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 $T_c=37^\circ C$ 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 $T_c=35^\circ C=308 \, \text{K}$. Consider a person with a skin/fat layer of thickness $L=3 \, \text{mm}$ and effective thermal conductivity $k=0.3 \, \text{W/m.K}$ the person has a surface area $A=1.8 \, \text{m}^2$ and is dressed in a bathing suit. The emissivity of the skin is $\varepsilon=0.95$.

1. When the person is in still air at $T_{\text{air}}=297\, \text{K}$, 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 $h=2 \, \text{W/m}^2\text{K}$

2. When the person is in water at $T_{\text{w}}=297\, \text{K}$, what is the skin surface temperature and heat loss rate? Heat transfer to the water is characterized by a convection coefficient of $h=200 \, \text{W/m}^2\text{K}$

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 $\varepsilon_l=0.2$) 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 m²/s, ν=1.556x10⁻⁵ m²/s, Pr=0.711)