Transient Heat Conduction in Nuclear Fuel Pin

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Radial Heat conduction in nuclear fuel elements

Reactor fuel pin is a cylindrical fuel element that contain fuel pellet, gap and cladding as shown in Figure 4.1. Coolant can be in single phase or two phase. Fuel and clad properties are available as a function of temperature. The state of the coolant is obtained from convection equations. Thus, the information is provided by these to transient conduction solver. As the equation is non-linear due to complex property and boundary conditions, numerical solutions are called for

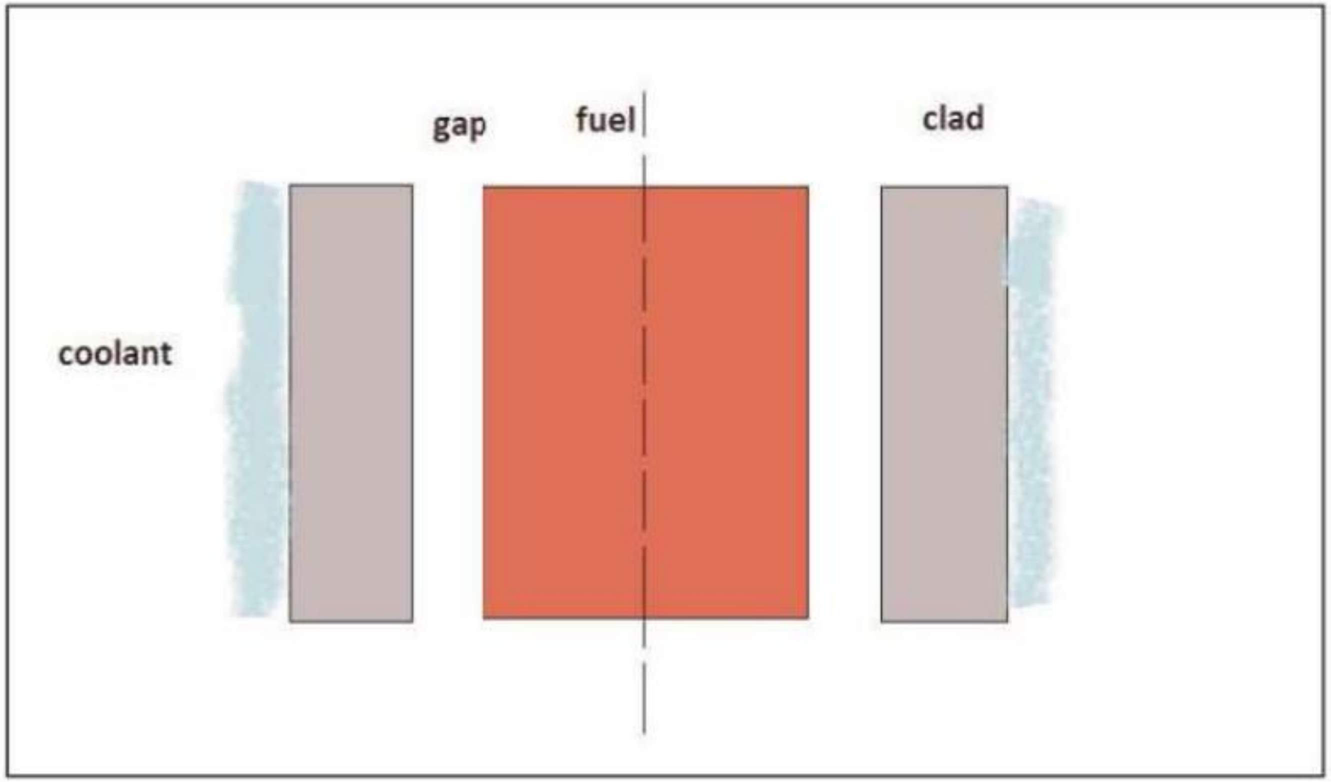

Figure 4.1 Illustrative representation of fuel pin geometry

Basic governing equation

(after Over assumption of azimuthal symmetry and neglecting axial conduction affects)

$$\frac{\partial}{\partial t}(\rho c_p T) = \frac{1}{r}\frac{\partial}{\partial r}\left(rk\frac{\partial T}{\partial r}\right) + q'''$$

Discretized equations for fuel pin geometry

(using finite volume approach)

In this section, the governing equation (shown in the previous slide) is integrated over volume and time at node$_i$ to obtain the discretized equations.

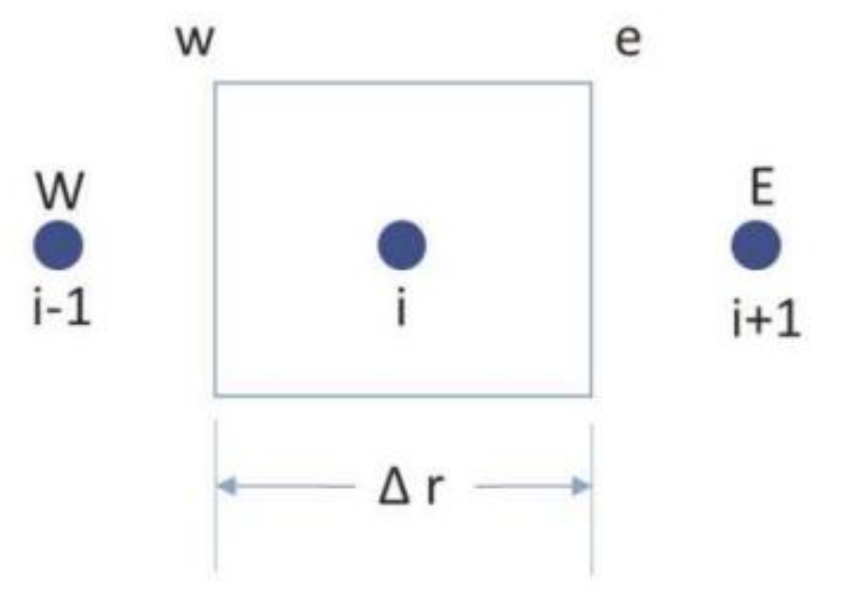

Figure 4.2 Unit cell representation

I. Transient term

$$\int_{r-(\Delta r/2)}^{r+(\Delta r/2)} \int_{t}^{t+\Delta t} \frac{\partial}{\partial t}(\rho C T) r\,dr\,dt = \rho C_{Ti}(T_i^{n+1} - T_i^{n}) r_i \Delta r_i$$

T_i^{n+1} T_{i+1}^{n} represents average values in the control volume at n+1[th] and n[th] timesteps at i[th] node location.

II. Conduction term

$$\int_{t}^{t+\Delta t} \int_{w}^{e} \frac{1}{r}\frac{\partial}{\partial r}\left(rk\frac{\partial T}{\partial r}\right) r\,dr\,dt = \frac{r_e k_e}{\left(\frac{\Delta r_i + \Delta r_{i+1}}{2}\right)} T_e^{n+1} + \frac{r_w k_w}{\left(\frac{\Delta r_{i-1} + \Delta r_i}{2}\right)} T_w^{n+1} - \left[\frac{r_e k_e}{\left(\frac{\Delta r_i + \Delta r_{i+1}}{2}\right)} + \frac{r_w k_w}{\left(\frac{\Delta r_{i-1} + \Delta r_i}{2}\right)}\right] T_p^{n+1}$$

III. Heat generation term

$$\int_{t}^{t+\Delta t} \int_{w}^{e} q''' r\,dr\,dt = q_i''' \Delta t \left(\frac{r_e^2 - r_w^2}{2}\right) = q_i''' \Delta t\, r_i \Delta r_i$$

On substituting the equations in the previous slide in the Governing Equation, we get:

$$A_i T_{i+1}^{n+1} + D_i T_i^{n+1} + B_i T_{i-1}^{n+1} = C_i$$

$$A_i = \frac{r_e k_e}{\left(\frac{\Delta r_i + \Delta r_{i+1}}{2}\right)} \quad \text{where} \quad r_e = \left(\frac{r_i + r_{i+1}}{2}\right)$$

$$B_i = \frac{r_w k_w}{\left(\frac{\Delta r_{i-1} + \Delta r_i}{2}\right)} \quad \text{where} \quad r_w = \left(\frac{r_i + r_{i-1}}{2}\right)$$

$$D_i = -A_i - B_i - \frac{\rho_i C_i}{\Delta t} r_i \Delta r_i$$

$$C_i = -\frac{\rho_i C_i}{\Delta t} r_i \Delta r \, T_i^n + q_i''' r_i \Delta r_i$$