Heat flow and temperature distribution in cylindrical fuel elements

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Table of Contents

1 Quiz

1.1 *Questions*

1. A cylindrical fuel rod of 10 mm radius made of a material with thermal conductivity 1 W/mK generates heat at the rate of 1200 kW/m^3. The fuel rod is surrounded by a cladding layer of thickness 5 mm. The thermal conductivity of cladding layer is 2 W/mK. If the cladding is cooled by coolant at 35 °C, determine the maximum temperature in the fuel, temperature at the outer surface of the fuel and temperature at the outer surface of the cladding. Heat transfer coefficient may be taken as 1050 W/m^{2}K. The length of fuel rod is 1 m.

2. A cylindrical fuel rod of 12 mm radius made of a material with thermal conductivity 1.2 W/mK generates heat at the rate of 6000(r/R$_f$) kW/m^3. The fuel rod is surrounded by a cladding layer of thickness 6 mm. The thermal conductivity of cladding layer is 5 W/mK. If the cladding is cooled by coolant at 30 °C, determine the maximum temperature in the fuel, temperature at the outer surface of the fuel and temperature at the outer surface of the cladding. Heat transfer coefficient may be taken as 950 W/m^{2}K. The length of fuel rod is 1 m.

1.2 *Answers*

1. Data:

R_f = 10x10^{-3} m; R_c = R_f+clad thickness = 15x10^{-3} m
k_f = 1 W/mK; k_c = 2 W/mK
h = 1050 W/m^{2}K
T_∞ = 35 °C
P" = 1.2x10^6 W/m^3

Step – I: Determine Tc using Eq. (4)

$$T_c = T_\infty + \frac{P''R_f^2}{hR_c}$$

Tc = 35 + 1.2e6*(10x10^{-3})^2/(1050*15x10^{-3}) = 42.6 °C

Step – II: Determine Q

Q = P"πR$_f^2$L = 1.2x10^6*3.14*(10x10^{-3})^2*1 = 376.8 W

Step – III: Determine T$_f$ using Eq. (8)

$$T_f = T_c + \frac{Q ln\left(\frac{R_c}{R_f}\right)}{2\pi L k_c}$$

$$T_f = 42.6 + \frac{376.8 ln(15/10)}{2\pi * 2} = 54.76$$

T_f = 54.76 °C

Step – IV: Determine maximum fuel temperature (T_{max}) from Eq. (11)

$$T_{max} = T_c + \frac{Q ln(R_c/R_f)}{2\pi L k_c} + \frac{R_f^2 P''}{4k_f}$$

T_{max} = 42.6+376.8*ln(1.5)/(2*3.14*1*2)+10e-3*10e-3*1.2e6/(4*1) = 84.8 °C

2. Step – I: Determine average volumetric rate of heat generation using Eq. (15)

P_{avg}" = 2P_{max}"/3 = 4000 kW/m^3

Using Eq. (16), T_c can be calculated as follows:

$$T_c = T_\infty + \frac{P''_{avg} R_f^2}{h R_c}$$

T_c = 30+4e6*0.012*0.012/(950*0.018)

T_c = 63.7 °C

Rate of heat transfer (Q) can be found out using Eq. (17)

Q = P_{avg}"πR_f^2L = 4e6*3.14*12e-3*12e-3*1 = 1808.6 W

Using Eq. (8), T_f can be calculated as shown below:

$$T_f = T_c + \frac{Q ln\left(\frac{R_c}{R_f}\right)}{2\pi L k_c}$$

T_f = 63.7 +1808.6*ln(18/12)/(2*3.14*1*5)

T_f = 87 °C

Using Eq. (18), the maximum temperature at the centre of the fuel rod can be calculated as:

$$T_{max} = T_c + \frac{Q\ln(R_c/R_f)}{2\pi L k_c} + \frac{R_f^2 P_{avg}^{''}}{4k_f} ;$$

T$_{max}$ = 87+12e-3*12e-3*4e6/(4*1.2)

T$_{max}$ = 207 °C