Consider a circular tube of internal diameter *D* (m) and length *L* (m). The tube wall is thin, but has a finite thickness *t* (m).

The flow in the tube is fully turbulent with a mass flow rate of $\dot{m}$ kg/s. The mean temperature of the fluid entering the tube section is T_{in} (K). The outer surface of the tube is subjected to a net inward constant heat flux of q" (W/m^2). The tube material has a finite thermal conductivity denoted by k_s (W/m/K). The density and specific heat of the solid and fluid are denoted by ρ_s, C_{ps} and ρ_f, C_{pf}, respectively. The fluid viscosity is denoted by μ_f (N/m/s).

Assume that the internal Nusselt number is constant in the section under consideration. Also assume that for all practical purposes heat flow is only in the radial direction.

1. (20 points)Identify the relevant expressions for heat energy transfer stating your assumptions. Write expressions for the mean fluid temperature $T_f(x)$, the inner wall temperature $T_{wi}(x)$, and the outer wall temperature $T_{wo}(x)$.
2. (5 points)Using (1.), plot the expected variation of T_f(x), T_{wi}(x) and T_{wo}(x) in relation to each other.

Assume the following properties and conditions.

Fluid:

ρ_f = 6.62 kg/m^3; C_{pf} = 1097 J/kg/K; k_f = 5.68×10^{-2} W/m/K; μ_f=3.62×10^{-5} kg/m/s;

Solid:

ρ_s = 560 kg/m^3; C_{ps} = 640 J/kg/K; k_s = 0.4 W/m/K ; T_{in} = 800 K.

Flow Conditions:

D = 0.01 m; *L* = 0.1 m; *t* = 0.0002 m; U_{in} = 55 m/s; *q"* = 500,000 W/m^2.

3. (15 points)If the Nusselt number in a smooth turbulent tube is given by $Nu_D = 0.023Re_DPr^{0.4}$, where Pr is the Prandtl number and Re_D is the Reynolds number, calculate the maximum metal temperature in the tube. What is the maximum mean fluid temperature?
4. (10 points) If the maximum tube temperature cannot exceed 1250 K, calculate the heat transfer coefficient needed to achieve that goal. What is the maximum mean fluid temperature in this case?

(50 points total)