NE 533

Nuclear Fuel Performance

Exam 1

1) $$\frac{\partial}{\partial x}\left(K \frac{\partial T}{\partial x}\right) + Q = 0$$

$T'(x_0) = 0$ $\quad x_0 = 0$ $\qquad x_1 = X$ $\quad T(x_1) = T_1$

$$\int \frac{\partial}{\partial x}\left(K \frac{\partial T}{\partial x}\right) dx = \int -Q \, dx$$

$$K \frac{\partial T}{\partial x} = -Qx + C_1 \quad \rightarrow \quad K(0) = -Q(0) + C_1$$

$$C_1 = 0$$

$$\int K \frac{\partial T}{\partial x} = -Qx \quad dx$$

$$T(x) = \frac{-Q}{2K} x^2 + C_2 \qquad T(x_1) = \frac{-Q}{2K} X^2 + C_2 = T_1$$

$$C_2 = T_1 + \frac{Q}{2K} X^2$$

$$T(x) = \frac{-Q}{2K} x^2 + T_1 + \frac{Q}{2K} X^2$$

$$T(x) - T_1 = \frac{Q}{2K}\left(X^2 - x^2\right)$$

- Steady State
- 1-D
- K is constant

2) T_0 w/ + w/o Coating

$T_{cool} = 600\text{ K}$

$Q = 250\ \text{W/cm}^3$

$R_F = 0.6\text{ cm}$

$t_g = 0.005\text{ cm}$

$t_{clad} = 0.05\text{ cm}$

$t_{coat} = 0.01\text{ cm}$

$K_F = 0.05\ \text{W/cm·K}$

$K_g = 0.004\ \text{W/cm·K}$

$K_{clad} = 0.15\ \text{W/cm·K}$

$K_{coat} = 0.015\ \text{W/cm·K}$

$$LHR = \pi R_F^2 Q = \pi (0.6)^2 (250) = 283\ \text{W/cm}$$

$$\frac{LHR}{2\pi R_F} = \frac{283}{2\pi(0.6)} = 75\ \text{W/cm}^2$$

$$T_{co} = T_{clad} + \frac{LHR}{2\pi R_F}\frac{t_{coat}}{K_{coat}} = 600 + 75\left(\frac{0.01}{0.015}\right) = 650\text{ K}$$

$$T_{ci} = T_{co} + \frac{LHR}{2\pi R_F}\frac{t_{clad}}{K_{clad}} = 650 + 75\left(\frac{0.05}{0.15}\right) = 675\text{ K}$$

$$T_F = T_{ci} + \frac{LHR}{2\pi R_F}\frac{t_g}{K_g} = 675 + 75\left(\frac{0.005}{0.004}\right) = 769\text{ K}$$

$$T_0 = T_F + \frac{LHR}{4\pi K_F} = 769 + \frac{283}{4\pi(0.05)} = \boxed{1219\text{ K}}$$

ΔT over coating $= 50\text{ K}$

T_0 w/o coating $= \boxed{1169\text{ K}}$

3) UN $x_e = 19.5\%$ $\rho = 12.3\ g/cc$ $\sigma_f = 570\ b$

$Q = E_f \Phi \sigma_f N_f$

$A(U) = 235 \times 0.195 + 238 \times 0.805 = 237.4$

N_f ?

$A(UN) = 237.4 + 14 = 251.4$

$$N_f \Rightarrow 12.3\ g/cc \ \frac{1\ mol}{251.4\ g} \ \frac{6.022 \times 10^{23}\ molec}{1\ mol} \ \frac{1\ U}{1\ UN} \times 0.195$$

$$N_f = 5.75 \times 10^{21}\ U^{235}/cc$$

$$Q = (200 \times 10^6)(1.602 \times 10^{-19}\ J/eV)(5 \times 10^{12}\ n/cm^2 \cdot s)(570 \times 10^{-24}\ cm^2)(5.75 \times 10^{21})$$

$$\underline{Q = 525\ W/cc}$$

b) x_e for UO_2 ?

$$N_f(UN) = N_f(UO_2)$$

$$N_f = 5.75 \times 10^{21} = 10.97\ g/cc \ \frac{1\ mol}{A(UO_2)} \ \frac{6.022 \times 10^{23}}{1\ mol} \ \frac{1\ U}{1\ UO_2} \ x_e$$

$$\frac{x_e}{A(UO_2)} = 8.7 \times 10^{-4}$$

$$A(UO_2) = 235 x_e + 238(1 - x_e) + 32$$

$$x_e = (8.7 \times 10^{-4})(270 - 3 x_e)$$

$$1.0026\ x_e = 0.2349$$

$$x_e = 0.243 \rightarrow \boxed{24.3\ \%}$$

4) $L = 3.5\,m \quad z_0 = 1.75\,m \quad LHR^\circ = 350\ W/cm \quad \gamma = 1.3$

a) $LHR\,(z = 1.4\,m)$

$$\frac{\pi}{2\gamma} = 1.2$$

$$LHR = LHR^\circ \cos\left[\frac{\pi}{2\gamma}\left(\frac{z}{z_0} - 1\right)\right]$$

$$LHR = 350 \cos\left(1.2\left(\frac{1.4}{1.75} - 1\right)\right) = \boxed{340\ W/cm}$$

b) ΔT ?

$$\Delta T = \frac{2\gamma}{\pi} \frac{z_0\, LHR^\circ}{\dot{m}\, c_p}\left[\sin\frac{\pi}{2\gamma} + \sin\left(\frac{\pi}{2\gamma}\left(\frac{z}{z_0} - 1\right)\right)\right]$$

$$\Delta T = \frac{1}{1.2} \frac{(175)(350)}{(0.22)(4200)}\left[\sin(1.2) + \sin\left(1.2\,(2 - 1)\right)\right]$$

$$\boxed{\Delta T = 103\ K}$$

5) Backward Euler $\quad Y_{n+1} = Y_n + dt\, Y'_{n+1}$

$y' = t\exp(-2t) \quad t_0 = 0 \quad y_0 = 4 \quad dt = 0.5$

$t_1 = 0.5 \quad Y_1 = Y_0 + dt\, Y'_1 = 4 + 0.5(0.5 \exp(-2 \times 0.5))$

$Y_1 = 4.09$

$t_2 = 1 \quad Y_2 = Y_1 + dt\, Y'_2 = 4.09 + 0.5(1 \exp(-2 \times 1))$

$Y_2 = 4.16$

$t_3 = 1.5 \quad Y_3 = Y_2 + dt\, Y'_3 = 4.16 + 0.5(1.5 \exp(-2 \times 1.5))$

$\boxed{Y_3 = 4.20}$

6) Fertile → can be converted into a fissile atom via neutron capture

Fissile → can undergo fission w/ a neutron of any energy

Fissionable → can undergo fission w/ a high energy neutron

7) Low melting point

Anisotropic thermal expansion

Anisotropic irradiation growth

Poor oxidation behavior

Extreme swelling

8) Smear density is the relative volume of fuel compared to the maximum possible volume inside the cladding

Necessary because of fuel swelling and thermal expansion

9) We enrich U to increase N_f, number density of U^{235}

Results in higher heat generation rate.

UF_6 is the compound used for enrichment

Centrifuge

- spinning cylinder w/ a feed of UF_6 gas
- centrifugal forces preferentially push U^{238} to outside of cylinder
- enriched product removed from center of cylinder

10) Finite difference, finite volume, finite element

- FD is only known at discreet points, typically restricted to rectangular geometries
- other answers are acceptable

11) DNBR

- ratio of the heat flux that causes dryout to the actual heat flux
- minimum DNBR is taken in the hottest channel
- greater than 1.15

CHR
- the heat flux at which dryout occurs, whee the rod is coated in steam
- beyond CHR cladding has large temperature increase

12) Fuel Kernel, buffer, IPyC, SiC, OPyC

- High temperature gas reactor