National Exams May 2016

04-Agric-A3, Heat Engineering

3 hours duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. This is an OPEN BOOK EXAM.
   Any non-communicating calculator is permitted.

3. Four (4) questions constitute a complete exam paper.

4. Each question is of equal value.

5. All questions require calculation.

Problem 1(25 points)

The wall of an industrial furnace is constructed from 0.15 m thick fireclay brick having a thermal conductivity of 1.7 W/m.K. Measurements made during steady state operation reveal temperature of 1400K and 1150K at the inner and outer surfaces respectively. What is the rate of heat loss through a wall that is 0.5 m by 1.2 m on a side?

Problem 2(25 points)

Humans are able to control their heat production rate and heat loss to maintain a nearly constant core temperature of T_c=37°C under a wide range of environmental conditions. This process is called thermoregulation. From the perspective of calculating heat transfer between a human body and its surroundings, we focus on a layer of skin and fat, with its outer surface exposed to the environment and its inner surface at a temperature slightly less than the core temperature T_c=35°C=308 K. Consider a person with a skin/fat layer of thickness **L=3 mm** and effective thermal conductivity **k=0.3 W/m.K** the person has a surface area **A=1.8 m²** and is dressed in a bathing suit. The emissivity of the skin is **e=0.95.**

1. When the person is in still air at T_{air}=297K, what is the skin surface temperature and rate of heat loss to the environment. Convective heat transfer to the air is characterized by a free convection coefficient of **h=2 W/m².K**
2. When the person is in water at T_w=297K, what is the skin surface temperature and heat loss rate? Heat transfer to the water is characterized by a convection coefficient of **h=200 W/m².K**

Assume steady state condition, one dimensional heat transfer by conduction through the skin/fat surface, bathing suit has no effect on heat loss from body and body is completely immersed in water for part 2.

Problem 3(25 points)

A physics experiment uses liquid nitrogen as a coolant. Saturated liquid nitrogen at 80K flows through 6.35 mm O.D stainless steel line(emissivity ε_l=0.2) inside a vacuum chamber. The chamber walls are at T_c=230K and are at some distance from the line.

Determine the heat gain of the line per unit length.

If a second stainless steel tube, 12.7 mm in diameter, is placed around the line to act as radiation shield

Determine the revised heat gain per unit length.

Hint: Assume that the chamber area is large compared to the shielded line.

Problem 4 (25 points)

A thin-walled metal tank containing fluid at 40°C cools in air at 14°C(β=0.00348 K^{-1}); the average natural convection heat transfer coefficient h is very large inside the tank. If the sides are 0.4 m high, compute h, the average heat flux q, and the thermal boundary layer thickness δ at the top.
(Air properties at 27°C, α=2.203x10^{-5} m^2/s, ν=1.556x10^{-5} m^2/s, Pr=0.711)