Geometric Effects of Spacer Grid in an Annulus Flow Channel During Reflooding Period

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1. Introduction

A number of studies on the reflooding phase were actively carried out from the early 70's due to its importance for the safety of the nuclear reactor. (Martini et al., 1973; Henry, 1974; Chung, 1978;) However, few studies have presented the spacer grid effect during the reflooding period. Since the grid is an obstruction in the flow passage, it causes an increased pressure drop due to form and skin friction losses. On the other hand, the spacer grid tends to increase the local wall heat transfer. The present work has been performed in a vertical annulus flow channel with various flow conditions. The objective of this paper is to evaluate the effects of a swirl-vane spacer grid on the rewetting phenomena during the reflooding phase.

2. Experimental Descriptions & Results

2.1 Test Facility

Two types of spacer grids have been used, i.e. straight egg-crate grid (Flat type) and swirl vane grid. Four spacer grids are installed in the test section.

2.2 Test method and conditions

Table 1 Experimental ranges of investigated parameters and physical characteristics of test section

Parameter	Symbol	Unit	Value
Flooding velocity	U_F	cm/s	2, 5, 8
Inlet coolant temperature	T_{in}	°C	20, 50, 75
Initial wall temperature	T_w	°C	500, 600, 700
Type of Spacer grid	-	-	flat, swirl-vane
Pressure	P	bar	1
Sheath material of heater rod	-	-	Inconel 600
Sheath diameter of heater rod	D_{sh}	mm	9.5
Inner diameter of Pyrex-glass tube	D_{glass}	mm	20
Heated length	L	m	1.830

The present study has been performed at the atmospheric pressure condition. Overall heat losses were determined in steady-state conditions versus wall average temperature calculated from measured wall temperatures. Table 1 shows the test conditions.

2.3 Spacer Grid Effects

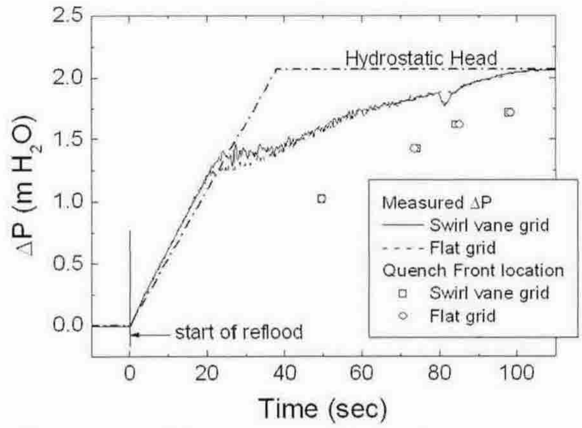

Fig. 1 Differential pressure transients of two spacer grids (U_F = 5 cm/s, T_{wall} = 600 °C, T_{in} = 20 °C)

Differential pressure (*ΔP*) behaviors and corresponding quenching front locations of two investigated spacer grids with hydrostatic head under cold conditions are shown in Fig. 1. During initial stage of reflood □*P* transients of two spacer grids are nearly same and show a little bit higher value than the corresponding hydrostatic head due to possible higher acceleration term. After this initial stage, when gravity term becomes dominant, the *ΔP* is lower than cold hydrostatic head, and finally it tends to reach hydrostatic head at the end of quenching transient.

The spacer grid effect is important in the cooling of a fuel during the reflood phase. The spacer grids affect the thermal-hydraulic behavior of fuel rods by disturbing the thermal boundary layer and increasing turbulence downstream of the spacer grids.

The wall temperature variations of the two investigated spacer grids with the elapsed time from the start of reflooding can be seen in Fig. 2. At the initial stage of the experiment of 5 seconds, the axial temperatures show nearly the same level except for TW06 due to the axial heat loss to the end. As time goes by, the temperatures of TW03, installed just downstream of the spacer grid, are lower than those of TW02. Moreover, the temperature difference of TW03 between the swirl-vane grid and the flat spacer grid becomes larger with the elapsed time. At 125 seconds after the initiation of reflooding, the TW03 of the swirl-vane grid shows a relatively lower temperature than that of the flat spacer grid. From this result, the effects of the swirl-vane spacer grid on the heat transfer can be estimated.

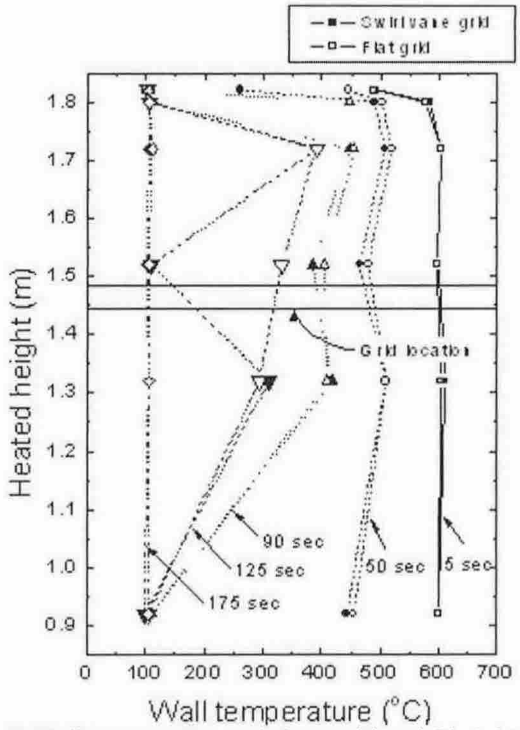

Fig. 2 Wall temperature variations with axial height (U_F = 8 cm/s, T_{wall} = 600 °C, T_{in} = 75 °C)

2.4 Parametric effects on the rewetting temperature and velocity

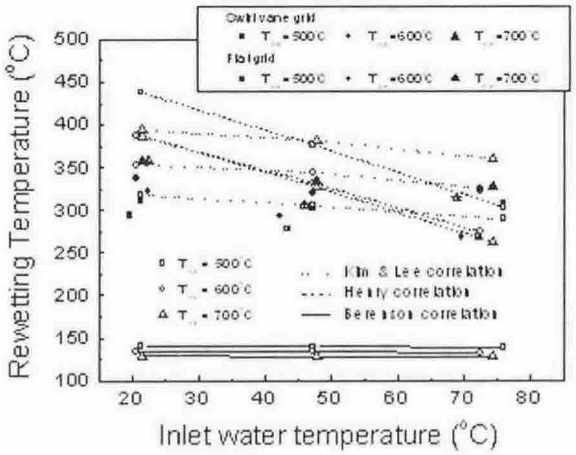

Fig. 3 Rewetting temperature with the previous correlations (U_F = 2 cm/s)

Berenson (1961) proposed the analytical correlation on the minimum film boiling temperature of an isothermal surface for simple geometry base on the Taylor hydrodynamic instability in Eq. (1).

$$(\Delta T_{\min})_l = 0.127\frac{\rho_v h_{fg}}{k_v}\left[\frac{g(\rho_l-\rho_v)}{\rho_l+\rho_v}\right]^{2/3}\left[\frac{\sigma}{g(\rho_l-\rho_v)}\right]^{1/2}\left[\frac{\mu_v}{g(\rho_l-\rho_v)}\right]^{1/3} \qquad (1)$$

To consider the effects of the wall to fluid interface temperature gradient, Henry (1974) proposed the micro-layer evaporation model based on Berenson's theory in Eq.(2).

$$\frac{T'_{\min}-(T'_{\min})_l}{(T'_{\min})_l - T_l} = 0.42\left[\sqrt{\frac{k_l\rho_l C_{pl}}{k_w\rho_w C_{pw}}}\frac{h_{fg}}{C_{pw}(\Delta T_{\min})_l}\right]^{0.6} \qquad (2)$$

where $(T'_{\min})_l = (\Delta T_{\min})_l + T_s$. Kim et al. (1979) also suggested the following Eq. (3) of the rewetting temperature correlation on the basis of dimensional analysis for the vertical circular channels.

$$T_q = 19.51 T_{WS}\left[\frac{T_{Sl}}{T_{WS}}\right]^{0.107}\left[\frac{C_{pw}G\delta}{k}\right]^{-0.162}\left[\frac{k\rho^2 T_{WS}}{\delta G^3}\right]^{-0.0989}\left[\frac{Z}{\delta}\right]^{-0.163} + T_S \qquad (3)$$

where $T_{Sl} = T_S - T_l$, $T_{WS} = T_W - T_S$. The present geometry of the present test section is different from that of the above-mentioned investigators, and the heat capacity of heated section is resultantly different. To evaluate this difference of the geometry and thermal capacity, the thickness of the present heater rod has been calculated by Eq. (4).

$$\delta_{rod} = \sum_{n=1}^{N}\left[\frac{k_n\rho_n C_{pn}}{k_1\rho_1 C_{p1}}\right]\delta_n \qquad (4)$$

where n means the n-th material of the present heater rod configuration from the cladding to the core. The present data is compared with the Eqs. (1), (2), and (3) in Fig. (3).

3. Conclusions

In the present work, upper part of the heated length is cooled by top-down flooding phenomenon. From the visual observation, only for the case with swirl vane spacer grid, another quenching front develops at the downstream of spacer grid when the bottom-up quenching front is gradually approaching the spacer grid from the upstream. These two simultaneous quenching fronts through the spacer grid are due to not only the oscillatory motion of coolant in the test section but also the heat transfer enhancement by turbulent mixing near the spacer grid, and it shows the effects of the spacer grid. Generally, the swirl-vane grid shows a better heat transfer performance.

References

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