22.312 ENGINEERING OF NUCLEAR REACTORS

Due November 7, 2008 by 12:00 pm

TAKE HOME QUIZ 2

Problem 1 (75%) – Cooling system for an accelerator target

An electron accelerator is used to generate X-rays for industrial radiography. The electron beam impinges on a tungsten target of thickness δ = 2 mm, width w = 10 mm and length L = 50 mm. The volumetric energy deposition in the target can be described by the following equation:

$$q'''(x,z) = q'''_{\max} e^{-\alpha x} \cos\left(\frac{\pi z}{L}\right)$$

Where α = 2 mm^{-1} is the attenuation coefficient for electrons in tungsten, and x and z are the Cartesian coordinates shown in Figure 1. The target is cooled by 5.3×10^{-3} kg/s of molten sodium-potassium eutectic alloy (Na-K) flowing along the side not exposed to the beam. The Na-K channel cross section is rectangular with one side being w = 10 mm and the other s = 2 mm, and an upstream length of 300 mm. The Na-K coolant enters the channel at 50°C.

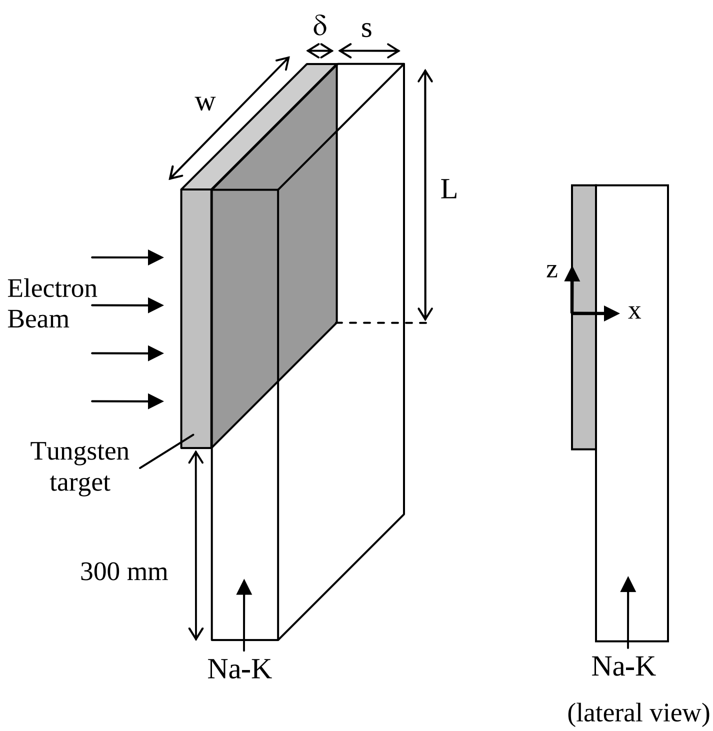


Figure 1. Geometry and dimensions of the accelerator target and the coolant channel.
(drawing not to scale)

i) Determine q'''_{max}, such that the total beam power is 200 W. (5%)

ii) Calculate the temperature distribution in the target, $T(x,z)$. (45%)

In answering question 'ii' please make the following assumptions:

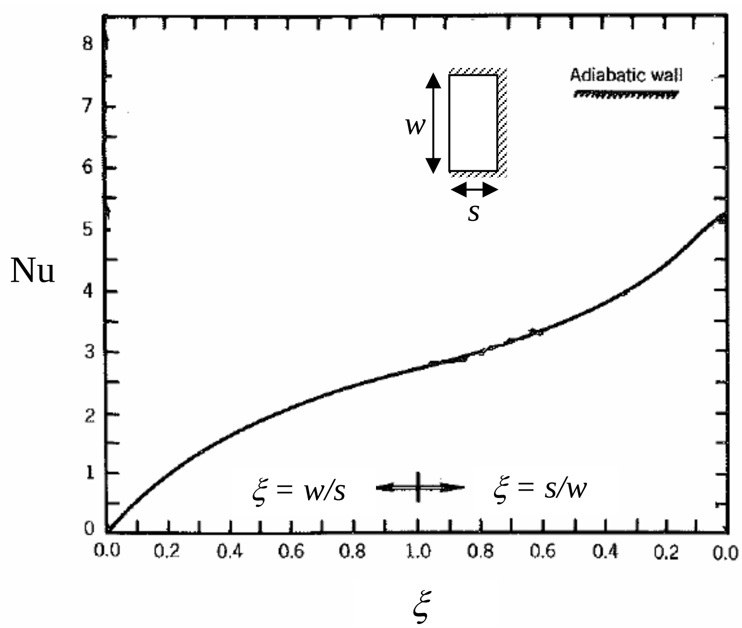
- Heat conduction in the z and y directions is negligible
- Radiative heat transfer is negligible
- Use the chart below to estimate the heat transfer coefficient; neglect entrance effects
- Use the following material properties (assumed constant):

Tungsten:	k = 174 W/m°C, ρ = 19300 kg/m^3, c = 132 J/kg°C
Na-K:	k = 24 W/m°C, μ = 4.9×10^{-4} Pa-s, ρ = 850 kg/m^3, c_p = 946 J/kg°C

iii) Find the location and value of the maximum temperature in the target. (10%)

iv) Sketch qualitatively the axial distributions of the coolant bulk temperature ($T_b(z)$), and the target temperature at $x = 0$ and $x = \delta$. (10%)

v) An assumption was made in 'ii' that entrance effects could be neglected in calculating the heat transfer coefficient for Na-K. Is this assumption accurate? (5%)



Nusselt number for laminar fully-developed flow in a rectangular channel with 3 adiabatic walls. (adapted from the "Handbook of Single-Phase Convective Heat Transfer" by S. Kakaç et al., 1987)

Problem 2 (25%) – Natural circulation flow

Water is flowing in a loop with a single riser pipe and two downcomer pipes (see Figure 2). Heat is added at point *A* and rejected at point *B*, so that the temperature difference between the riser and downcomer sections is 30°C. The diameter of the two downcomer pipes is D_1=10 cm and D_2=5 cm, respectively.

i) Calculate the mass flow rate in the loop. (25%)

Assumptions:

- Neglect all acceleration, friction and form pressure changes in the loop, except for the friction pressure changes in the downcomer pipes.
- To calculate the friction factor in the pipes, ignore entrance effects, assume the flow is turbulent and use the MacAdams correlation.
- Use the Boussinesq's approximation to estimate the water density dependence on temperature. ($\beta = 3\times10^{-4}$ K^{-1}, ρ_c = 1000 kg/m^3)

Other properties of water at the conditions of interest

$\mu = 8\times10^{-4}$ Pa·s, k = 0.61 W/m-K, c_p = 4.18 kJ/kg-K