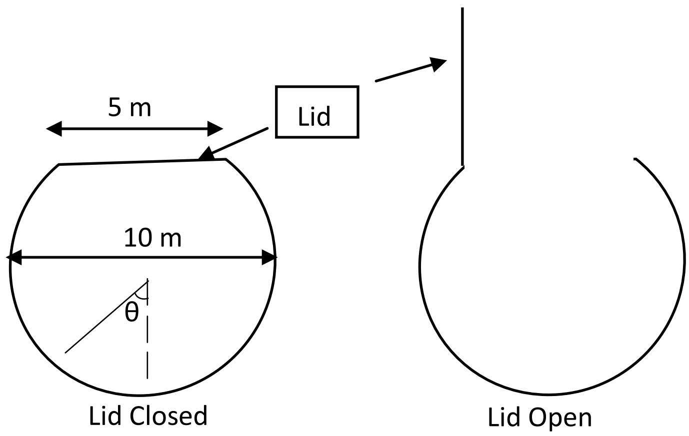
DEPARTMENT OF MECHANICAL ENGINEERING
HEAT TRANSFER QUALIFIER EXAM – January 2019

Each question carries 10 marks. Passing Marks: 32

Note:

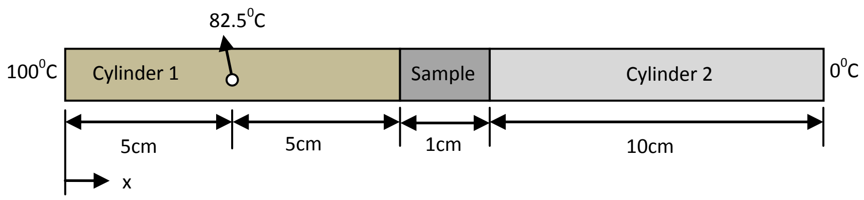
1. **Closed text book, only handwritten notes permitted, no photocopies.**
2. **This question papers consists of 5 printed pages.**
3. **Please begin each question on a new page and keep all subparts of a question together.**
4. **Strike out any unwanted work**

Problem 1: Consider an infinitely long pipe having a lid on its top as shown in the figure. Temperature of pipe's cylindrical surface is maintained at 100°C and the lid is maintained at 25 °C. Emissivity of pipe lid is unity while for the inside cylindrical surface, emissivity is given as $(1 + |sin\theta|)/2$ where θ is measured as shown in the figure. Determine (a) The average emissivity of the cylindrical surface, (b) heat transfer from pipe cylindrical surface to pipe lid if the lid is closed and (c) heat transfer from pipe cylindrical surface to pipe lid if the lid is open as shown in figure. Ambient temperature is 25^{o}C.



Problem 2: Consider a hollow cylindrical heat transfer medium having inside and outside radii of r_i and r_0 with the corresponding surface temperatures T_1 and T_0. If the thermal conductivity variation may be described as a linear function of temperature according to $k = k(1+\beta T)$, calculate the steady state heat transfer rate in the radial direction using the above relation for the thermal conductivity and compare the result with that using a k value calculated at the arithmetic mean temperature.

Problem 3: A methodology to measure the thermal conductivity of a material is to make a small sample disc and squeeze it in between two cylindrical rods and measure the temperature at a few locations on the cylinder. The left and right ends of the assembly are maintained at 100°C and 0°C respectively. The cylinder curved surfaces are perfectly insulated. The length of each cylinder is 10 cm and the length of the specimen is 1 cm. The thermal conductivity of the cylinder 1 varies as $1/(1+x)$ W/m-K where x is in cm and whereas that for cylinder 2 conductivity is constant and equal to 0.1 W/m-K. Assume contact resistance between the materials is negligible. At steady state if the temperature at a location at the center of the cylinder 1 is 82.5°C, determine the conductivity of the specimen, assuming it to be constant.



Problem 4: A plate, having a heater inside it, generates volumetric heat q''' inside it. This plate is centrally placed inside the pipe and is cooled by a coolant on either side as shown in the figure below. The width of the plate is 2L and its thickness is t. The heat transfer coefficient between the coolant and the pipe is h and the coolant bulk temperature is T_∞.The temperature at the interface between the pipe and the plate is T_w.Using the following data, answer the following questions:

$h = 62\frac{W}{m^2 °C}$,

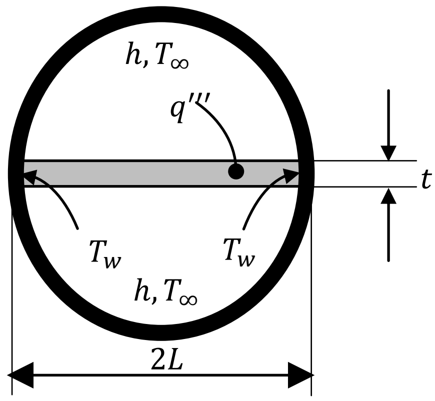
$2L = 50\ mm, t = 0.5\ mm$,

$T_w = 110$ °C,

$T_\infty = 94\ °C$,

$q''' = 2.5 \times 10^7\ W/m^3$,

$k\ (plate) = 18\ W/m$°C



a. Derive the equation depicting steady state temperature distribution inside the plate.
b. Maximum temperature and its location inside the plate.
c. Sketch the qualitative temperature profile inside the plate.

Problem 5: A flat channel with gap between two plates is 5 mm and a heated length is 1.30 m is subjected to a constant wall heat flux. A Newtonian liquid flow through the duct with a mass flow rate of 0.25 kg/s per meter of channel width. The average fluid temperature at inlet and exit of the heated segment are 20°C and 80°C respectively.

a. Assume that at the entrance to the heated section the fluid velocity and temperature profiles are both uniform. Determine the heat transfer coefficient and wall surface temperature at the exit of the heated section.
b. Now assume that at the entrance to the heated section the flow is hydrodynamically fully developed but has uniform temperature. Calculate the wall surface temperature at 8 mm downstream from the entrance to the heated section.

The Nusselt number based on hydraulic diameter for hydrodynamic fully developed and thermally developing flow in channel with constant wall heat flux condition is

$$Nu = \left\{1.490(x^*)^{-\frac{1}{3}}\right\}, for\ x^* \leq 0.0002$$

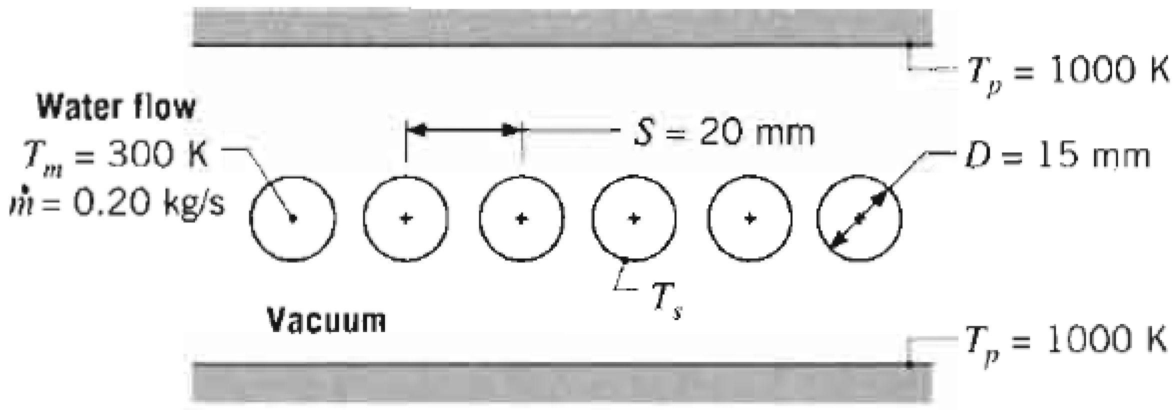
$$= \left\{1.490(x^*)^{-\frac{1}{3}} - 0.4\right\}, for\ 0.0002 \leq x^* \leq 0.001$$

$$= 8.235 + 8.68(1000x^*)^{-0.506}\exp(-164x^*), for\ x^* \geq 0.00$$

Where $x^* = x/(D_h Re Pr)$

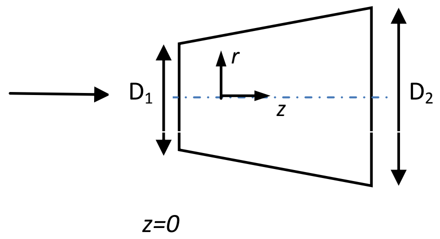
The thermo-physical properties of liquid is ρ = 753 kg/m^3, c_p = 2090 kJ/kg-K, k = 0.137 W/m-K, and $\mu = 6.61\times10^{-4}$ N-S/m^2

Problem 6: Water flowing through a large (inifinte) number of circular thin-walled tubes is heated by means of hot parallel plates (infinite) placed above and below the tube array. The space between the plates is evacuated and all surfaces may be assumed black. Neglecting axial variations, determine the tube surface temperature, T_s, if water flows through each tube with a mass flow rate of 0.2 kg/s and mean temperature of $T_m = 300K$.



Properties of water: $\mu = 8.55\times10^{-6} Pa.s, k = 0.613\frac{W}{m-K}, Pr = 5.83$

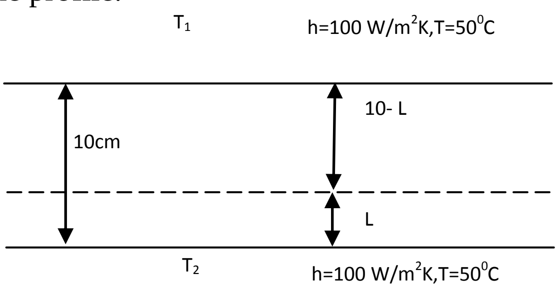
Problem 7: Consider the case of flow (Mass flow rate = $\dot{m}$) through a **diverging** tube of length L of circular cross section. The tube wall is subjected to constant wall heat flux, q_w'' . Assume inlet velocity profile to be uniform. Use the conventional notation for properties for consistency.



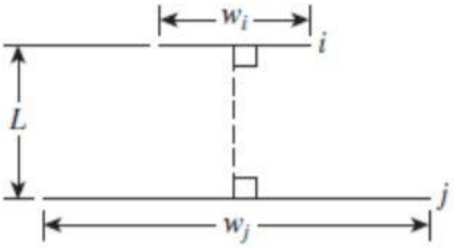
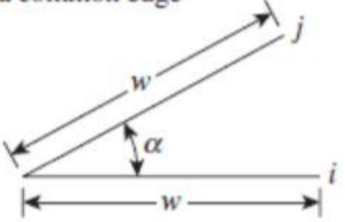
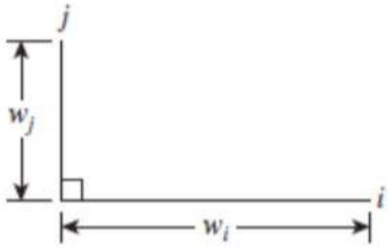
a. Starting with a differential control volume, listing all assumptions, derive an expression for the variation of the bulk mean temperature of the fluid, $T_m(z)$. Sketch the axial variation of the bulk fluid temperature For the differential control volume, the **local** diameter at the section can be taken as constant, $D(z)$
b. Neatly sketch the axial variation of the following quantities along the flow direction, Show all work
   i. velocity
   ii. Reynolds number for the flow

c. Sketch the velocity profiles at two different axial locations along the flow direction. The sketch should be qualitatively very clear. Very briefly, explain the similarities or differences in the velocity profiles. Will the flow be hydrodynamically fully developed? Give reasons for your answer.

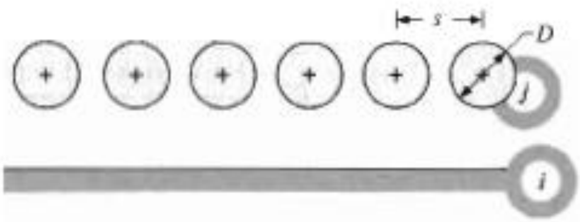
Problem 8: Consider the 1D heat conduction with heat generation in a slab with temperatures T_1 and T_2 at the ends as shown. The two sides of the slab are subjected to a flow with a constant heat transfer coefficient 100 W/m^{2}K and bulk temperature 50^{o}C. The temperature difference between the two faces of the slab is 20^{o}C (i.e. T_1-T_2 = 20^{o}C). The length of the slab is 10cm and for a length ***L*** the heat generation is uniform and equal to q_1''' while for the rest of the length ***10-L*** the heat generation is uniform and equal to q_2'''. q_1''' and q_2''' are not necessarily equal but it is known that entire heat generated in length L is removed from the face with temperature T_2 while the entire heat generated in **10-L** is removed from the face with temperature T_1. However, the total heat generation is equal to 10000W/m^2. Determine the temperature profile in the slab if the thermal conductivity is constant and there are no discontinuities in the profile.



View factors

Geometry	Relation
Parallel plates with midlines connected by perpendicular line 	$W_i = w_i/L$ and $W_j = w_j/L$ $F_{i\to j} = \frac{[(W_i + W_j)^2 + 4]^{1/2} - (W_j - W_i)^2 + 4]^{1/2}}{2W_i}$
Inclined plates of equal width and with a common edge 	$F_{i\to j} = 1 - \sin\frac{1}{2}\alpha$
Perpendicular plates with a common edge 	$F_{i\to j} = \frac{1}{2}\left\{1 + \frac{w_j}{w_i} - \left[1 + \left(\frac{w_j}{w_i}\right)^2\right]^{1/2}\right\}$

Infinite Plane and Row of Cylinders



$$F_{ij} = 1 - \left[1 - \left(\frac{D}{s}\right)^2\right]^{1/2} + \left(\frac{D}{s}\right)\tan^{-1}\left[\left(\frac{s^2 - D^2}{D^2}\right)^{1/2}\right]$$