Ph.D. Qualifying Examination in Heat Transfer

- One open book.
- Calculators are permitted.
- Answer all questions
- All questions carry the same weight (25% of the exam).

Exam prepared by

Professor C. W. Somerton
Professor I. S. Wichman

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Question 1: Melting an iceberg: Air flows with a relative velocity of 3.24 m/s over the top surface of a flat iceberg. The iceberg may be modeled as a block of frozen fresh water at 0 °C. The length of the iceberg in the direction of drift is \( L = 100 \text{ m} \) and its width is \( W = 200 \text{ m} \). The air temperature outside the boundary layer is 40 °C. The latent heat of melting of the ice is \( h_f = 333.4 \text{ kJ/kg} \). Calculate the \( L \)- averaged heat flux deposited by the air into the upper surface of the iceberg: model this surface as flat. Calculate in \text{mm/hour} \), the rate of melting caused by this heat flux. This is the rate of erosion or thinning of the iceberg. How much mass is converted from ice to water in one day?

Question 2: Cooling of a hot droplet of water in a shower: Consider a droplet emerging from a shower nozzle. We take the droplet velocity to be 3 m/s and its initial temperature to be 70 °C. The droplet diameter is \( D = 1 \text{ mm} \). The surrounding “fluid” in which the droplet falls is air at 20 °C. Using the Nusselt number correlation

\[
(Nu_D)_{avg} = 2 + [0.4 \text{Re}_D^{1/2} + 0.06 \text{Re}_D^{2/3}] \text{Pr}^{4/10} \left( \mu_w / \mu_\infty \right)^{1/4},
\]

where the subscript ‘\( D \)’ denotes a quantity based on the diameter of the droplet. The quantities \( \mu_w \) and \( \mu_\infty \) are the air viscosities in the far field and at the droplet surface, respectively. Using the heat transfer coefficient \( h_{avg} \) so derived, calculate using the lumped heat transfer method the transient droplet temperature \( T(t) \). Calculate the time at which the droplet temperature has dropped by 20% relative to the total temperature difference between initial droplet (70 °C) and ambient temperature (20 °C).

Question 3: Heat transfer along the handle of a pan: Consider a pan heating water on the stove. The handle is 0.02 m x 0.03 m with a thermal conductivity of 2 W/(m·K). Determine the length of the handle required for safe handling under the following conditions:

\[
T_{air} = 290 \text{ K}, h_{air} = 1.5 \text{ W/(m}^2\cdot\text{K}), T_{water} = 365 \text{ K}, h_{water} = 25 \text{ W/(m}^2\cdot\text{K})
\]
Question 4: Furnace wall temperatures: A fire in a room begins in a chair located in the center of the room. Modeling the chair as a hemisphere of diameter 1.25 m with emissivity 0.8 and at 2200 K, determine the radiation heat transfer of the chair. The floor, ceiling, and walls are at 300 K with an emissivity of 0.9.