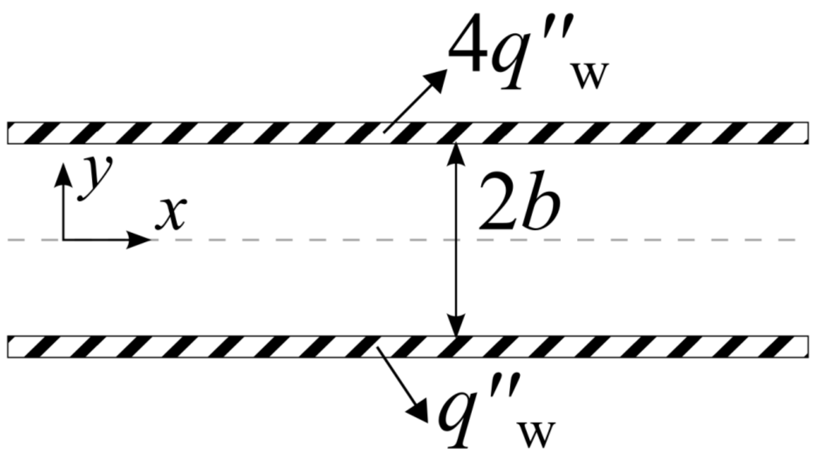
Ph.D. Qualifying Examination, Spring 2014

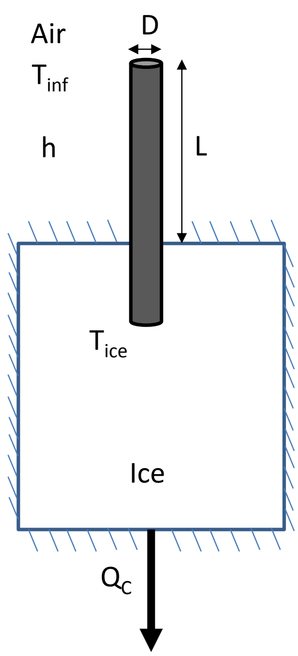
Heat Transfer

1. Consider the laminar, thermally fully developed, flow of a liquid metal between two parallel plates shown below separated by a distance 2*b*, when each plate has a uniform wall heat flux. Let the upper wall flux be $4q''_w$, and the lower wall flux be q''_w, both outwards.



1. Derive an expression for the temperature profile of the fluid between the two plates.
2. Sketch this temperature profile between the plates.
3. Show that temperature difference between the two plates can be expressed as $a \bullet q''_w \bullet b/k$, where a is an integer constant and *k* is the thermal conductivity of the liquid.

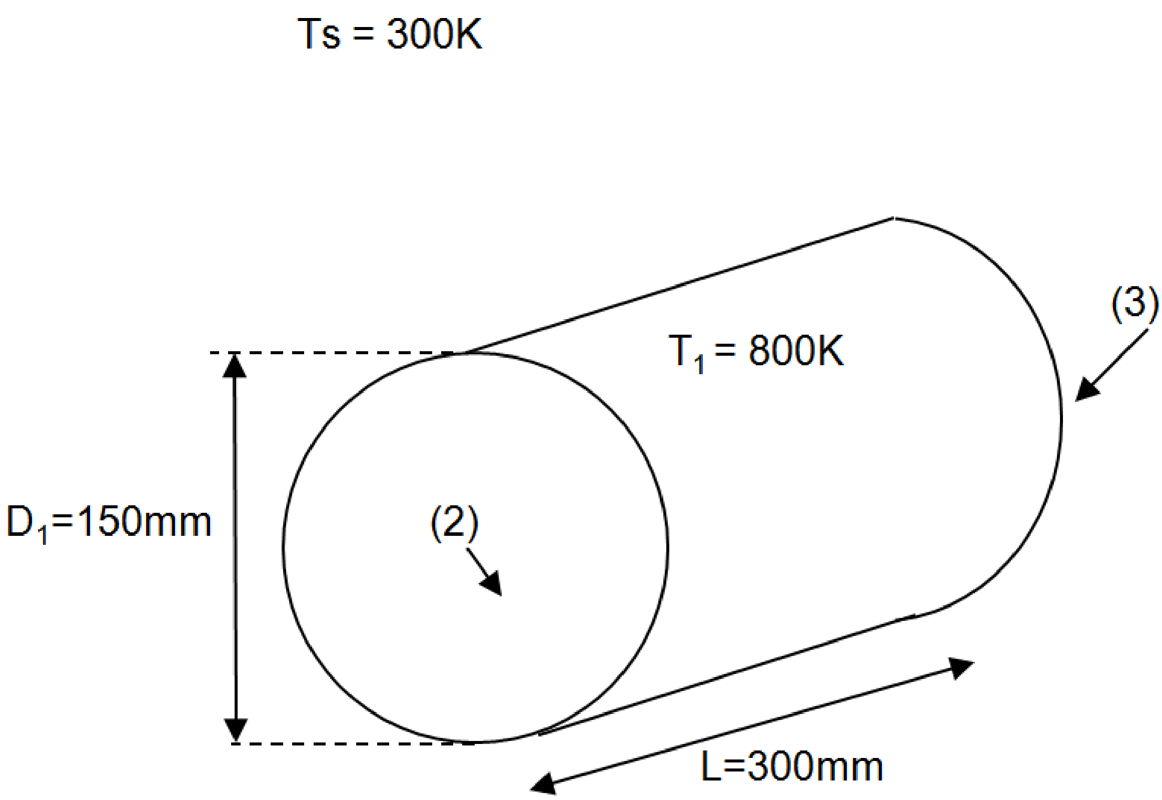
2. A block of ice at its melting temperature (T_{ice}) is being constantly cooled at a rate Q_c. The surrounding air is warmer and at temperature T_{inf}. If one places a cylinder of high thermal conductivity on the surface it enhances the heat transfer from the air to the ice and the ice will melt locally around the cylinder causing it to sink into the ice. The cylinder will sink until only length L is exposed above the ice surface.



Clearly state the condition required for the cylinder to stop sinking. Then develop an expression for the steady state cooling rate of the ice Q_C as a function of the exposed cylinder length L.

Employ the following assumptions to simplify your analysis: **(1)** Assume the temperature varies much more along the length of the cylinder than across the cross-section. **(2)** Assume the only heat transfer into the ice is through the cylinder and the only heat transfer out of the ice is through the cooling rate Q_c. Assume all other surfaces are perfectly insulated. **(3)** Assume the net heat transfer (convection + radiation) from the air to the cylinder can be represented by a single average (constant) heat transfer coefficient h. **(4)** Neglect any temperature variations below the top surface of the ice, assume it is all at a constant temperature T_{ice}. Assume the temperature of submerged part of the cylinder is T_{ice}, and assume the temperature of the ice and any melted ice surrounding the submerged part of the cylinder is T_{ice}. **(5)** Assume all properties and dimensions are known.

3. A thin walled cylindrical tube heater is placed in a large vacuum chamber with walls cooled to 300K. The tube will be used to heat small objects to anneal them at a fixed temperature. To do this, surface temperature of the heater will be held at 800K during the annealing process. The emissivity of the heater surface is 0.3 and the emissivity of the walls of the vacuum chamber is 0.9. All surfaces are diffuse and gray.



(a) Calculate the view factors between the tube and the surroundings (consider the inside and outside surfaces in your evaluation).

(b) Determine the power input under steady-state conditions.

To reduce the power required by the heater, it is suggested that either the inside walls of the vacuum chamber be coated to reduce the emissivity to 0.1 to reflect back more thermal energy to the heater, or an insulation sleeve of thickness 25mm with thermal conductivity 0.1W/mK, and diffuse, gray emissivity 0.8, be added to the outside surface of the heater. The heater will be operated at 800K. Which do you think is more reasonable and why? Calculate the reduction in the power required for the method that you think will have the greater effect. State any additional assumptions you make.

View factor between two concentric parallel disks.