Thermal Sciences Qualifying Exam – Fall 2004

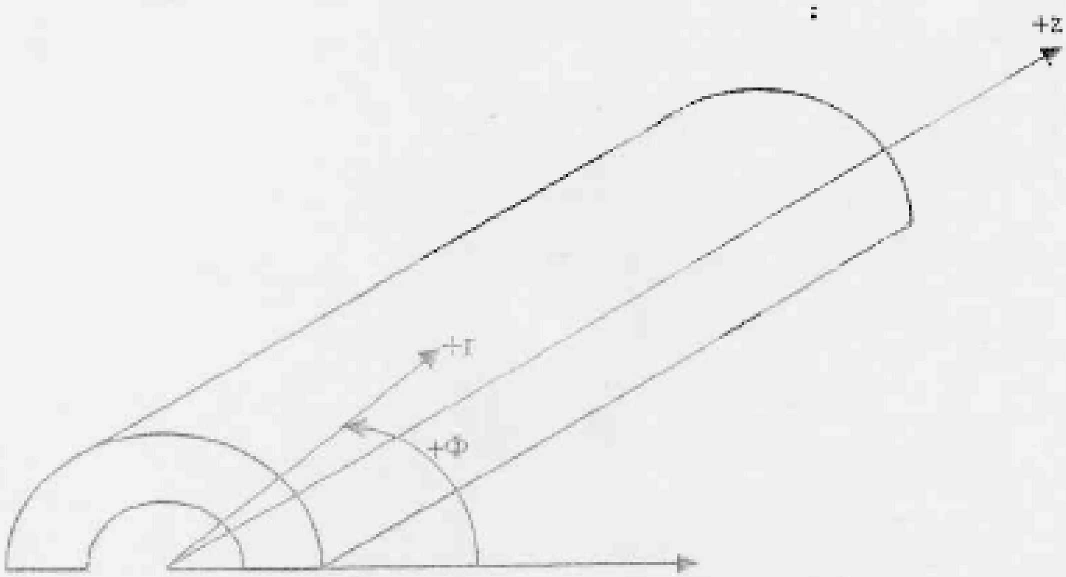
Closed book and closed notes. Formula sheet provided. Select and solve one of the (**A**) problems, one of the (**B**) problems, and one of the (**C**) problems for a total of three problems. Select and solve any one of the remaining three problems. Each problem is worth 25 points, for a total of 100 points. Do <u>not</u> solve more than four problems.

Each solution must contain a clear statement of assumptions

(A1) A piece of thick pipe is sliced in half along the length of the pipe, producing the solid semi-cylinder shown below, with two flat bottom surfaces. The inner radius is **a**, the outer radius is **b**, and the length is **L**. Significant constant heat flux $\mathbf{q_o''}$ is added along one of the flat bottom surfaces defined by $\Phi = 0$. The added heat is dissipated by spray cooling water along the two curved surfaces ($r = \mathbf{a}$ and $r = \mathbf{b}$) and along the other flat bottom surface at $\Phi = \pi$. For this spray cooling application, the surface temperature is maintained at the saturation temperature of the coolant and heat is dissipated via phase change (i.e. coolant vaporization). The ends of the semi-cylinder ($z=0$ and $z=L$) are insulated.

(i) Using the given coordinate system, calculate the steady-state temperature distribution.

(ii) Calculate the total rate (W) that heat is removed from the flat bottom surface at $\Phi = \pi$.



(A2) A sheet of ice (1 m by 1 m by 4 cm thick) falls into a large swimming pool in the winter and floats on the surface. The pool is heated to a temperature of 22°C and a filtration system maintains good mixing. The sheet of ice is at a uniform temperature of 270 K when it enters the pool. The ambient air temperature is constant at about 273 K. It is observed that the ice disappears (i.e. completely melts) in 6.5 hours. The properties of ice are:

Thermal conductivity = 3 W/m-K
Density = 920 kg/m^3
Specific heat = 2040 J/kg-K
Heat of fusion = 163 kJ/kg

(i) Estimate the average convection heat transfer coefficient?

(ii) Sketch the temperature profile in the sheet of ice after two hours.

(iii) Calculate and discuss the relevant dimensionless parameter for consideration of the conduction heat transfer analysis? Discuss the appropriate conduction problem.

(iv) Discuss heat transfer at the boundaries, including relevant energy balance equations.

(v) Estimate the rate of melting (mm/s) using your energy balance.

(B1) A closed-cycle engine operates on the Brayton cycle as shown below:

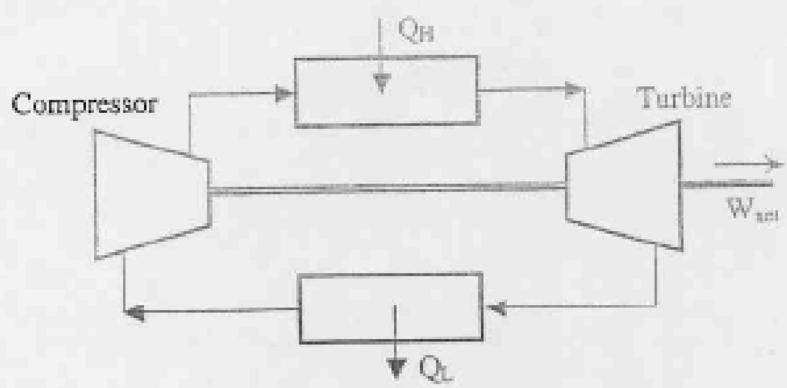
(i) On an enthalpy-entropy diagram, show both the ideal and real processes.

(ii) Identify the sources of irreversibility and discuss them in terms of the state points which you specified in your diagram.

(iii) Regeneration is heating of the compressor discharge gas by the turbine exhaust gas. Under what circumstances can regeneration be used? Sketch a new h-s diagram including regeneration in that case.

(iv) Why does regeneration usually improve the thermal efficiency? Does it also improve the specific work?

(v) With regeneration, what sources of irreversibility change? Describe them and their positive or negative effects on the cycle efficiency.



(B2) Three particles are contained in an isolated chamber, and they possess four units (quanta) of energy.

(i) Explain the relationship between the number of microstates available to the system and the system entropy.

(ii) Which would result in greater entropy, distinguishable particles or indistinguishable particles? Why? Give a physical example of each case.

(iii) How does the system entropy depend upon the number of available internal energy storage modes (translation, vibration, etc.).

(iv) As the temperature of a real gas is increased, the constant-pressure specific heat is observed to increase. Use the Gibbs equation to explain why in terms of increasing entropy.

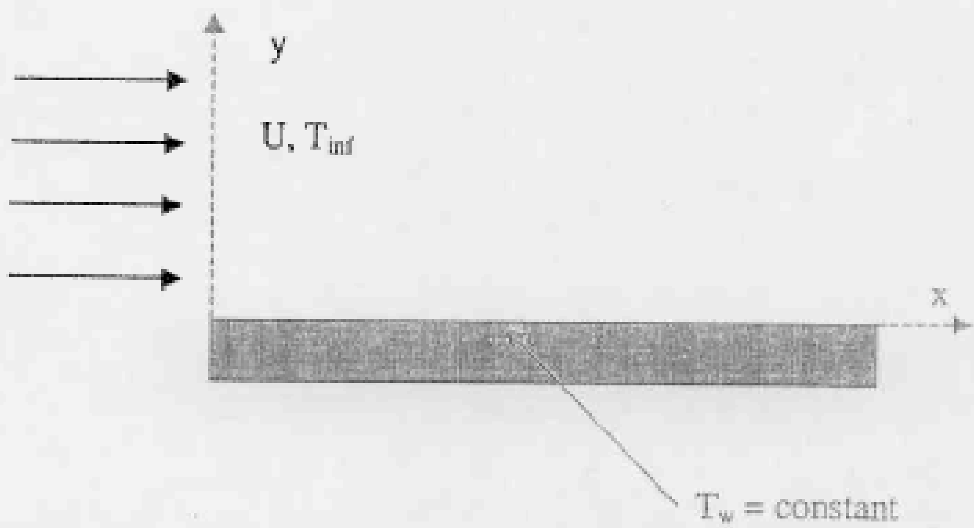
(C1) Consider steady laminar flow over a flat plate as illustrated below.

(i) Write the appropriate form of the energy equation for the illustrated problem. Assume a Newtonian fluid with constant properties and negligible viscous dissipation.

(ii) Write the boundary conditions required to solve this problem.

(iii) Transform this equation into similarity form.

(iv) Write the boundary conditions in similarity form.



(C2) Given a vertical electrically heated plate in a large room full of air moving at very low velocity parallel to the plate, as illustrated below. Assume the plate is well insulated on the left, so that thermal energy is lost only from the right side of the plate. Assume that the flow over the plate is laminar and steady-state.

(i) Sketch the velocity profile, $v_x(y)$ at 3 downstream locations, labeling boundary conditions at each end of the profile.

(ii) Sketch the temperature profile, T (y) at 3 downstream locations, labeling boundary conditions at each end of the profile.

(iii) Write the appropriately simplified forms of the conservation of mass, momentum and energy equations. Start with equations from the attached formula sheet.

(iv) Write the boundary conditions required to solve the above set of equations.

(v) What are the unknowns? Demonstrate that you have an equal number of unknowns and equations.

(vi) If this system of equations were solved for the unknowns, how would you find the convection coefficient? Write a specific equation showing how the convection coefficient would be found from known quantities.