Problem 1 [25 points]

(a) [6 points] Two hot spheres initially at temperature T_i = 500°C are quenched by dropping into a liquid bath. The liquid bath is at a constant temperature T_∞ = 25°C and it provides uniform convective heat transfer coefficient h = 100 W/(m^2·K) around the entire surface of both spheres.

Sphere A: D_A = 10 mm, k_A = 10 W/(m·K)

Sphere B: D_B = 100 mm, k_B = 1 W/(m·K)

Which sphere has nearly uniform temperature from the surface to its center during cooling? Circle your answer below.

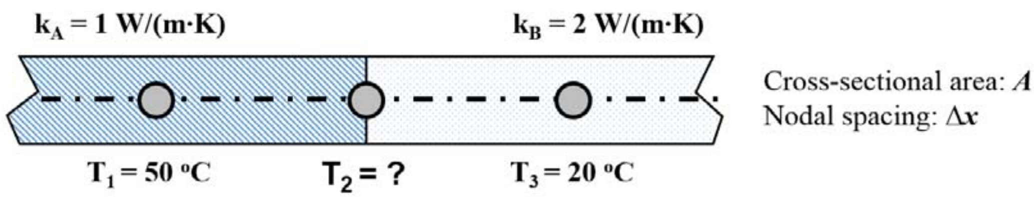
Sphere A Sphere B

Briefly justify your answer in the box below.

Circle your division: 1 2 3 4 Name________________________________

Problem 1 – continued

(b) [6 points] Use Energy Balance Method to numerically solve steady-state conduction in a 1D composite bar. Some nodal temperatures and properties are shown in the figure below. All nodes are evenly spaced. There is no contact resistance and no heat generation. Neglect radiation and convection.

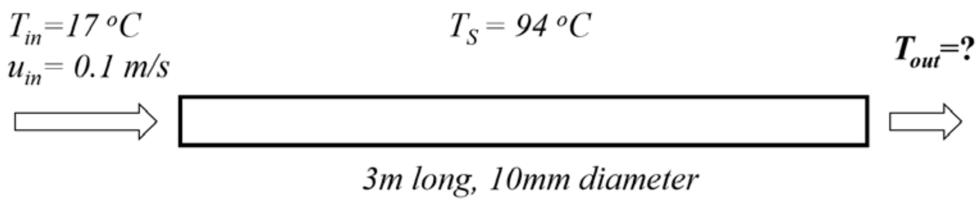


(i) Derive the nodal equation at node T_2

(ii) Calculate the value of T_2 (°C).

Problem 1 – continued

(c) [7 points] Saturated steam condenses on the outer surface of a thin-walled pipe of 10 mm in diameter and 3m in length, making the surface temperature of the pipe uniform at 94°C. Water flows through the pipe at 0.1 m/s and the temperature of water at the inlet is 17°C.

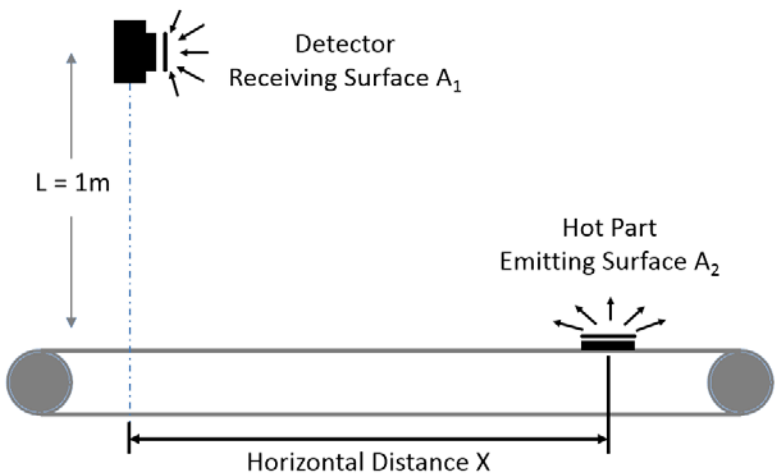


What is the temperature (°C) of the water at outlet? Evaluate the water properties at an assumed average temperature of 27°C. Fully-developed flow can be assumed throughout the pipe.

Water at 27°C:
ρ=1003 kg/m^3; c=4.179 kJ/(kg·K); μ=855×10^{-6} N·s/m^2; k=0.613 W/(m·K); Pr=5.83.

Problem 1 – continued

(d) [6 points] As shown in the figure below, a small hot part moves on a long horizontal conveyer belt. A small radiation detector is placed 1m above the conveyer belt and its receiving surface faces to the right. If the detector receives 1W of radiative energy when X = 1m, how much radiant energy [W] would it receive when X= $\sqrt{3}$ m?
The top surface of the hot part is diffuse and its radiosity does not change with time. Radiation from other surfaces can be ignored.



Circle your division: 1 2 3 4 Name________________________________

Problem 2 [25 points]

A long horizontal cylindrical rod of diameter D_i = 200 mm has thermal conductivity of k_r = 0.5 W/(m·K). Uniform volumetric heat generation occurs within the rod at the rate of $\dot{q}$. The rod is fitted with a cylindrical sleeve having an outer diameter of D_o = 400 mm and the sleeve has thermal conductivity of k_s = 4 W/(m·K). The outer surface of the sleeve T_s is measured to be 127 °C at steady state and it is exposed to quiescent air at T_∞ = 27°C. Assume the following thermophysical properties of air at the film temperature: $\nu = 20.92 \times 10^{-6}$ m²/s, $\alpha = 29.9 \times 10^{-6}$ m²/s, $k = 30 \times 10^{-3}$ W/(m·K).

(a) Calculate the convective heat transfer coefficient (W/m²K) on the outer surface.
(b) Calculate the uniform volumetric heat generation $\dot{q}$ (W/m³).
(c) Find the temperature (°C) at the interface between the rod and the sleeve T_i.
(d) What is the temperature (°C) at the center of the rod T_o?

List your assumptions below. [2 points]

Start your answer to part (a) here. [8 points]

Problem 2 – continued

Start your answer to part (c) here. [5 points]

Start your answer to part (c) here. [5 points]

Start your answer to part (d) here. [5 points]

Circle your division: 1 2 3 4 Name________________________________

Problem 3 [25 points]

A small sphere is suspended inside a large enclosed chamber for thermal processing. The sphere surface temperature is $T_S = 400$ K and the temperature of the chamber wall is $T_w = 1{,}000$ K. The sphere and the chamber wall are made of same material, which are diffuse and opaque and have the same spectral absorptivity of $\alpha_\lambda = 0.2$ for $\lambda < 3$ µm and $\alpha_\lambda = 0.6$ for $\lambda > 3$ µm.

(a) Find the total emissivity of the sphere surface ε.
(b) Find the total absorptivity of the sphere surface α.
(c) Find the radiosity for the sphere surface J [W/m^2]
(d) Find the radiation exchange between the sphere and the chamber q'' [W/m^2].

TABLE 12.1 Blackbody Radiation Functions

λT (μm · K)	$F_{(0\rightarrow\lambda)}$	$I_{\lambda,b}(\lambda,T)/\sigma T^5$ (μm · K · sr)$^{-1}$	$\dfrac{I_{\lambda,b}(\lambda,T)}{I_{\lambda,b}(\lambda_{max},T)}$
200	0.000000	0.375034×10^{-27}	0.000000
400	0.000000	0.490335×10^{-13}	0.000000
600	0.000000	0.104046×10^{-8}	0.000014
800	0.000016	0.991126×10^{-7}	0.001372
1,000	0.000321	0.118505×10^{-5}	0.016406
1,200	0.002134	0.523927×10^{-5}	0.072534
1,400	0.007790	0.134411×10^{-4}	0.186082
1,600	0.019718	0.249130	0.344904
1,800	0.039341	0.375568	0.519949
2,000	0.066728	0.493432	0.683123
2,200	0.100888	0.589649×10^{-4}	0.816329
2,400	0.140256	0.658866	0.912155
2,600	0.183120	0.701292	0.970891
2,800	0.227897	0.720239	0.997123
2,898	0.250108	0.722318×10^{-4}	1.000000
3,000	0.273232	0.720254×10^{-4}	0.997143
3,200	0.318102	0.705974	0.977373
3,400	0.361735	0.681544	0.943551
3,600	0.403607	0.650396	0.900429
3,800	0.443382	0.615225×10^{-4}	0.851737
4,000	0.480877	0.578064	0.800291
4,200	0.516014	0.540394	0.748139
4,400	0.548796	0.503253	0.696720
4,600	0.579280	0.467343	0.647004
4,800	0.607559	0.433109	0.599610
5,000	0.633747	0.400813	0.554898

Problem 3 – continued

5,000	0.633747	0.400813	0.554898
5,200	0.658970	0.370580×10^{-4}	0.513043
5,400	0.680360	0.342445	0.474092
5,600	0.701046	0.316376	0.438002
5,800	0.720158	0.292301	0.404671
6,000	0.737818	0.270121	0.373965
6,200	0.754140	0.249723×10^{-4}	0.345724
6,400	0.769234	0.230985	0.319783
6,600	0.783199	0.213786	0.295973
6,800	0.796129	0.198008	0.274128
7,000	0.808109	0.183534	0.254090
7,200	0.819217	0.170256×10^{-4}	0.235708
7,400	0.829527	0.158073	0.218842
7,600	0.839102	0.146891	0.203360
7,800	0.848005	0.136621	0.189143
8,000	0.856288	0.127185	0.176079
8,500	0.874608	0.106772×10^{-4}	0.147819
9,000	0.890029	0.901463×10^{-5}	0.124801

Start your answer to part (a) here. [7 points]

Problem 3 – continued

Start your answer to part (b) here. [6 points]

Start your answer to part (c) here. [6 points]

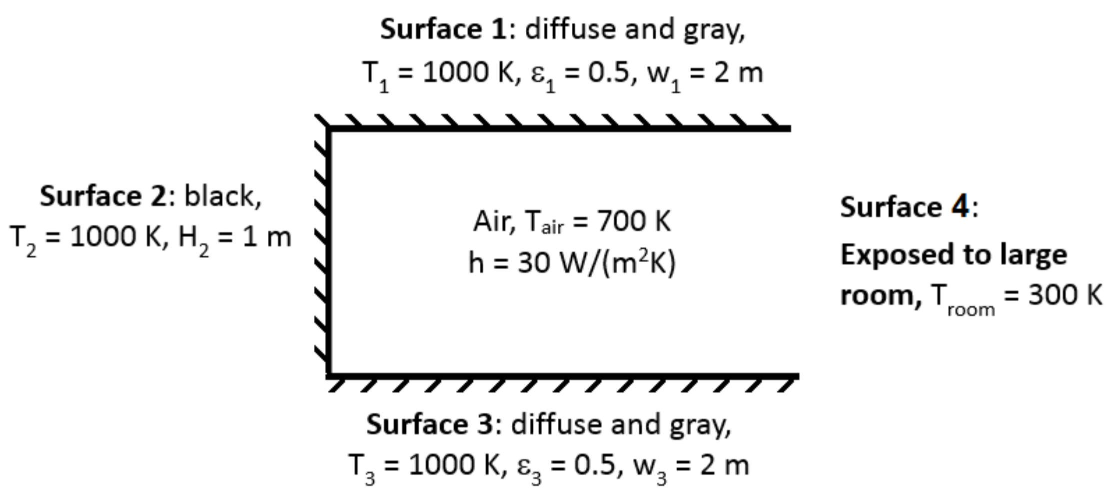
Problem 3 – continued

Start your answer to part (d) here. [6 points]

Circle your division: 1 2 3 4 Name________________________________

Problem 4 [25 points]

A rectangular, open furnace is made of three very long surfaces with cross sectional dimensions as shown in the figure below. Surface 1 and surface 3 are diffuse gray and have an emissivity of 0.5. Surface 2 is black. The right side of the furnace is exposed to a large room whose wall temperature is 300 K. It is known that surface 1, surface 2, and surface 3 are all maintained at 1,000 K using electrical heaters. One view factor F_{13} is given as 0.618. Convection heat transfer occurs with air inside the furnace at 700 K and a convection heat transfer coefficient h = 30 W/(m^2·K).



(a) For each surface, write the basic radiation heat transfer equation (also called equation of radiosity).
(b) Calculate the relevant view factors.
(c) Calculate the radiosity of each surface of the furnace J1, J2, and J3 (W/m2).
(d) Calculate the power per unit length (W/m) needed to be supplied to surface 2 in order to maintain its temperature at 1,000 K, assuming the outer wall of the furnace is insulated.

List your assumptions below [2 points].

Problem 4 – continued

Start your answer to part (a) here. [6 points]

Start your answer to part (b) here. [4 points]

Problem 4 – continued

Start your answer to part (c) here. [8 points]

Problem 4 – continued

Start your answer to part (d) here. [5 points]