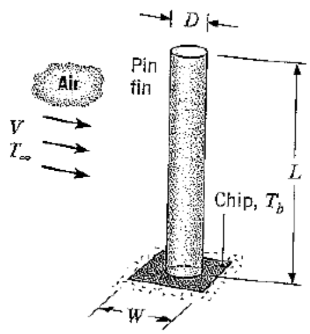
Final exam review packet

1.

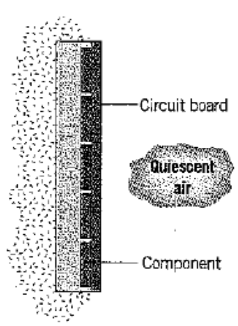
To enhance heat transfer from a silicon chip of width W=4 mm on a side, a copper pin fin is brazed to the surface of the chip. The pin length and diameter are L=12 mm and D=2 mm, respectively, and atmospheric air at V=10 m/s and T=300 K is in cross flow over the pin. The surface of the chip, and hence the base of the pin, are maintained at a temperature of T_b = 350 K.



(a) Assuming the chip to have a negligible effect on flow over the pin, what is the average convection coefficient for the surface of the pin?
(b) Neglecting radiation and assuming the convection coefficient at the pin tip to equal that calcu-lated in part (a), determine the pin heat transfer rate.
(c) Neglecting radiation and assuming the convection coefficient at the exposed chip surface to equal that calculated in part (a), determine the total rate of heat transfer from the chip.

2.

The components of a vertical circuit board, 150 mm on a side, dissipate 5 W. The back surface is well insulated and the front surface is exposed to quiescent air at 27°C.



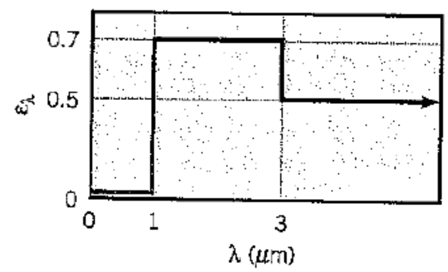
Assuming a uniform surface heat flux, what is the maximum temperature of the board? What is temperature of the board for an isothermal surface temperature condition?

3.

A horizontal electrical cable of 25-mm diameter has a heat dissipation rate of 30 W/m. ff the ambient air temperature is 27°C, estimate the surface temperature of the cable

4.

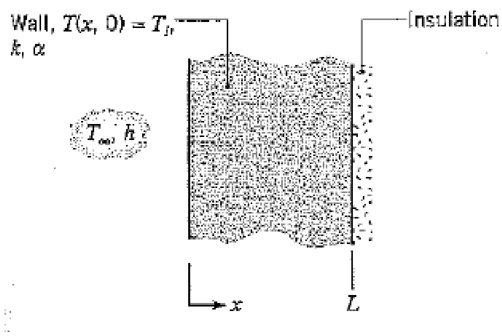
A small, opaque, diffuse object at T_s = 400 K is suspended in a large furnace whose interior walls are at T, = 2000 K. The walls are diffuse and gray and have an emissivity of 0.20. The spectral, hemispherical emissivity for the surface of the small object is given below.



(a) Determine the total emissivity and absorptivity of the surface.
(b) Evaluate the reflected radiant flux and the net radiative flux *to* the surface.
(c) What is the spectral emissive power at A=2 μm?
(d) What is the wavelength $\lambda_{1/2}$ for which one- half of the total radiation emitted by the surface is in the spectral region $\lambda \geq \lambda_{1/2}$

5.

Consider the one-dimensional wall shown in the sketch, which is initially at a uniform temperature T_1 and is suddenly subjected to the convection boundary condition with a fluid at T_∞.



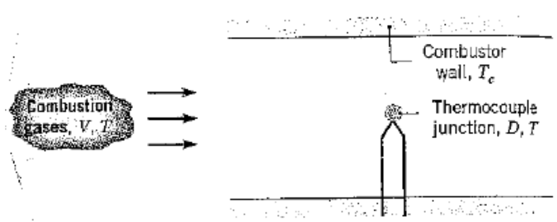
For a particular wall, case 1, the temperature at $x{=}L_1$ after t_1 = 100 s is $T_1(L_1, t_1)$ = 315°C. Another wall, case 2, has different thickness and thermal conditions as shown below.

Case	L [m]	α [m²/s]	k [W/m-K]	T_i [°C]	T_∞ [°C]	h [W/m²-K]
1	0.10	15×10^{-6}	50	300	400	200
2	0.40	25×10^{-6}	100	30	20	100

How long will it take for the second wall to reach 28.5°C at the position $x{=}L_2$? Use as the basis for analysis, the dimensionless functional dependence for the transient temperature distribution in an infinite plane wall

6.

A spherical thermocouple junction 1.0 mm in diameter is inserted in a combustion chamber to measure the temperature T_∞, of the products of combustion. The hot gases have a velocity of V = 5 m/s.



(a) If the thermocouple is at room temperature, T_i when it is inserted in the chamber, estimate the time required for the temperature difference T_∞-T to reach 2% of the initial temperature difference, T_∞-T_i. Neglect radiation and conduction through the leads. Properties of the thermocouple junction are approximated as k = 10 W/m K, c = 385 J/kg K, and ρ = 892 k g/m³, while those of the combustion gases may be approximated as k = 0.05 W/m K, ν = 50 × 10^{-6} m²/s, and Pr= 0.69.

(b) If the thermocouple junction has an emissivity of 0.5 and the cooled walls of the combustor are at T = 400 K, what is the steady-state temperature of the thermocouple junction if the combustion gases are at 1000 K? Conduction through the lead wires may be neglected.

7.

A spherical hailstone that is 5 mm in diameter is formed in a high-altitude cloud at -30°C. If the stone begins to fall through warmer air at 5°C, how long will it take before the outer surface begins to melt? What is the temperature of the stone's center at this point in time, and how much energy (J) has been transferred to the stone? A convection heat transfer coefficient of 250 W/m² K may be assumed, and the properties of the hailstone may be taken to be those of ice.

8.

The energy flux associated with solar radiation incident on the outer surface of the earth's atmosphere has been accurately measured and is known to be 1353 W/m². The diameters of the sun and earth are 1.39×10^{9} and 1.29×10^{7} m, respectively, and the distance between the sun and the earth is 1.5×10^{11} m.

(a) What is the emissive power of the sun?

(b) Approximating the sun's surface as black, what is its temperature?

(c) At what wavelength is the spectral emissive power of the sun a maximum?

Assuming the earth's surface to be black and the sun to be the only source of energy for the earth, estimate the earth's surface temperature

9.

Oil at 150°C flows *slowly* through a long, thin-walled pipe of 30-mm inner diameter. The pipe is suspended in a room for which the air temperature is 20°C and the convection coefficient at the outer tube surface is 11 W/m² K. Estimate the heat loss per unit length of tube.

10.

A spheric.tl shell of inner and outer radii r_1 and r_o, respectively, contains heat-dissipating components, and at a particular instant the temperature distribution the shell is known to be of the form

$$T(r) = C_1/r + C_2$$

Are conditions steady-state or transient? How do the heat flux and heat rate vary with radius?

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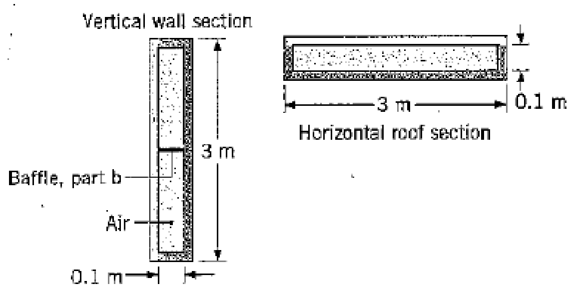
11.

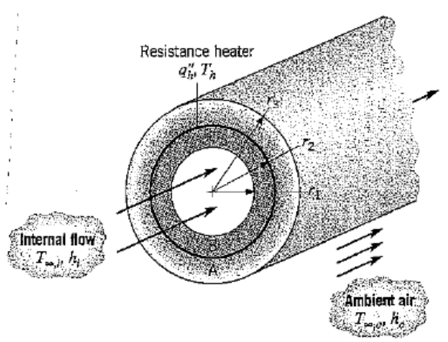
Consider a horizontal flat roof section having the same dimensions as a vertical wall section. For both sections, the surfaces exposed to the air gap are at 18°C (inside) and -10°C (outside).



(a) Estimate the ratio of the convection heat rate for the horizontal section to that of the vertical section.
(b) What effect will inserting a baffle at the mid-height of the vertical section have on the convection heat rate for that section?

12.

A composite cylindrical wall is composed of two materials of thermal conductivity k_A and k_B, which · are separated by a very thin, electric resistance heater for which interfacial contact resistances are negligible.



Liquid pumped through the tube is at a temperature $T_{\infty,i}$ and provides a convection coefficient h_1 at the inner surface of the composite. The outer surface is exposed to ambient air, which is at $T_{\infty,o}$ and provides a convection coefficient of h_o • Under steady-state conditions, a uniform heat flux of q_h" is dissipated by the heater.

(a) Sketch the equivalent thermal circuit of the system and express all resistances in terms of relevant variables.
(b) Obtain an expression that may be used to determine the heater temperature, T_h.
(c) Obtain an expression for the ratio of heat flows to the outer and inner fluids, q_o'/q_i';. How might the variables of the problem be adjusted to minimize this ratio?

13.

A heat exchanger consists of a bank of 1200 thin-walled tubes with air in cross flow over the tubes. The tubes are arranged in-line, with 40 longitudinal rows (along the direction of airflow) and 30 transverse rows. The tubes are 0.07 min diameter and 2 m long, with transverse and longitudinal pitches of 0.14 m. The hot fluid flowing through the tubes consists of saturated steam condensing at 400 K. The convection coefficient of the condensing steam is much larger than that of the air.

If air enters the heat exchanger $\dot{m}$ = 12 kg/s, 300 K, and 1 aim, what is its outlet temperature?

14.

A shell-and-tube heat exchanger is to heat 10 000 kg/h of water from 16 to 84°C by hot engine oil flowing through the shell. The oil makes a single shell pass, entering at 160°C and leaving at 94°C, with an average heat transfer coefficient of 400 W/m^2-K. The water flows through 11 brass tubes of 22.9-mm inside diameter and 25.4-mm outside diameter, with each tube making four passes through the shell.

Assuming fully developed flow for the water, determine the required tube length per pass

15.

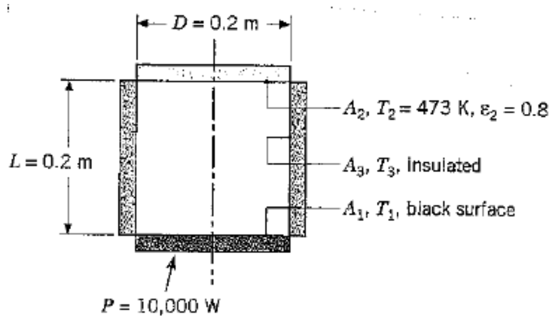
Air at a pressure and a temperature of 1 atm and 50°C, respectively, is in parallel flow over the top surface of a flat plate that is heated to a uniform temperature of 100°C. The plate has a length of 0.20 m (in the flow direction) and a width of 0.10 m. The Reynolds number based on the plate length is 40,000. What is the rate of heat transfer from the plate to the air? If the free stream velocity of the air is doubled and the pressure is increased to 10 atm, what is the rate of heat transfer?

16.

An experimental arrangement for measuring the. thermal conductivity of solid materials involves the use of two long rods that are equivalent in every respect, except that one is. fabricated from a standard material of known thermal conductivity k_A while the other is fabricated from the material whose thermal conductivity k_B is desired. Both rods are attached at one end to a heat source of fixed temperature T_b, are exposed to a fluid of temperature T_∞, and are instrumented with thermocouples to measure the temperature at a fixed distance *x1* from the heat source. If the standard material is aluminum., with k_A = 200 W/m-K, and measurements reveal values of T_A = 75°C and T_B = 60°C at x_1 for T_b = 100°C and T_∞ = 25°C, what is the thermal conductivity k_B of the test material?

17.

Consider the three-surface enclosure shown. The lower plate (A_1) is a black disk of 200-mm diameter and is supplied with a heat rate of 10,000 W. The upper plate (A_2), a disk coaxial to A_1, is a diffuse, gray surface with ε_2 = 0.8 and is maintained at T_2 = 473 K. The diffuse, gray sides between the plates are perfectly insulated. Assume convection heat transfer is negligible.



Determine the operating temperature of the lower plate T_1 and the temperature of the insulated side T_3.

18.

Consider a 20 cm thick brick wall separating a room at T_i = 25 °C from the outside air at T_o = -5°C. The heat transfer coefficient on both sides of the wall is 10 W/m^2-K. The thermal conductivity of the brick is 0.7 W/m-K. Neglect the effect of radiation.

(a) Evaluate the inner surface temperature of the wall, T_i.
(b) Now, let the outer coefficient of heat transfer be increased to 100 W/m^2-K due to a change in the condition of air outside from stagnant to windy. Reevaluate the inner surface temperature.
(c) Assume that a human standing in the room can be approximated as a cylinder 1,8m tall, 30 cm/in diameter. Neglecting radiation, evaluate the steady heat loss from the, human being by means of convection both for (a) and (b).
(d) Reevaluate (c) by including the effect of radiation as well as that of convection.

19.

Water at a flow rate of $\dot{m}$ = 0.215 kg/s is cooled from 70° to 30°C by passing it through a thin-walled tube of diameter D = 50 mm and maintaining a coolant at T_∞ = 15°C in cross flow over the tube.

(a) What is the required tube length if the coolant is air and its velocity is V = 20 m/s?
(b) What is the tube length if the coolant is water and V= 2 m/s?

20.

A 25-rnm diameter, high-tension line has an electrical resistance of 10^{-4} Ω/m and is transmitting a current of 1000 A.

(a) If ambient air at l0°C and 5 m/s is in cross flow over the line, what is its surface temperature?
(b) If the line may be approximated as a solid copper rod, what is its centerline temperature

21.

In manufacturing lead shot, molten lead droplets fall from a tower through cool air into a tank of water. The intent is to have the lead solidify before hitting the water. Consider each pellet to be a sphere 3 mm, in diameter, moving at the terminal velocity (for which the drag force equals the gravitational force) throughout the descent. If pellets at the melting point are to be converted from the molten to the solid state in air at 15°C, what is the necessary height of the tower above the tank? The latent heat of fusion of lead is 2.45×10^4 J/kg.

22.

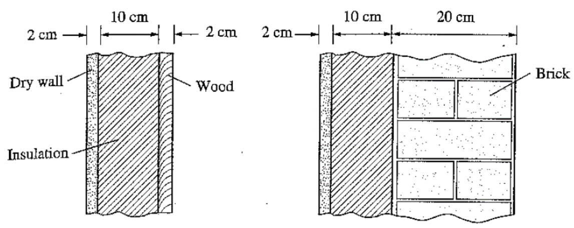
Steel balls 12 mm in diameter are annealed by heating to 1150 K and then slowly cooling to 400 in an air environment for which T_∞ = 325 K and h = 20 W/m^2-K. Assuming the properties of the steel to be k = 40 W/m-K, ρ = 7800 kg/m^3, and c = 600 J/kg-K, estimate the time required for the cooling process.

23.

The bottom of a copper pan, 150 mm in diameter, is maintained at 115°C by the heating element of an electric range. Estimate the power required to boil the water in this pan. Determine the evaporation rate. What is the ratio of the surface heat flux to the critical heat flux? What pan temperature is required to achieve the critical heat flux?

24.

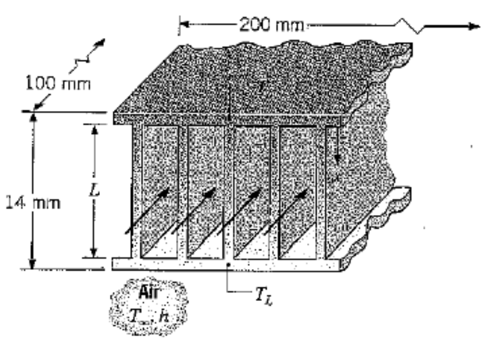
The cross section of the wall of a wooden house is shown in the figure. To save heating costs, the outside wood is to be replaced with a brick wall. Find the reduction in heat loss from the house. *Data:* Conductivities for drywall, insulation, wood, and brick are k_d = 0.2, k_i = 0.1, k_w = 0.2, and k_b = 0.7 W/m-K, the inside and outside coefficients of heat transfer are *h,* = 10, and h_o = 30 W/m^2-K.



(a) Wooden house (b) Brick house

25.

Finned passages are frequently formed between parallel plates to enhance convection heat transfer in compact heat exchanger cores. An important application is in electronic equipment cooling, where one or more air-cooled stacks are placed between heat-dissipating electrical components. Consider a single stack of rectangular fins of length *L* and thickness *t,* with convection conditions corresponding to *h* and T_∞.



(a) Obtain expressions for the fin heat transfer rates, $q_{f,o}$ and $q_{f,L}$ in terms of the base temperatures, T_o and T_L.

(b) In a specific application, a stack that is 200 mm wide and 100 mm deep contains 50 fins, each of length L = 12 mm. The entire stack is made from aluminum, which is everywhere 1.0 mm thick. If temperature limitations associated with electrical components joined to opposite plates dictate maximum allowable plate temperatures of T_o = 400 K and T_L = 350 K, what are the corresponding maximum power dissipations if h = 150 W/m^2-K and T_∞ = 300 K?