

Code Number :.....1

HEAT TRANSFER QUALIFYING EXAM

August 2019

One book allowed

Answer all questions

All questions have equal weight

TIME: 3.0 hrs

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Problem #1)

A spherical stainless-steel ball with diameter $D = 0.2\text{ m}$ is cooled in a flow of oil from its initial temperature at 900°C .

oil, $T_\infty = 30^\circ\text{C}$

$u_\infty = 1\text{ m/s}$



$D = 0.2\text{ m}$

a) Find the time required for the center of the ball bearing to reach 200°C . Give your answer in seconds. You can assume that the oil flow has $T_\infty = 30^\circ\text{C}$ and free stream velocity $u_\infty = 1\text{ m/s}$. Properties for the oil and the ball are given in the adjacent table.

Stainless Steel	
α	$3.48 \times 10^{-6}\text{ m}^2/\text{s}$
ρ	8200 kg/m^3
k	13.4 W/mK
c_p	460 J/kgK
Oil	
α	$0.76 \times 10^{-7}\text{ m}^2/\text{s}$
ρ	880 kg/m^3
k	0.15 W/mK
c_p	1900 J/kgK
$\mu (30^\circ\text{C})$	$.48\text{ N}\cdot\text{s/m}$
$\mu (200^\circ\text{C})$	$.05\text{ N}\cdot\text{s/m}$
Pr	375
ν	$545 \times 10^{-6}\text{ m}^2/\text{s}$

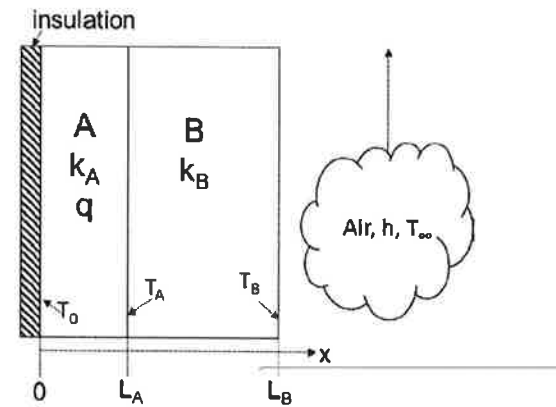
b) What is the surface temperature at that time? Give your answer in $^\circ\text{C}$.

Problem #2)

A plate (A) carries electrical power through a resistance, leading to internal energy generation.

The temperature distribution in plate A is $T(x) = \frac{\dot{q}_A L_A^2}{2k} \left(1 - \frac{x^2}{L_A^2}\right) + T_A$ with $L_A = 10\text{mm}$ and $T_A =$ the surface temperature of plate A. The thermal conductivity of the material in plate (A) is $k_A = 150 \text{ W/m}^2\text{K}$. The left side plate A shown below is fully insulated. The plate is covered by another material (plate B), with $L_B = 30\text{mm}$ (total length of B is 20mm) and $k_B = 0.1 \text{ W/mK}$. There is an external flow of air over the surface of the outer plate with $h = 40 \text{ W/m}^2\text{K}$ and $T_\infty = -10^\circ\text{C}$.

- a) What is the minimum energy generation in plate A so that the outer temperature of plate B (T_B) remains at least 4°C , to prevent ice formation? Give your answer in W/m^3 .

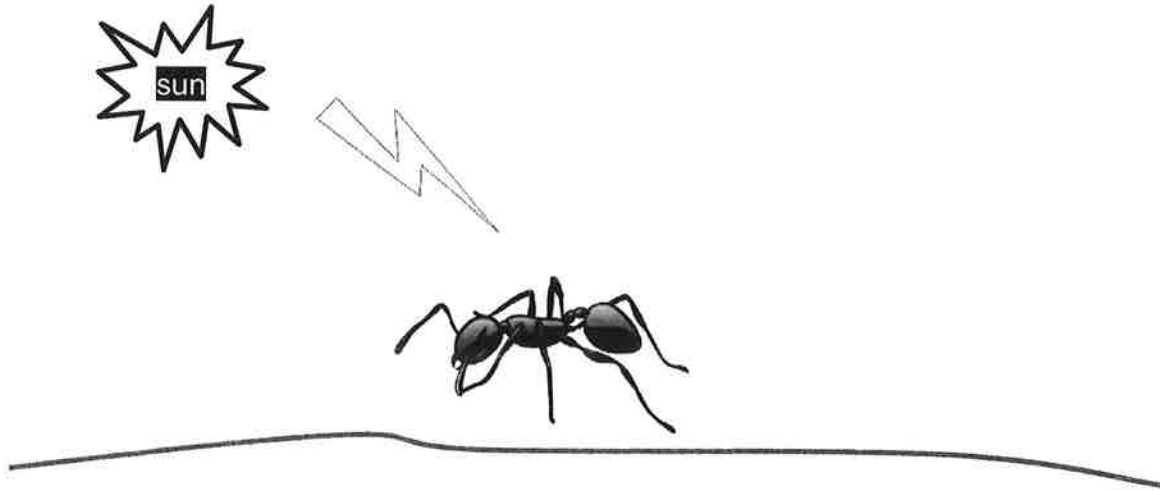


a:

b) In (a) you were given $T(x)$ for plate A. But imagine that, instead, you have to develop the exact $T(x)$ **for plate A** in this situation from the general solution for conduction with energy generation. Circle which two boundary conditions you would use.

- convection condition at a given position,
- constant surface heat flux at a given position,
- zero temperature gradient at a given position,
- prescribed surface temperature at a given position, radiation heat transfer at a given position.

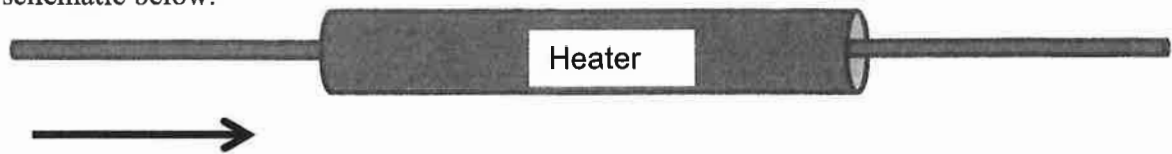
Problem #3) Saharan silver ants are one of most heat-resistant animals known. They have a critical (at which they die) thermal maximum temperature of 53.6°C . The ants are covered on their top and side with hairs that keep them “cool” by being highly reflective to solar radiation and being highly emissive. You are asked to develop a steady energy balance for a Saharan silver ant temperature. In you energy balance, treat the solar irradiation of $900\text{W}/\text{m}^2$ separately from the surrounding radiation. Use a heat transfer coefficient of $25\text{ W}/\text{m}^2\text{K}$, and the following parameters: $\varepsilon = 0.97$, $\alpha_{\text{sun}} = 0.1$, $T_{\text{surr sky}} = 40^{\circ}\text{C}$, $T_{\infty} = 49^{\circ}\text{C}$. Assume that only the top half of the ant is exposed to solar irradiation, but that all of the rest of its body is exposed to ambient convection and radiation.



- a) Write an energy balance below for one ant (state your assumptions)

- b) Solve the energy balance of a) for the ant temperature (hint: don't forget to convert all temperature to Kelvin)

Problem #4) It is proposed to heat a special 2-cm-diameter cylindrical tubing by a radiant heating element placed concentrically around the tubing. The production method consists of feeding tubing continuously at 60cm/s. The tubing does not touch the heater. The radiant heater is 10 cm in diameter and has an emissivity of 0.9. The tubing acts as a black body. Please refer to the schematic below.



a) Write the expression for the net heat transfer rate between the tubing and the heater if the tube is stationary.

b) Write down the relevant energy balance around the tubing if the tube is moving. Keep your answer in symbolic form.

c) Solve for the net heat transfer required of the heater and estimate the length needed to heat the tubing from 15°C to 85°C if the specific heat per unit length of tubing is 40 J/mk .