Heat flow and temperature distribution in cylindrical fuel elements

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1 Quiz

1.1 *Questions*

1. A cylindrical fuel rod of diameter 2 cm generates heat at the rate of 100 MW/m^3. If water at a temperature of 250 °C extracts the heat from the fuel rod, determine the maximum temperature of the fuel rod and the surface temperature of the fuel rod. The heat transfer coefficient may be taken as 1200 W/m^2K. The thermal conductivity of fuel is 3 W/mK.

2. A cylindrical fuel rod of diameter 2 cm generates heat at the rate of 60(r/R) MW/m^3. If water at a temperature of 200 °C extracts the heat from the fuel rod, determine the maximum temperature of the fuel rod and the surface temperature of the fuel rod. The heat transfer coefficient may be taken as 1100 W/m^2K. The thermal conductivity of fuel is 3 W/mK. The average power per unit volume is 40 MW/m^3.

3. A rod of 2 cm diameter generates heat at the rate of 10 MW/m^3. The outer surface of the rod is at 400 °C. If the thermal conductivity of rod varies with temperature as k=0.25+0.005*T where 'k' and 'T' are in W/mK and °C respectively, determine the maximum temperature in the rod.

1.2 *Answers*

1. Data: T_c = 250°C; P_{avg}''=10^8 W/m^3; D = 0.02 m; h = 1200 W/m^2K; k = 3 W/mK

Before estimating the maximum temperature, the temperature on the outer surface of the rod (T_S) can be calculated using Eq. (17)

$$T_S = T_c + P''_{avg}\frac{D}{4h}$$

Therefore, T_s =250+10^8*0.02/(4*1200) = 667 °C

Using Eq. (18) with T_S=667 to determine the maximum temperature as

$$T = T_c + P''_{avg}\frac{D}{4h} + \frac{R^2 P''_{avg}}{4k}$$

T_{max} =250+10^8*0.02/(4*1200)+0.01^2*10^8/(4*3)=1500 °C

2. In this case, power per unit volume varies with radial distance as per the following equation:

$P'' = P_{max}''(r/R)$ and $P_{avg}'' = 40\ MW/m^3 = 4e7\ W/m^3$

Equation (17) can be used to determine the temperature on the surface of fuel rod.

$$T_S = T_c + P''_{avg} \frac{D}{4h}$$

T_s = 200+4e7*0.02/(4*1100)= 381.8 °C

Maximum temperature of the fuel rod is determined by substituting r=0 in Eq. (28)

$$T = T_s + \frac{P''_{max} R^3}{9kR}\left(1 - \frac{r^3}{R^3}\right)$$

T=381.8+6e7*0.01^3/(9*3*0.01)= 604 °C

3. Data: T_s=400 °C; P"=1e7 W/m^3; R=0.01 m

k=0.25+0.005*T = 0.25(1+0.02*T)

Therefore, β=0.02;

Substituting above in Eq. (40), we get

$$T = \frac{-1 + \sqrt{1 + 2 * 0.02\left\{400 + 0.02 * \frac{400 * 400}{2} + \frac{1e7 * 0.01 * 0.01}{4 * 0.25}(1)\right\}}}{0.02}$$

The maximum temperature is 500 °C.