Problem 10.2

Assume:
- ***Fast reactor fuel pin characteristics as in Table 10.2***
- ***Gap closure***
- ***Only He fill gas***
- ***linear power, R , is symmetric***
- $\int \mathbf{kdT}$ ***from eq. 10.20***
- $\mathbf{h_{coolant}} = \dfrac{\mathbf{12\,Watts}}{\mathbf{cm^2\,{}^\circ C}}$
- $\mathbf{k_c} = \mathbf{0.22}\,\dfrac{\mathbf{Watts}}{\mathbf{cm\,{}^\circ C}}$

Wanted: ***T_o and T_s @ midplane (before core restructuring)***

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Schematic

(Diagram)

See Hard Copy of Class Notes

$$T_{Na}\ \text{(midplane)} = 470 + \frac{650 - 470}{2} \approx 560^\circ C$$

Na Film Temperature Drop
(at midplane)

q_{Na} = heat flux from clad surface to coolant

$$q_{Na} = \frac{P}{2\pi R_c} = h_{Na}(T_{co} - T_{Na})$$

or

$$T_{co} - T_{Na} = \frac{550\,\frac{\text{Watts}}{\text{cm}}}{2\pi \bullet (0.315\text{cm}) \bullet 12\,\frac{\text{Watts}}{\text{cm}^2 \circ \text{C}}}$$

or,

$$T_{co} = 560 + 23 = 583°\text{C}$$

Temperature Drop Through Clad

q_c = heat flux through cladding (ave)

$$q_c = \frac{P}{2\pi\left[R_c - \left(\frac{t_c}{2}\right)\right]} = \left(\frac{k_c}{t_c}\right) \bullet (T_{ci} - T_{co})$$

for stainless steel, $k_c = 0.22\,\frac{\text{Watts}}{\text{cm}\circ\text{C}}$

$$\frac{k_c}{t_c} = \frac{0.22}{0.04} = 5.5\,\frac{Watts}{cm^2 \circ C}$$

So, $T_{ci} - T_{co} = \dfrac{550}{2\pi(0.315 - 0.020) \bullet 5.5} = 54°C$

or, $T_{ci} = 583 + 54 = 637$ °C

<u>Temperature Across the Gap</u>

q_F = Surface heat flux from the fuel

$$= \frac{P}{2\pi R} = \left(\frac{k_g}{t_g}\right) \bullet (T_s - T_{ci})$$

from (10.63) $\displaystyle\int_{T_s}^{T_o} kdT = \frac{P}{4\pi}$

or, $\displaystyle\int_0^{T_o} kdT - \int_0^{T_s} kdT = \frac{P}{4\pi} = \frac{550}{4\pi} = 43.8\,\frac{W}{cm}$ 1)

For (He) gas conductivity use Eq. 10.102

$k_g \approx 15.8 \times 10^{-6} (920)^{0.79} = 3.5 \times 10^{-3}$ W/cm°C

Approximate gas T, °K

now,

$$\mathbf{T_s - T_{ci} = t_g \bullet \frac{P}{k_g 2\pi R}}$$

$$= \frac{(0.007\,\text{cm})}{\left(0.0035\,\frac{\text{W}}{\text{cm}^\circ\text{C}}\right)} \bullet \frac{87.6\,\frac{\text{W}}{\text{cm}}}{0.268\,\text{cm}}$$

Ts = 637 +654 = 1291 °C

w/o gap closure

Gap Closure

Fuel Thermal Expansion $= \Delta R/R = \alpha_F(\overline{T_f} - T_a)$

T_a **= Fabrication T** $\approx 25\ ^\circ C$

Clad Thermal Expansion $= \Delta R_c/R_c = \alpha_c\ (\overline{T_c} - T_a)$

Hot fuel Radius $= R_f^{hot} = R_f^{cold}[\ 1+\alpha_f(\overline{T_f} -\ T_a)]$

Hot inner clad radius $= R_c^{hot} - t_c^{hot}$

gap width $t_g^{hot} = R_{ci}^{hot} - R_f^{hot}$

$t_g^{cold} = R_{ci}^{cold} - R_f^{cold}$

so,

$$t_g^{hot} - t_g^{cold} = R_{ci}^{cold}\alpha_c\left(\overline{T_c} - T_a\right) - R_f^{cold}\alpha_f\left(\overline{T_f} - T_a\right)$$

Inserting numbers

$$\overline{T_c} = \frac{(637 + 583)}{2} = 610^\circ C$$

$\alpha_f \approx 1.2 \times 10^{-5}\ {}^\circ C^{-1}$ (fig. 10.8) $\approx 1600^\circ C$ (Pu-15%)

$\alpha_c \approx 1.8 \times 10^{-5}\ {}^\circ C^{-1}$ (fig 10.9)

$R_f^{cold} = 0.315 - 0.04 - 0.007 = 0.268$ cm

$R_{ci}^{cold} = 0.315 - 0.04 = 0.275$ cm

$$t_g^{hot} - t_g^{cold} = 0.275 \bullet 1.8 \times 10^{-5} (610-25) - 0.268 \times 1.2 \times 10^{-5} (\overline{T_f} - 25)$$

$$t_g^{hot} - t_g^{cold} = 2.9 \times 10^{-3} - 3.22 \times 10^{-6} (\overline{T_f} - 25) \quad 2)$$

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Solve for $\overline{T_f}$

- Use an iterative procedure, start with $T_s = 1291^\circ C$ w/o gap closure

From figure 10.20 $\int_0^{1291} kdT = 51$ W/cm

From Equation **1**

$$\int_0^{T_o} k dT = 51 + 43.8 = 94.8 \text{ W/cm}$$

from figure 10.20

$$T_o \approx 2700\ ^\circ C$$

Since fuel has not restructured assume parabolic profile

$$\frac{(T - T_s)}{(T_0 - T_s)} = 1 - \left(\frac{r}{R}\right)^2$$

$$T = T_s + (T_0 - T_s)\left[1 - \left(\frac{r}{R}\right)^2\right] = T_0 - [T_0 - T_s]\left(\frac{r}{R}\right)^2$$

Then $$\overline{T_f} = \left(\frac{1}{\pi R^2}\right)\int_0^R \left\{T_0 - [T_0 - T_s]\left(\frac{r}{R}\right)^2\right\} 2\pi r dr$$

$$= T_0 - \frac{T_0 - T_s}{2} = \frac{T_0 + T_s}{2}$$

or,

$$\overline{T_f} = \frac{1291 + 2700}{2} = 1996\ ^\circ C$$

Hence, from eq. above

$$t_g^{hot} = t_g^{cold} + 2.9 \times 10^{-3} - 3.22 \times 10^{-6}(1996-25)$$

$$= 0.007 + 0.0029 - 0.00635$$
$$= 0.00355 \text{ cm}$$

First Iteration

$$\frac{k_g}{t_g} = \frac{0.0035}{0.00355} = 0.985 \text{ W/cm}^2{}^\circ\text{C}$$

therefore,

$$T_s - T_{ci} = \frac{t_g}{k_g} \bullet \left[\frac{P}{2\pi R}\right]$$

$$= \left(\frac{1}{0.985}\right)\left\{\left(\frac{550}{2\pi}\right) \bullet \frac{1}{0.268[1 + 0.000012(996 - 25)]}\right\}$$

$$R_f^{hot} \quad \text{(above)}$$

$$= \left[\frac{550}{2\pi \bullet 0.985 \bullet 0.275}\right]$$

$$= 323\ ^\circ\text{C}$$

$$T_s = 637 + 323 = 960\ ^\circ\text{C}$$

Now go back to Figure 10.20

$$\int_0^{T_s=960} kdT = 41 \text{ W/cm}$$

$$\int_0^{T_0} kdT = 43.8 + 41 = 84.8 \text{ W/cm}$$

$$T_o = 2520\ °C$$

recalculate,

$$\overline{T_F} = \left(\frac{2520 + 960}{2}\right) = 1740°\ C$$

and $t_g^{hot} = t_g^{\ cold} + 2.9 \times 10^{-3} - 3.22 \times 10^{-6}$

$$(1740 - 25)$$

$$= 4.525 \times 10^{-3} \text{ cm}$$

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Repeat this until convergence occurs

$$T_o = 2530\ °C$$

$$T_S = 1050\ °$$