CHAPTER - 8
INVESTIGATION OF CLAD AND SODIUM TEMPERATURE DISTRIBUTIONS

8.0 INTRODUCTION

One of the purposes of pin bundle thermal hydraulics is to obtain the clad temperature distribution on the surface of each and every pin of the 217 pin bundle. The sodium temperature distribution in each and every sub channel of the pin bundle is also equally important. As the clad and sodium temperatures are the highest at the outlet of the bundle, their circumferential distributions are presented here at the outlet of the 217 pin bundle. Based on these distributions, the heat transfer from the clad to sodium can be ascertained on the surface of every pin and in every sub channel. From the maximum values of clad and sodium temperatures, the hot spot factors and the hot channel factors which are important from safety analysis of the core can be evaluated (Chapter 10).

8.1 PIN NUMBERING OF THE 217 PIN BUNDLE

For the purpose of identifying the pins and for obtaining corresponding circumferential clad temperature distribution, the 217 pin bundle is numbered as shown in Fig 8.1 (a). From the pin numbering, it can be seen that the central pin is numbered as No.1. Also, the sub-channels enclosed by three pins in the triangular pitch in the case of central sub-channels, and the peripheral sub-channels enclosed by the pins and the hexagonal sheath can be identified. The angular locations of the sub-channels of the nine hexagonal rows can also be identified. For example, the angular location of the sub-channel of the first hexagonal row (surrounded by the central pin) from 0° to 60° are 1_2_3. The pins and the sub channels within the hexagonal sheath are divided into six zones as shown in Fig. 8.1 (a). Thus, zone I consists of pins and sub channels in the 1/6\(^{th}\) quadrant between \(\theta = 240^\circ\) to \(300^\circ\). The
definition of the angle along the circumference of the pin is also shown in Fig 8.1 (b) for the purpose of studying clad temperature distribution.

Fig. 8.1 (a) Pin numbering of the 217 pin bundle and angular locations of the sub-channels of various hexagonal rows.
8.2 EFFECT OF BUNDLE LENGTH ON CLAD TEMPERATURE DISTRIBUTION IN 217 PIN BUNDLE

Figure 8.2 (a) shows the clad temperature distribution around the central and peripheral pins at 200 mm length from the entry of the bundle. Fig 8.2 (b) shows the same at the outlet of the bundle (i.e.) at 1000 mm from the entry of the bundle. The circumferential variation in clad temperature exhibits intense distribution with alternate crests and troughs which remains unaltered with increase in the length of the bundle. But, the location of the pin having maximum clad temperature moves towards the center with the increase in the length of the bundle. This is due to the three distinct sodium temperature regions viz. hottest, coldest and intermediate becoming more distinct and uniform with the increase in the length of the bundle due to the transverse velocity induced by the helical wire.
Fig. 8.2 (a) Clad temperature distribution around the central and peripheral pins at 200 mm from the inlet.

Fig. 8.2 (b) Clad temperature distribution around the central and peripheral pins at the outlet (1000 mm from the inlet).
8.3 EFFECT OF BUNDLE LENGTH ON SUB-CHANNEL SODIUM TEMPERATURE DISTRIBUTION IN 217 PIN BUNDLE

It is of interest to know the average outlet temperature of each sub-channel in the pin bundle. The average outlet temperature of sodium in the first row is obtained from each of the six sub-channels surrounded by the pin number 1 (i.e.) 1_2_3, 1_3_4, 1_4_5, 1_5_6, 1_6_7 and 1_7_2. This is plotted against the angular location of the hexagonal rows corresponding to the sub-channels. Similarly, the average outlet temperature of sodium in all other rows is obtained from each of the sub-channels surrounded by the subsequent row of pins in the pin bundle.

Figure 8.3 (a) shows the sodium temperature distribution in the nine rows of the sub-channels at 200 mm length from the entry of the bundle. Fig. 8.3 (b) shows the same at the outlet of the bundle (i.e.) at 1000 mm from the entry of the bundle. It is seen that the three temperature regions, viz. hottest, coldest and intermediate becomes more distinct with the increase in the length of the bundle and becomes more uniform. In addition, the temperature distribution in each row becomes closer to one another reducing the average temperature difference between them. Thus, the transverse velocity induced by the helical wire is able to reduce the temperature difference between the central and peripheral sub channels significantly due to the enhance heat transfer coefficient due to the helical wire induced transverse velocity along the length of the bundle and makes the sodium outlet temperature more uniform.
Fig. 8.3 (a) Sodium temperature distribution at 200 mm from the inlet of 217 pin bundle

Fig. 8.3 (b) Sodium temperature distribution at 1000 mm from the inlet of 217 pin bundle
8.4 EFFECT OF HELICAL WIRE PARAMETERS ON CLAD TEMPERATURE DISTRIBUTION IN 217 PIN BUNDLE

As it is not possible to present the temperature distribution on the surface of each and every pin, a representative pin in each of the six zones is presented here. It is seen from the temperature fields at the outlet of 217 pin bundle presented in Chapter 7, the temperatures of clad and sodium are maximum in zones IV and V where wire is present in the peripheral sub-channels. The temperatures are minimum in the zones I and II which are diametrically opposite to maximum temperature zones.

8.4.1 Influence of Helical Pitch

Figures 8.4.1 (a) – 8.4.1 (g) show the clad temperature distribution at 100 mm from the bundle entry for different helical pitches of 100 mm, 200 mm and 300 mm for representative pins in each zone with pin numbers No. 1 (central pin), No.145 (zone IV), No.152 (zone III), No. 160 (zone II), No. 166 (zone I), No.131 (zone II) and peripheral pin No.217. The clad temperature around the pin decreases with decrease in helical pitch for central pin as the transverse flow increases the heat transfer coefficient in the central sub-channels. The circumferential variation in clad temperature exhibits intense distribution with alternate crests and troughs. These crests and troughs are strongly influenced by (i) the radial gap between the pin under consideration and the neighboring pin and (ii) cross flow velocity induced by the spacer wire. While a smaller radial gap increases the clad temperature, larger cross stream velocity reduces the clad temperature. The clad temperature increases with decrease in helical pitch for the 7th row of pins due to the fact that the cross flow direction in different cases are different due to variation in helical pitch length.

In the peripheral pins, the decrease in clad temperature with decrease in helical pitch is more. This is because of the enhanced mixing due to higher cross flow in the peripheral
sub-channels for shorter helical pitch. Also, the sodium temperature is less in the peripheral sub-channels since the heat input per unit length in these channels are less due to the presence of adiabatic hexagonal sheath. The clad temperature for 100 mm helical pitch is higher from 0°-180° which is facing the central pins and the same is lower from 180°-360° which is facing the hexagonal sheath. The clad temperatures for 200 and 300 mm helical pitch are higher due to reduced transverse velocities.

8.4.2 Influence of Helical Wire Diameter

Figures 8.4.2 (a) - 8.4.2 (c) show the normalized clad temperature distribution at the bundle exit for different helical wire diameters of 1.25 mm, 1.65 mm and 2.0 mm for representative pins in the central, 7th row and peripheral pins.

The clad temperature is normalized as follows,

\[ T_{\text{nor., clad}} = K_f \times \left( (T_c - T_f) / (q'' \times d_{eq}) \right) \]

Where \( T_{\text{nor., clad}} \) – Normalized clad temperature, \( K_f \) – Thermal conductivity of sodium, \( T_c \) – Mean clad temperature at the bundle exit, \( T_f \) – Mean sodium temperature at the bundle exit, \( q'' \) – Pin surface heat flux, W/m², \( d_{eq} \) – Equivalent diameter of the pin bundle.

It is seen that the normalized clad temperature decreases with increase in helical wire diameter for central pin and 7th row of pins as the transverse flow increases the heat transfer coefficient in the central sub-channels. In the peripheral pins, the normalized clad temperature also decreases with increase in wire diameter as the transverse flow is higher in the peripheral sub-channels. The peripheral pin clad temperature for all helical wire diameters is higher in the region 0° - 180° which is facing the central pins and the same is lower from 180° – 360° which is facing the hexagonal sheath.
Fig. 8.4.1 (a) Clad temperature around the central pin for different helical pitches

Fig. 8.4.1 (b) Clad temperature around the pin no. 145 located at the 7th row for different helical pitches
Fig. 8.4.1 (c) Clad temperature around the pin no. 152 located at the 7th row for different helical pitches

Fig. 8.4.1 (d) Clad temperature around the pin no. 160 located at the 7th row for different helical pitches
Fig. 8.4.1 (e) Clad temperature around the pin no. 166 located at the 7th row for different helical pitches

Fig. 8.4.1 (f) Clad temperature around the pin no. 131 located at the 7th row for different helical pitches
Fig. 8.4.1 (g) Clad temperature around the pin no. 217 located at the peripheral row for different helical pitches

Fig. 8.4.2 (a) Clad temperature around the central pin for different wire diameters
Fig. 8.4.2 (b) Clad temperature around the pin no. 145 located at the 7th row for different wire diameters

Fig. 8.4.2 (c) Clad temperature around the pin no. 217 located at the peripheral row for different wire diameters
8.5 EFFECT OF HELICAL WIRE PARAMETERS ON
SUB-CHANNEL SODIUM TEMPERATURE DISTRIBUTION
IN 217 PIN BUNDLE

8.5.1 Influence of Helical Pitch

Figures 8.5.1 (a) - 8.5.1 (c) show the sodium temperature distribution at 100 mm from the bundle entry in the nine rows of the sub-channels of the bundle for various helical pitches of 100 mm, 200 mm and 300 mm respectively. It is seen that the sodium outlet temperature distribution in all the central sub-channels are uniform except in the eighth row which is adjacent to the peripheral row. The peripheral sub-channel sodium temperature is much lower and non-uniform than that of the central sub-channels. The sodium temperature is higher in the central sub-channels, as these are formed by the fuel pins and consequently the rate of heat addition per unit length of the channel is more. For similar reason, the sodium temperature is less in the peripheral sub-channels since the heat input per unit length in these channels are less due to the presence of hexagonal sheath which is adiabatic. It is seen that the sodium temperature difference between the central sub-channels in the eight rows of pin bundle and the peripheral sub-channels at the same hexagonal face is lower for shorter helical pitch which is attributed to the enhanced mixing due to higher cross flow in the shorter helical pitch case. The maximum sodium temperature occurs at the location beneath the wire wrap as well as in the minimum gap between the wire wrap and the neighboring fuel pin.
Fig. 8.5.1 (a) Sodium temperature at 100 mm elevation of 217 pin bundle
helical pitch = 100 mm

Fig. 8.5.1 (b) Sodium temperature at 100 mm elevation of 217 pin bundle: helical pitch = 200 mm
Fig. 8.5.1 (c) Sodium temperature at 100 mm elevation of 217 pin bundle: helical pitch = 300 mm

8.5.2 Influence of Helical Wire Diameter

Figures 8.5.2 (a) – 8.5.2 (c) show the sodium temperature distribution at the bundle exit in the nine rows of the sub-channels of the bundle for helical wire diameter of 1.25 mm, 1.65 mm and 2.0 mm respectively. It is seen that the sodium temperature distribution is similar in all the cases due to fixed outlet temperature. Further, the sodium temperature distribution in the sub-channels in the various rows of pin bundle is not varying much for smaller helical wire diameter which is attributed to the lower cross flow. Whereas, the sodium temperatures in the sub-channels of various rows of pin bundle are varying with increase in helical wire diameter which is attributed to the increased cross flow.
Fig. 8.5.2 (a) Sodium temperature distribution at the outlet of 217 pin bundle: Helical wire diameter = 1.25 mm

Fig. 8.5.2 (b) Sodium temperature distribution at the outlet of 217 pin bundle: Helical wire diameter = 1.65 mm
Fig. 8.5.2 (c) Sodium temperature distribution at the outlet of 217 pin bundle : Helical wire diameter = 2.0 mm

8.6 SELECTION OF ECONOMICAL HELICAL PITCH AND WIRE DIAMETER

The helical wire basically serves as a spacer between the pins and provides support for pins. Unlike grid spacers, it induces a transverse flow in the pin bundle which increases the heat transfer coefficient of sodium flow through the pin bundle. It reduces the hot spots and makes the outlet sodium temperature more uniform. But, it increases the pressure drop in the bundle. As the performance of helical wire increases with Reynolds number, it is much preferred in the turbulent flow regime compared to transition, laminar regime and buoyant flow regime. As the friction factor and Nusselt number increases with decrease in helical pitch, it is always economical to keep the helical pitch above 100 mm but below 300 mm. The wire diameter should be above 1.25 mm and below 2.0 mm. Hence, the optimum helical pitch and wire diameter are 200 mm 1.65 mm. These helical wire parameters are found to be economical and the fuel pins wound over with this wire is found to be easy to manufacture.
8.7 CLOSURE

The clad temperature decreases with decrease in helical pitch for central pin as the transverse flow increases the heat transfer coefficient in the central sub-channels. The circumferential variation in clad temperature exhibits intense variation with alternate crests and troughs. These crests and troughs are strongly influenced by (i) the radial gap between the pin under consideration and the neighboring pin and (ii) cross flow velocity induced by the spacer wire. While a smaller radial gap increases the clad temperature, large cross stream velocity reduces the clad temperature. In the peripheral pins, clad temperature decreases with decrease in helical pitch as the transverse flow increases the heat transfer coefficient in this row of pins. The sodium temperature is higher in the central sub-channels and the same is lower in the peripheral sub-channels. It is seen that the sodium temperature difference between the central sub-channels in the eight rows of pin bundle and the peripheral sub-channels at the same hexagonal face is lower for shorter helical pitch which is attributed to the enhanced mixing due to higher cross flow in the shorter helical pitch case. With larger wire diameters, the normalized clad temperature around the pin is lower due to higher cross flow because of increased wire size and reduced cross flow resistance.