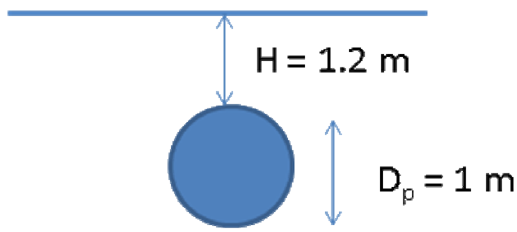
Problem #1

The TransCanada Keystone pipeline project proposes to build a 1,700 mile, $7B pipeline to pump oil from Alberta, Canada to the United States Gulf Coast. The proposed pipeline route passes through agricultural states such as Nebraska, where shallow fresh water aquifers will be in its close proximity. It is crucial that the pipeline be structurally safe during its intended life. Assume the pipeline is thin and 1 m in diameter, buried 1.2 m below the ground as seen below.



1. At the end of November, the average ground temperature at a location is 4.4 ^oC. Assume a prolonged cold spell suddenly drops the surface temperature to -7 ^oC for 120 days. If the oil temperature were to drop below – 3 ^oC, its viscosity and the resulting pumping costs sharply increase, and there may also be potential damage to the pipeline. Develop and solve the equation that can be used to determine the temperature at a depth of 1.2 m after 120 days. Use this solution to determine how far below the surface will the change in surface temperature will be felt after 120 days. For the soil, assume the thermal conductivity, k = 1.5 W/mK, density ρ = 1,300 kg/m^3, and specific heat C_p = 1,200 J/kgK.
2. One option to reduce the pumping power is to flow heated oil. Assuming a ground surface temperature of -7^{o}C and a pipe wall temperature of 4 ^oC, find the steady state rate of heat loss per unit pipe length for a known shape factor. It is desirable to reduce the heat loss by wrapping an insulation of thermal conductivity k_{ins} around the pipe. Find an expression for the resulting heat loss rate per unit pipe length.

Problem #2

A Newtonian fluid with constant properties (ρ, μ, k, c_p) flows laminarly in a long circular tube of radius R. For z<o, The fluid temperature is uniform and equal to T_o. For z>0 there is a constant heat flux q" (W/cm^2) through the tube wall, so that the fluid is gradually heated as it continues to flow through the tube. The velocity distribution in the tube is given by:

$$u_r = 0, u_\theta = 0, and\, u_z = u_{z,max}\,[1 - (r/R)^2]$$

Where r is the radial direction, θ is the azimuthal direction and z is the axial flow direction.

a. Ignoring heat conduction in the flow direction, show by means of a differential energy balance that the governing differential equation for the steady state fluid temperature distribution is:

$$\rho\, c_p\, u_{z,max}\,[1 - (r/R)^2]\,\frac{\partial T}{\partial z} = \frac{k}{r}\,\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)$$

b. List the boundary conditions for the differential equation in "a".

c. Rewrite parts "a" and "b" in terms of the non-dimensional quantities:

$$\Theta \equiv (T - To)/(q"R/k)\,,\ \ \xi \equiv r/R, and\ \ \eta \equiv zk/\rho c_p R^2 u_{z,max}$$

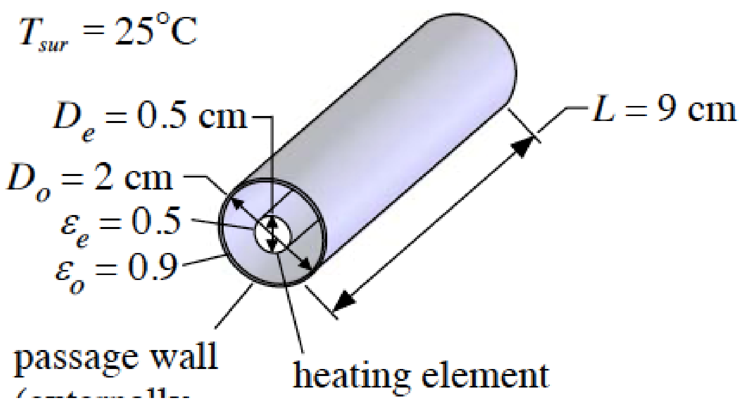
d. The fully developed non-dimensional temperature distribution $(\eta \gg 0)$ is given by :

$$\Theta = 4\eta + \xi^2 - \frac{1}{4}\,\xi^4 - \frac{7}{24}$$

Show that the fully- developed Nusselt number equals (48/11)

Problem #3

A cylindrical heating element is used to heat a fluid inside of a tube. In an accident, the tube breaks and the fluid drains out, but the heating element stays on (See Figure). The length and diameter of the element are 9 cm and 0.5 cm, respectively. The emissivity of the element is ε=0.5. The concentric wall around the element has a diameter of 2 cm and an emissivity of 0.9. The outer surface of the wall is insulated and the surroundings are held at 25°C. Both ends of the tube are open to the surroundings.



A) Assuming radiation dominance and an adiabatic external wall, setup a heat transfer problem for finding the heating element and the wall temperatures and identify relevant view factors required for solving the problem?

B) Assuming radiation dominance but non-adiabatic external wall kept at 80°C, setup a heat transfer problem for finding the heating element temperature and the wall heat flux?

C) Using expressions for the standard view factors given to you in the problem statement along with the rules of the view factor algebra, numerically evaluate the relevant view factors for questions Q1 and Q2 and compute the temperatures and heat flux at the element and the wall as asked for in Q1 and Q2? (The view factor of the concentric wall to itself is 0.6)

D) Comment on the relative magnitude of the element temperature in questions Q1 and Q2 even if you didn't manage to find their numerical values. Physically justify your conclusions.