 K and 25 m/s.

   1.Evalute the boundary layer thickness at distances of x = 1,10, and 100 from the leading edge.If a second plate were installed parallel to and at a distance of 3 mm from the first plate ,what is the distance from the leading edge at which boundary layer merger would occur?

   2. Evalute the surface shear stress and the y-velocity component at the outer edge of the boundary layer for the single plate at x=1,10, and 10

   3. Comment on the validity of the boundary layer approximation

   Ans:

   1)Boundary Layer marger occur at x=141mm

2) x(m)	0.001	0.01	01
δ (mm)	0.126	0.399	1.262

3) x(m)	0.001	0.01	01
$\tau(N/m^2)$	6.07	1.92	0.61

   Properties :density =1.161kg/m^3 viscosity=15.89 10^{-6} m^2/s

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Heat Transfer ME30005

Tutorial -10 Date: 26/10/2010

1) Air at 2 atm and 200°C is heated as it flows through a tube with a diameter of 1 in (2.54 cm) at a velocity of 10 m/s. Calculate the heat transfer per unit length of tube if a constant-heat-flux condition is maintained at the wall and the wall temperature is 20°C above the air temperature, all along the length of the tube. How much would the bulk temperature increase over a 3-m length of the tube? (Ans: 103.5 W/m, 40.04˚C)
Air T_b=200˚C, Pr=0.681, μ=2.57x10-5 kg/m-s, k=0.0386 W/m˚C, C_p=1.025 kJ/kg˚C

2) A 2.0-cm-diameter tube having a relative roughness of 0.001 is maintained at constant wall temperature of 90°C. Water enters the tube at 40°C and leaves at 60°C. If the entering velocity is 3 m/s, calculate the length of tube necessary to accomplish the heating. (Ans: 1.4m)
ρ = 978 kg/m^3, μ= 4.0 x10-4 kg/m-s, k = 0.664 W/m-˚C Pr = 2.54 μ_b= 5.55 x 10^{-4} kg/m-s, μ_w=2.81 x 10^{-4} kg/m-s

3) A thick-walled, stainless steel (AISI 316) pipe of inside outside diameters D_i = 20 mm and D_o= 40 mm is heated electrically to provide a uniform heat generation rate of q = 10^6 W/m^3. The outer surface of the pipe is insulated, while water flows through the pipe at a rate of m = 0.1 kg/s. (a) If the water inlet temperature is $T_{m,i}$ = 20°C and the desired outlet temperature is $T_{m,o}$ = 40°C, what is the required pipe length? (b) What are the location and value of the maximum pipe temperature? (Ans: 8.87m, 52.4°C)
Stainless steel 316 (T =400K): k = 15 W/m-K;
Water (T_m =303 K) Cp = 4178 J/kg-K, k = 0.617 W/m-K, μ= 803 x10^{-6} Ns/m^2 , Pr = 5.45

4) Atmospheric air enters a 10m long, 150mm diameter uninsulated heating duct at 60°C and 0.04 kg/s. The duct surface temperature is approximately constant at T_s = 15°C. (a) What are the outlet air temperature, the heat rate q, and pressure drop Δp for these conditions?
(Ans: 29.9°C,-1212W, 4.03N/m^2)
Air (Tm =310 K, 1 atm): ρ= 1.128 kg/m^3, Cp = 1007 J/kg-K, μ= 189 x10^{-7} Ns/m^2, k = 0.027 W/m-K, Pr = 0.706.

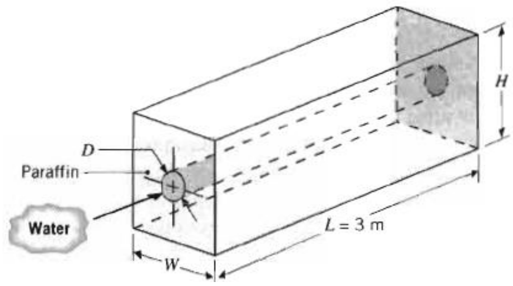
5) Hot air flows with a mass rate of 0.050 kg/s through an uninsulated sheet metal duct of diameter D = 0.15 m, which is in the crawlspace of a house. The hot air enters at 103°C and, after a distance of L = 5 m, cools to 77°C. The heat transfer coefficient between the duct outer surface and the ambient air at T_∞ = 0°C is known to be h_0 = 6 W/m^2-K.
1. Calculate the heat loss (W) from the duct over the length L.
2. Determine the heat flux and the duct surface temperature at x = L. (Ans: -1313W, 50.7˚C)
Air (T_m = 363 K): C_p = 1010 J/kg- K, Air ($T_{m,L}$= 350K): k = 0.03W/m-K, μ =208.2X10^{-7}Ns/m2, Pr = 0.70

6) Liquid mercury at 0.5 kg/s is to be heated from 300 to 400 K by passing it through a 50-mm-diameter tube whose surface is maintained at 450 K. Calculate the required tube length by using an appropriate liquid metal convection heat transfer correlation. Compare your result with that which would have been obtained by using a correlation appropriate for $Pr \geq 0.70$.
(Ans: 0.39 m, 0.35 m)
Mercury T_m = 350K: C_p = 137.7 J/kg-K, μ= 0.1309x 10^{-2} N-s/m^2, k = 9.18 W/m-K, Pr=0.0196.

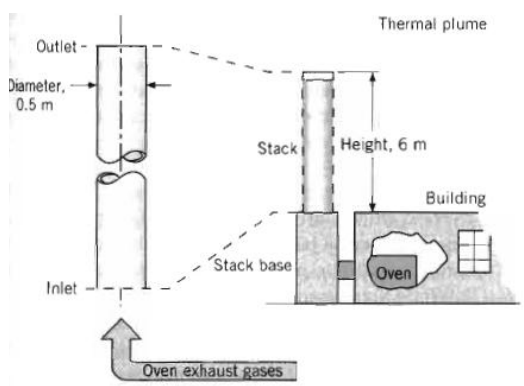
7) The products of combustion from a burner are routed in an industrial application through a thin-walled metallic duct of diameter D_i = 1 m and length L = 100 m. The gas enters the duct at atmospheric pressure and a mean temperature and velocity of $T_{m,i}$ = 1600 K and $u_{m,i}$ = 10 m/s. respectively. It must exit the duct at a temperature that is no less than $T_{m,o}$ = 1400 K. What is the minimum thickness of an alumina-silica insulation (k_{ins} = 0.125 W/rn-K) needed to meet the outlet requirement under worst case conditions for which the duct is exposed to ambient air at T_∞=250K and a cross-flow velocity of V = 15 m/s? The properties of the gas may be approximated as those of air and as a first estimate, the effect of the insulation thickness on the convection coefficient and thermal resistance associated with the cross flow may be neglected.
(Ans: 0.11m)
Air (p = 1 atm). $T_{m,i}$ = 1600K: ρ_i = 0.218 kg/m^3). $T_m = (T_{m,i} + T_{m,o})/2$ = 1500K: ρ = 0.232 kg/m^3, Cp = 1230 J/kg-K, μ= 557x10^{-7} Ns/m^2, k = 0.100 W/m-K, Pr = 0.685).
Tf $\approx$ 300K (assumed): ν= 15.89x10^{-6} m^2/s, k = 0.0263 W/m-K, Pr = 0.707.

8) The core of a high-temperature, gas-cooled nuclear reactor has coolant tubes of 20 mm diameter and 780 mm length. Helium enters at 600 K and exits at 1000 K when the flow rate is 8x10^{-3} kg/s per tube. (a) Determine the uniform tube wall surface temperature for these conditions. (b) If the coolant gas is air, determine the required flow rate if the heat removal rate and tube wall surface temperature remain the same. What is the outlet temperature of the air?
(Ans: 1384 K, 5.22 10^{-1} kg/s, 890 K)
Helium: (T_m=800K, 1 atm) : ρ= 0.06272 kg/m^3, Cp = 5193 J/kg K, k= 0.304 W/m-K, μ= 382x10^{-7} Ns/m^2 , ν= 6.09x10^{-4} m^2/s, Pr = 0.654; Air (T_m=800K, 1 atm) ρ= 0.4354 kg/m^3, Cp = 1099 J/kg K, k = 57.3x10^{-3} W/m K, ν = 84.93x10^{-6} m^2/s, Pr = 0.709.

9) Consider a horizontal, thin-walled circular tube of diameter D = 0.025 m submerged in a container of n-octadecane (paraffin), which is used to store thermal energy. As hot water flows through the tube, heat is transferred to the paraffin, converting it from the solid to liquid state at the phase change temperature of T_∞= 27.4˚C. The latent heat of fusion and density of paraffin are h_{sf} = 244 kJ/kg and ρ= 770 kg/m^3, respectively, and thermo physical properties of the water may be taken as Cp=4.185 kJ/kg.K, k=0.653 W/m-K,μ=467X10^{-6} kg/s. m, and Pr = 2.99. Assuming the tube surface to have a uniform temperature corresponding to that of the phase change, determine the water outlet temperature and total heat transfer rate for a water flow rate of 0.1 kg/s and an inlet temperature of 60°C. If H=W=0.25m, how long would it take to completely liquefy the paraffin, from an initial state for which all the paraffin is solid and at 27.4˚C? (Ans: 42.17 C, 7500W, 1.29 h)



10) Exhaust gases from a wire processing oven are discharged into a tall stack, and the gas and stack surface temperatures at the outlet of the stack must be estimated. Knowledge of the outlet gas temperature $T_{m,o}$ is useful for predicting the dispersion of effluents in the thermal plume, while knowledge of the outlet stack surface temperature $T_{s,o}$ indicates whether condensation of the gas products will occur. The thin-walled, cylindrical stack is 0.5 m in diameter and 6.0 m high. The exhaust gas flow rate is 0.5kg/s, and the inlet temperature is 600°C. Consider conditions for which the ambient air temperature and wind velocity are 4˚C and 5m/s respectively. Approximating the thermo physical properties of the gas as those of atmospheric air, estimate the outlet gas and stack surface temperatures for the given conditions.
(Ans: 543˚C, 232˚ C)
Air (assume $T_{m,o}$ = 773 K, T_m = 823 K, 1 atm): Cp = 1104 J/kgK, μ= 376.4x10^{-7} Ns/m^2, k = 0.0584 W/m-K, Pr = 0.712; air (assume T_s = 523 K, T_∞ = 4ºC = 277 K, T_f= 400 K, 1 atm): ν= 26.4x10^{-6} m^2/s, k = 0.0338 W/m-K, Pr = 0.690.

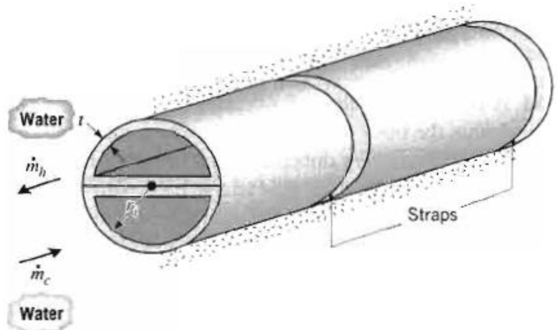


11) Consider a thin-walled tube of 10-mm diameter and 2-m length. Water enters the tube from a large reservoir at m = 0.2 kg/s and $T_{m,i}$ = 47°C. (a) If the tube surface is maintained at a uniform temperature of 27˚C, what is the outlet temperature of the water, $T_{m,o}$? To obtain the properties of water, assume an average mean temperature of T_m = 300 K. (Ans: 37.1 ^{o}C)
Water (T_m = 300 K):ρ=997 kg/m^3, Cp = 4179 J/kg-K, μ = 855 × 10^{-6} N-s/m^2, k = 0.613W/m-K, Pr = 5.83

12) A thin-walled, uninsulated 0.3-m-diameter duct is used to route chilled air at 0.05 kg/s through the attic of a large commercial building. The attic air is at 37˚C, and natural circulation provides a convection coefficient of 2 W/m^2-K at the outer surface of the duct. If chilled air

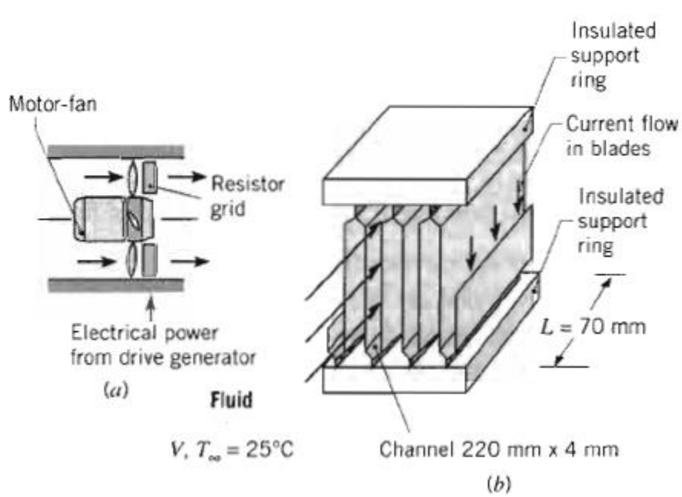
enters a 15-m-long duct at 7˚C, what is its exit temperature and the rate of heat gain? Properties of the chilled air may be evaluated at an assumed average temperature of 300 K.
(Ans: 15.7˚C, 438 W)
Air (300K, 1 atm): Cp = 1007 J/kg-K, μ = 184.6 x10^{-7} kg/s-m, k =0.0263 W/m-K, Pr = 0.707.

13) A double-wall heat exchanger is used to transfer heat between liquids flowing through semicircular copper tubes. Each tube has a wall thickness of t = 3 mm and an inner radius of r_i = 20 mm, and good contact is maintained at the plane surfaces by tightly wound straps. The tube outer surfaces are well insulated. (a) If hot and cold water at mean temperatures of $T_{h,m}$ = 330 K and $T_{c,m}$ = 290 K flow through the adjoining tubes at $m_h = m_c$ = 0.2 kg/s, what is the rate of heat transfer per unit length of tube? The wall contact resistance is 10^{-5} m^2 K/W. Approximate the



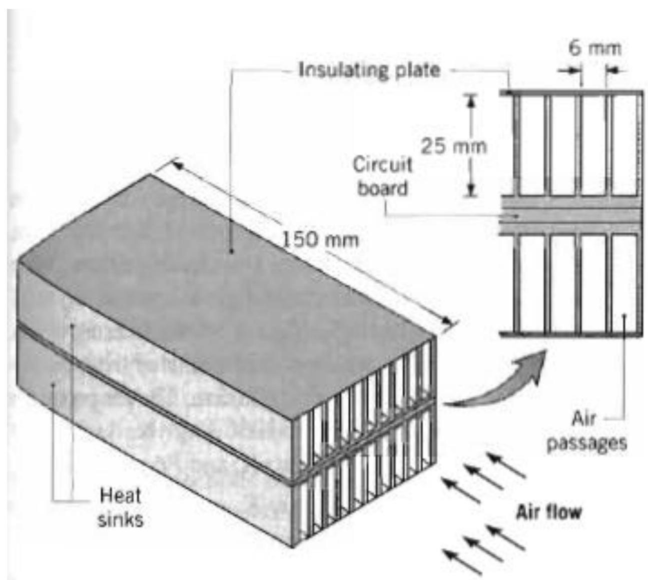
properties of both the hot and cold water as μ = 800 X 10^{-6} kg/s. m, k = 0.625 W/m-K, and Pr =5.35. Hint: Heat transfer is enhanced by conduction through the semicircular portions of the tube walls, and each portion may be subdivided into two straight fins with adiabatic tips. (b) Using the thermal model developed for part (a) determine the heat transfer rate per unit length when the fluids are ethylene glycol. Also, what effect will fabricating the exchanger from an aluminum alloy have on the heat rate? Will increasing the thickness of the tube walls have a beneficial effect? (Ans: 2600W/ m)
Copper (T=300 K): k = 400 W/m-K; Water (290 K): μ= 1080x 10^{-6} Ns/m^2, k = 0.598 W/mK, Pr = 7.56; (330 K): μ= 489 × 10^{-6} Ns/m^2, k = 0.65 W/mK, Pr = 3.15;

14) To slow down large prime movers like locomotives, a process termed dynamic electric braking is used to switch the traction motor to a generator mode in which mechanical power from the drive wheels is absorbed and used to generate electrical current. As shown in the schematic, the electric power is passed through a resistor grid (a), which consists of an array of metallic blades electrically connected in series (b). The blade material is a high-temperature, high electrical resistivity alloy, and the electrical power is dissipated as heat by internal volumetric generation. To cool the blades, a motor-fan moves high-velocity air through the grid. (a) Treating the space between the blades as a rectangular channel of 220-mm X 4-mm cross



section and 70-mm length, estimate the heat removal rate per blade if the air stream has an inlet temperature and velocity of 25°C and 50 m/s, respectively, while the blade has an operating temperature of 600°C. (b) On a locomotive pulling a 10-car train, there may be 2000 of these blades. Based on your result from part (a), how long will it take to slow a train whose total mass is 10^6kg from a speed of 120 km/h to 50 km/h using dynamic electric braking? (Ans: 3.346kW, 69s)
Air (Tm =350 K, 1 atm): ρ= 0.995 kg/m^3, Cp = 1009 J/kg-K, ν= 20.92 10^{-6} m^2/s, k = 0.030 W/m-K, Pr = 0.700.

15) An electronic circuit board dissipating 50 W is sandwiched between two ducted, forced-air-cooled heat sinks. The sinks are 150 mm in length and have 24 rectangular passages 6 mm by 25 mm. Atmospheric air at a volumetric flow rate of 0.060 m^3/s and 27ºC is drawn through the sinks by a blower. Estimate the operating temperature of the board and the pressure drop across the sinks. (Ans: 30^{o}C)
Air (T =310 K, 1 atm): rho= 1.1281 kg/m^3, Cp = 1008 J/kgK, ν=16.89 10^{-6} m^2/s, k = 0.0270 W/mK, Pr = 0.706.



16. A pre heater involves the use of condensing steam at 100^0C on the inside of a bank of tubes to heat air that enters at 1 atm and 25^0C. The air moves at 5 m/s in cross flow over the tubes. Each tube is 1 m long and has an outside diameter of 10mm. The bank consists of 196 tubes in a square, aligned array for which S_T=S_L=15mm. What is the total rate of heat transfer to the air? What is the pressure drop associated with the airflow?

(Ans: 58.5 kW, $5.9e^{-3}$ bar)

17. Copper sphere of 20 mm diameter are quenched by being dropped into a tank of water that is maintained at 280K. The spheres may be assumed to reach the terminal velocity on impact and to drop freely through the water. Estimate the terminal velocity by equating the drag and gravitational forces acting on the sphere. What is the approx height of water tank needed to cool the spheres from an initial temperature of 360K to a centre temperature of 320K?

(Ans: 2.1 m/s, 1.6m)

PROPERTIES: *Table A-1*, Copper (350K): $\rho = 8933\ kg/m^3$, $k = 398\ W/m{\cdot}K$, $c_p = 387\ J/kg{\cdot}K$; *Table A-6*, Water ($T_\infty = 280\ K$): $\rho = 1000\ kg/m^3$, $\mu = 1422 \times 10^{-6}\ N{\cdot}s/m^2$, $k = 0.582\ W/m{\cdot}K$, Pr = 10.26; ($T_s \approx 340\ K$): $\mu_s = 420 \times 10^{-5}\ N{\cdot}s/m^2$.

18. In a manufacturing process, a long coated plastic rod of diameter 20 mm is initially at uniform temperature 25^0C and is suddenly exposed to a cross flow of air at T_∞=350^0C and V=50m/s. How long will it take for the surface of the rod to reach 175^0C, the temperature above which the spherical coating will cure? (Ans: 15.2 s)

PROPERTIES: Rod (Given): $\rho = 2200\ kg/m^3$, $c = 800\ J/kg{\cdot}K$, $k = 1\ W/m{\cdot}K$, $\alpha = k/\rho c = 5.68 \times 10^{-7}\ m^2/s$; *Table A.4*, Air ($T_f \approx 500\ K$, 1 atm): $\nu = 38.79 \times 10^{-6}\ m^2/s$, $k = 0.0407\ W/m{\cdot}K$, Pr = 0.684.

19. An electric air heater consists of a horizontal array of thin metal strips that are each 10 mm long in direction of an air stream that is in parallel flow over the top of the strip. Each strip is 0.2 m wide and arranged side by side, forming a continuous and smooth surface over which air flows at 2 m/s. During operation, each strip is maintained at 25^0C. What is the rate of convection heat transfer from the first strip? The tenth strip and all the strips?

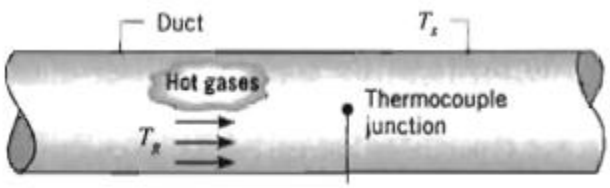
(Ans: 51.1W, 8.3W, 255.3W)

PROPERTIES: *Table A.4*, Air ($T_f = 535\ K$, 1 atm): $\nu = 43.54 \times 10^{-6}\ m^2/s$, $k = 0.0429\ W/m{\cdot}K$, Pr = 0.683.

20. A thermocouple junction is inserted in a large duct to measure the temperature of hot gasses flowing through the duct.

(a) If the duct temperature T_s is less than the gas temperature T_g will the thermocouple sense a temperature less than, equal to, or greater than T_g? Justify your answer on the basis of a simple analysis.

(b) A thermocouple junction in the shape of a 2 mm diameter sphere with a surface emissivity of 0.60 is placed in a gas stream moving at 3 m/s. If the thermocouple senses a temperature of 320^0C when the duct surface temperature is 175^0C, what is the actual gas temperature? The gas may be assumed to have a property as;



PROPERTIES: *Table A-4*, Air ($T_g \approx 650$ K, 1 atm): $\nu = 60.21 \times 10^{-6}$ m^2/s, k = 0.0497 W/m·K, Pr = 0.690, $\mu = 322.5 \times 10^{-7}$ N·s/m^2; Air ($T_j = 593$ K, 1 atm): $\mu = 304 \times 10^{-7}$ N·s/m^2.

(Ans: 337^0C)

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Tutorial -12 Date: 09/11/2010

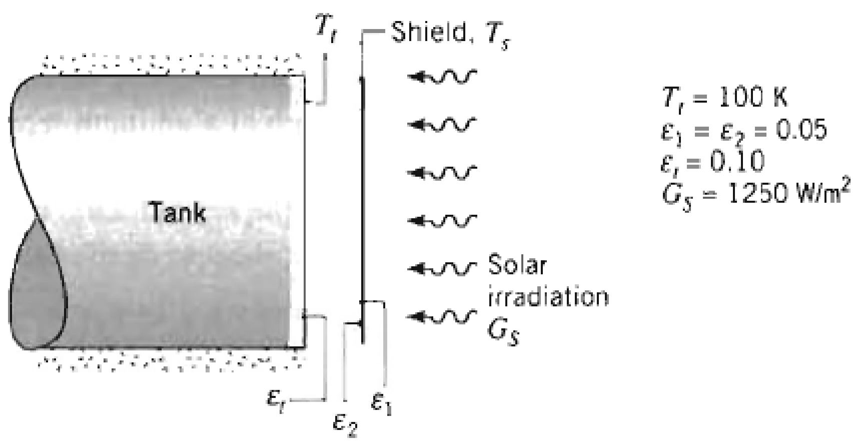
Radiation

1. A flat-bottomed hole 6 mm in diameter is bored to a depth of 24 mm in a diffuse, gray material having an emissivity of 0.8 and a uniform temperature of 1000 K. (a) Determine the radiant power leaving the opening of the cavity. (b) The effective emissivity, of a cavity is defined as the ratio of the radiant power leaving the cavity to that from a blackbody having the area of the cavity opening and a temperature of the inner surfaces of the cavity. Calculate the effective emissivity of the cavity described above. (c) If the depth of the hole were increased, would effective emissivity, Increase or decrease? What is the limit of effective emissivity as the depth increases? (Ans: (a) 1.580 W, (b) 0.986)

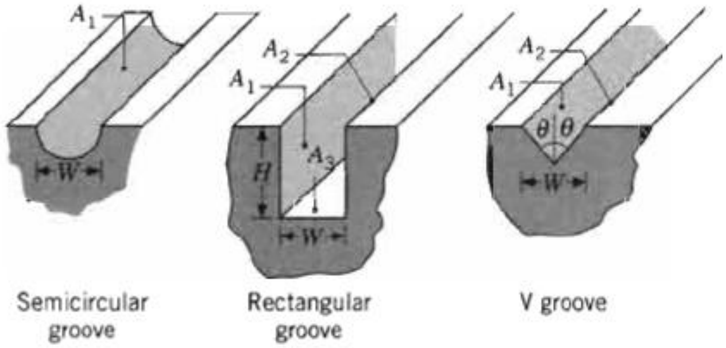
2. Determine the steady-state temperatures of two radiation shields placed in the evacuated space between two infinite planes at temperatures of 600 and 325 K. All the surfaces are diffuse and gray with emissivity of 0.7. (Ans: 548 K and 474 K)

3. The end of a cylindrical liquid cryogenic propellant tank in free space is to be protected from external (solar) radiation by placing a thin metallic shield in front of the tank. Assume the view factor *Ft.* between the tank and the shield is unity; all surfaces are diffuse and gray, and the surroundings are at 0 K. Find the temperature of the shield *Ts* and the heat flux (W/m^2) to the end of the tank.

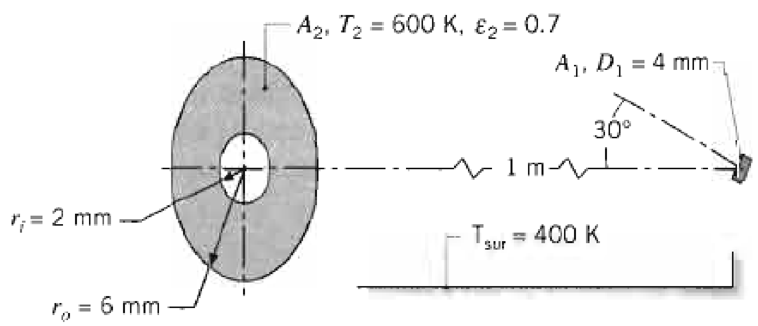
(Ans: 338 W, 25.3 W/m^2)



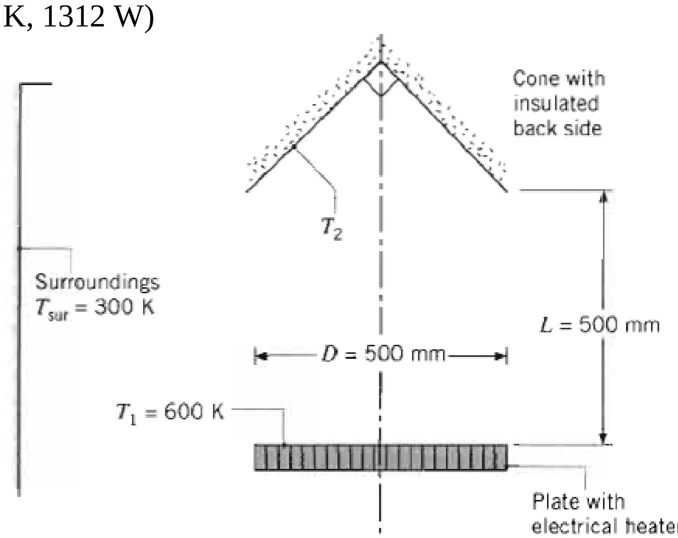
4) consider the following grooves, each of width W, that have been machined from a solid block of material. a) For each case obtain an expression for the view factor of the groove with respect to the surroundings outside the groove. (b) For the V groove, obtain an expression for the view factor F_{12}, where A_1 and A_2 are opposite surfaces. (c) If H = 2W in the rectangular groove, what is the view factor F_{12}? (Ans. 2/π,W/(W+2H),sin θ, 1-sin θ, 0.62)



5) As shown in the sketch, consider the disk A_1 located coaxially 1 m distant, but tilted 30º off the normal, from the ring-shaped disk A_2. What is the irradiation on A_1 due to radiation from A_2, which is a diffuse, grey surface with an emissivity of 0.7?
(Ans. 27.7 $\mu W/m^2$)



6) A circular plate of 500-mm diameter is maintained at T_1 = 600 K and is positioned coaxial to a conical shape. The back side of the cone is well insulated. The plate and the cone, whose surfaces are black, are located in a large, evacuated enclosure whose walls are at 300 K. (a) what is the temperature of the conical surface, T_2?
(b) What is the electrical power that would be required to maintain the circular plate at 600 K? (Ans. 413 K, 1312 W)



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Tutorial -13 Date: 16/11/2010

Heat Exchangers

1) A finned-tube, cross-flow heat exchanger is to use the exhaust of a gas turbine to heat pressurized water. Laboratory measurements are performed on a prototype version of the exchanger, which has a surface area of 10 m^2, to determine the overall heat transfer coefficient as a function of operating conditions Measurements made under particular conditions, for which m_h = 2 kg/s, $T_{h,i}$ = 325ºC, m_c = 0.5 kg/s, and $T_{c,i}$ = 25°C reveal a water outlet temperature of $T_{c,o}$ = 150°C. What is the overall heat transfer coefficient of the exchanger? (Ans. 160 W/m^2-K)

Water (87ºC): cp =4203J/kg-K Air ($T_c \approx$ 275 ºC) cp=1040 J / kg·

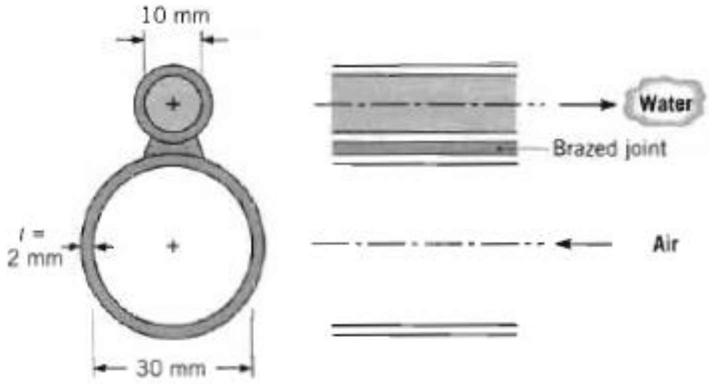
2) In a dairy operation, milk at a flow rate of 250 liter/hour and a cow-body temperature of 38.6°C must be chilled to a safe-to-store temperature of 13°C or less. Ground water at 10°C is available at a flow rate of 0.72 m^3/h. The density and specific heat of milk are 1030 kg/m^3 and 3860 J/kg-K respectively. a) Determine the UA product of a counterflow heat exchanger required for the chilling process. Determine the length of the exchanger if the inner pipe has a 50-mm diameter and the overall heat transfer coefficient is U = 1000 W/m^2-K. (b) Determine the outlet temperature of the water.

(Ans. 785 W / K, 5.0 m, 18.4 ºC)

Water T_c=287 K, assume $T_{c,o}$= 18 ºC: ρ = 1000 kg / m^3,c_p = 4187 J / kg-K; Milk (given): ρ = 1030 kg / m^3, c_p=3860 J/ kg-K.

3) A counterflow, twin-tube heat exchanger is made by brazing two circular nickel tubes, each 40 m long, together as shown below. Hot water flows through the smaller tube of 10-mm diameter and air at atmospheric pressure flows through the larger tube of 30-mm diameter. Both tubes have a wall thickness of 2 mm. The thermal contact conductance per unit length of the brazed joint is 100 W/m-K. The mass flow rates of the water and air are 0.04 and 0.12 kg/s respectively. The inlet temperatures of the water and air are 85 and 23°C, respectively. Employ the ε-NTU method to determine the outlet temperature of the air. Hint: Account for the effects of circumferential conduction in the walls of the tubes by treating them as extended surfaces. (Ans. 76.4ºC)

Water (T_h = 335 K): $c_h = c_{p,h}$ = 4186 J/kg-K, μ = 453x10^{-6} N-s/m^2, k= 0.656 W/m-K, Pr = 2.88; Air (300 K): $c_c = c_{p,c}$ = 1007 J/kg-K, μ = 184.6 x10^{-7} N-s/m^2, k= 0.0263 W/m-K, Pr = 0.707; Nickel (T = (23 + 85)°C/2 = 327 K): k = 88 W/m-K.



4) Saturated steam at 0.14 bar is condensed in a shell-and tube heat exchanger with one shell pass and two tube passes consisting of 130 brass tubes, each with a length per pass of 2 m. The tubes have inner and outer diameters of 13.4 and 15.9 mm, respectively. Cooling water enters the tubes at 20°C with a mean velocity of 1.25 m/s. The heat transfer coefficient for condensation on the outer surfaces of the tubes is 13,500 W/m^2-K. Determine the overall heat transfer coefficient, the cooling water outlet temperature, and the steam condensation rate. (Ans. 3549W/m^2-K, 41.1ºC, 0.85 kg/s)
$T_{sat} = T_h = 327$ K, $h_{fg} = 2373$ kJ/kg, $c_p = 1898$ J/kg-K;
Water (Assume $T_{c,o} \approx 44°C$ or $T_c \approx 305$ K): $v_f = 1.005 \times 10^{-3}$ m^3/kg , $c_p = 4178$ J/kg-K, $\mu_f = 769 \times 10^{-6}$ N-s/m^2 , $k_f = 0.620$ W/m-K, $Pr_f = 5.2$; Brass - 70/30 (Evaluate at $T = (T_h + T_c)/2 = 316$ K): k = 114 W/m-K.

5) Saturated water vapor leaves a steam turbine at a flow rate of 1.5 kg/s and a pressure of 0.51 bar. The vapor is to be completely condensed to saturated liquid in a shell-and-tube heat exchanger that uses city water as the cold fluid. The water enters the thin-walled tubes at 17°C and is to leave at 57ºC. Assuming an overall heat transfer coefficient of 2000 w/m2-K, determine the required heat exchanger surface area and the water flow rate. After extended operation, fouling causes the overall heat transfer coefficient to decrease to 1000 W/m^2-K and to completely condense the vapor; there must be an attendant reduction in the vapor flow rate. For the same water inlet temperature and flow rate, what is the new vapor flow rate required for complete condensation? (Ans. 41.9m^2, 20.7 kg/s, 0.936 kg/s)
Sat. water ($T_c = 310$ K): $c_{p,c} = 4178$ J/kg-K; (p = 0.51 bars): $T_{sat} = 355$K, $h_{fg} = 2304$ kJ/kg

6. An ocean thermal energy conversion system is being proposed for electric power generation. Such a system is based on the standard power cycle for which the working fluid is evaporated, passed through a turbine, and subsequently condensed. The system is to be used in very special locations for which the oceanic water temperature near the surface is approximately 300 K, while the temperature at reasonable depths is approximately 280 K. The warmer water is used as a heat source to evaporate the working fluid, while the colder water is used as a heat sink for condensation of the fluid. Consider a power plant that is to generate 2 MW of electricity at efficiency (electric power output per heat input) of 3%. The evaporator is a heat exchanger consisting of a

single shell with many tubes executing two passes. If the working fluid is evaporated at its phase change temperature of 290 K, with ocean water entering at 300 K and leaving at 292 K, what is the heat exchanger area required for the evaporator? What flow rate must be maintained for the water passing through the evaporator? The overall heat transfer coefficient may be approximated as 1200 W/m2-K. (Ans: (a) 11100 m^2, (b) 1994 kg/s)

7. A shell-and-tube heat exchanger with one shell pass and 20 tube passes uses hot water on the tube side to heat oil on the shell side, the single copper tube has inner and outer diameters of 20 and 24 mrn and a length per pass of 3 m. The water enters at 87°C and 0.2 kg/s and leaves at 27°C. Inlet and outlet temperatures of the oil are 7 and 37°C. What is the average convection coefficient for the tube outer surface?
(Ans: 878 W / m^2 K) (Assume for water: cp = 4184 J/kg K, k = 0.650 W/m K, m = 489x 10^{-6} N×s/m^2, Pr = 3.15)
8. Exhaust gas from a furnace is used to preheat the combustion air supplied to the furnace burners. The gas, which has a flow rate of 15 kg/s and an inlet temperature of 1100 K, passes through a bundle of tubes, while the air, which has a flow rate of 10 kg/s and an inlet temperature of 300 K, is in cross flow over the tubes. The tubes are un-finned, and the overall heat transfer coefficient is 100 W/m^2-K. Determine the total tube surface area required to achieve an air outlet temperature of 850 K. The exhaust gas and the air may each be assumed to have a specific heat of 1075 J/kg-K. (Ans: 243m^2)

9. Consider a concentric tube heat exchanger characterized by a uniform overall heat transfer coefficient and operating under the conditions given in table. What is the maximum possible heat transfer rate? What is the heat exchanger effectiveness? Should the heat exchanger be operated in parallel flow or in counter flow? What is the ratio of the required areas for these two flow conditions? (Ans: 44,625W, 0.65, 0.55)

	$\dot{m}$ (kg/s)	c_p (J/kg · K)	T_i (°C)	T_o (°C)
Cold fluid	0.125	4200	40	95
Hot fluid	0.125	2100	210	—

10. A boiler used to generate saturated steam is in the form of an un-finned, cross-flow heat exchanger, with water flowing through the tubes and a high-temperature gas in cross flow over the tubes. The gas, which has a specific heat of 1120 J/kg. K and a mass flow rate of 10 kg/s, enters the heat exchanger at 1400 K. The water, which has a flow rate of 3 kg/s, enters as saturated liquid at 450 K and leaves as saturated vapor at the same temperature. If the overall heat transfer coefficient is 50 W/m^2 • K and there are 500 tubes, each of 0.025-m diameter, what is the required tube length? (Ans: 4.56m)