Code Number :.............

HEAT TRANSFER QUALIFYING EXAM

August 2006

OPEN BOOK (only one book allowed)

Answer all four questions

All questions have equal weight

TIME: 3.0 hrs

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- **Take any required property from your book, approximate values if necessary.**
- **If you make any assumption to reach a solution state it clearly**

Question # 1

Emperor penguins, found in Antarctica, lay eggs at the beginning of winter and must protect them from the bitter cold air of this region. This is achieved by sheltering the eggs in a special pouch between their body and feet. Unfortunately, an egg occasionally falls out of its pouch and rolls out in the open.

A biologist friend asks you the following question: if an egg falls out of its sheltered position, could you estimate the time needed for the temperature at the center of the egg to drop to 0°C? The egg is initially at 35°C and rolls into a wind of 0.1m/s. The outside temperature is -30°C. The egg is approximately spherical, with a diameter of 10 cm, and its thermophysical properties are close to that of water i.e. $\rho = 1000 kg/m^3$, $c_p = 4181 J/kgK$, $k_s = 0.6 W/mK$. The cold ambient air has the following properties: Pr=0.72, k_f=0.223 W/mK, $\mu = 15.96\times10^{-6} Ns/m^2$, $\nu = 11.44\times10^{-6} m^2/s$, $\mu_{surface\ temperature} = 20.82\times10^{-6} Ns/m^2$ (if needed). To guide you in formulating your answer, please answer the following subset of questions.

a) What is the average heat transfer coefficient for the egg? Assume that the egg is suspended in air. Clearly state which equation you are using and carefully evaluate this expression.

b) What is the Biot number for the egg?

c) Using an approximate method, find the time required for the egg's center temperature to cool down to 0°C. What is the surface temperature at that time?

d) How can you check the validity of this answer?

e) Will the egg cool down as fast as you are predicting? i.e. what important phenomena are neglected in this analysis of the cooling process?

Question # 2

A 3 mm-radius electrical wire is insulated by a rubberized sheath that protect against electrical shocks (k=0.08 W/mK). The combined wire and the sheath have an outside diameter that provides ***the maximum cooling*** for the wire (hint: it's at the critical radius of insulation). The convection heat transfer coefficient at the outer surface of the sheath is 10 W/m^2K and the ambient temperature is 20°C.

a) If the temperature of the insulation cannot exceed 50°C at any point, what is the maximum allowable electrical power per unit length?

b) How much more power would be allowed by the addition of four rectangular fins at the surface of the sheath provide? Each fin has an efficiency of 0.8 and a perimeter (surface area per unit length) of 3.2 cm. Assume that the base temperature stays approximately the same.

Question # 3

Consider a cylindrical enclosure with a diameter of 4 m and height of 2 m. The top surface of the cylinder is maintained at uniform temperature of 900 K, the bottom surface is maintained at uniform temperature of 600 K and the side surface is maintained at temperature of 400 K. Determine the net rate of radiation heat transfer at each surface during steady operation and explain how these surfaces can be maintained at specified temperatures for the following conditions: (a) all surfaces act like a blackbody surface, (b) the top surface has emissivity of 0.7, the bottom surface has emissivity of 0.3 and the side surface closely approximates a blackbody.

Question # 4

Calculate the equilibrium temperature of a single spherical particle in a large air duct if the air temperature is 1367K, the duct wall temperature is 533K, the emissivity of the particle is 0.5, and the average convection heat transfer coefficient between particle and air is 114W/m^{2}K. How long does it take for the particle to reach to 90% of its equilibrium temperature from an initial temperature of 300K? The particle is made of Iron and is 2mm in diameter. The temperature inside the particle may be assumed to be uniform. For Iron, density, specific heat and conductivity coefficients are 7272 kg/m^3, 420 J/kg.K, and 52 W/m.K, respectively.