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Mitigation of Flooding under Externally Imposed Oscillatory Gas Flow

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Abstract

During the hypothetical loss of coolant accident in the nuclear power plant, the emergency core cooling water could not penetrate to the reactor core when the steam flow rate from the reactor core exceeds CCFL (Countercurrent flow limitation). The CCFL generated by earlier investigators are developed under the steady gas flow. However the flow instability in the reactor loop could generate oscillatory steam flow, hence their applicability under oscillating flow should be investigated.

In this work, an experimental investigation of countercurrent flow in the vertical flow channel has been conducted under oscillatory gas flow. Pulsation of gas under oscillatory flow disturbs the flow pattern significantly and prevents flooding (CCFL) when its minimum value is less than the threshold gas flow rate value.

1. Introduction

A phenomenon known as " flooding " or countercurrent flow limitation(CCFL) is of importance in the nuclear industry to determine the penetration flow rate of the emergency coolant into the hot reactor core during the hypothetical loss of coolant accident in the nuclear power plant. The study on flooding under oscillatory flow has not been intensively explored in spite of the presence of oscillation during the reactor accident. It partly results from the fact that the steady flooding is not fully understood yet: the geometry effect (entry shape and length), the mass transfer effect (evaporation and condensation), hysteresis effect between flooding and deflooding, and too many models for one phenomenon. Since the theoretical models based on the instability theory[1] or the force balance theory[1], the oscillatory effect or hysteresis effect could not be included . Recently, Lee and No [2] developed a " Hyperbolicity Breaking" model which could unify the above different models in a mathematical frame, but this model should be improved to include the effect of hysteresis or oscillatory pulsation.

In this stage, the experimental analysis is essential to understand flooding under oscillatory flow. From the previous experience in the reflux condenser experiments[3] and flooding experiments[4], the delivery flow rate was increased with the self initiated oscillation in those loop. If the externally imposed oscillation in gas flow could increase delivery flow or remove the countercurrent flow limit, it could be useful to design the advanced safety injection system of the nuclear power plant.

2. Experimental Apparatus and Instrumentations

The experiment was conducted in a vertical countercurrent flow loop as shown in Fig.1. A top plenum was fabricated out of aluminum and was designed to contain a brass porous mesh, with tapered injector within it. The water entered through this porous injector and excited via a smooth Teflon spacer in the bottom plenum. The bottom plenum was of steel construction and had provisions for water injection and water removal. The water level in the bottom tank was maintained constantly by pumping out water equal to the injection rate. The valve and control assemly amounted on the line of gas inlet generates oscillatory gas flow with various magenitude and frequencies.

Each signal is connected to Keithley 570 A/D convertor and data acquisition system and monitored by ASYST software installed in the personal computer compatible with IBM-PC.

3. Flooding under oscillatory gas flow

In addition to two parameters of liquid volumetric flow rate and gas volumetric flow rate, $\sqrt{j_f^*}$ and $\sqrt{j_g^*}$, flooding under oscillatory flow requires three more parameters: the maximum and minimum gas flow rate and frequency. It is not easy to represent the flooding data in the five dimensional space. To present the oscillatory flooding, normal steady flooding map and the magnitude map are prepared. As shown in Fig. 2, the normal flooding map with steady air flow has two regimes of annular flooding and slug flooding. For simplicity of this paper one sample case from each regime is selected. Figure 3 shows the flooding locus with oscillatory gas flow at the liquid flow rate of $\sqrt{j_l^*} = 0.4$, where the flow regime was annular flow before and after flooding for steady gas flow. Four frequencies of oscillations were tested. No flooding was observed with oscillation with any magnitude and frequencies of 1/2.54 Hz, 1/11 Hz, 1/22 Hz. when its minimum gas flow rate is less than steady deflooding value. So the flooding locus follows the vertical line at $\sqrt{j_{g,\min}^*} = 0.3$. Accumulated water in the upper plenum is delivered to the bottom plenum in the form of periodic slug/annular flow. However, flooding data follows the line MFL(maximum gas flow makes flooding) with the minimum gas flow less than the steady deflooding value. But for the high frequency oscillation, 1/0.76 Hz, flooding data follows the line of AFL(average gas flow makes flooding), because the oscillation time interval is too short to generate water slug in the tube.

The flooding locus for oscillatory gas flow is presented in Fig. 4 for $\sqrt{j_l^*} = 0.6$ which is correspondent with the transition from annular flooding regime to slug flooding regime for steady gas flow. Comparing with the previous figures, the most different thing is the left shift of no-flooding-locus line from the deflooding point in the minimum gas flow axes, $\sqrt{j_{g,\min}^*} = 0.2$. This no-flooding-locus is coincidentally close to the deflooding point of annular flooding regime, $\sqrt{j_{g,\min}^*} = 0.3$.

4. Concluding Remarks

Experimental investigations have been conducted to study the flooding under oscillatory gas flow and found the way to mitigate the flooding limit.

References

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[3] J.Y.Lee and J.S. Chang, " Modeling of Flow Patterns and Dynamic Characteristics of Reflux Condensation," (1995) To be published.

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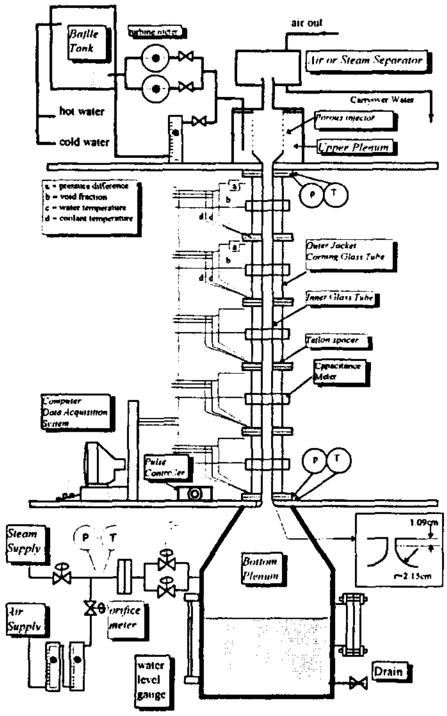

Fig.1 The experimental apparatus

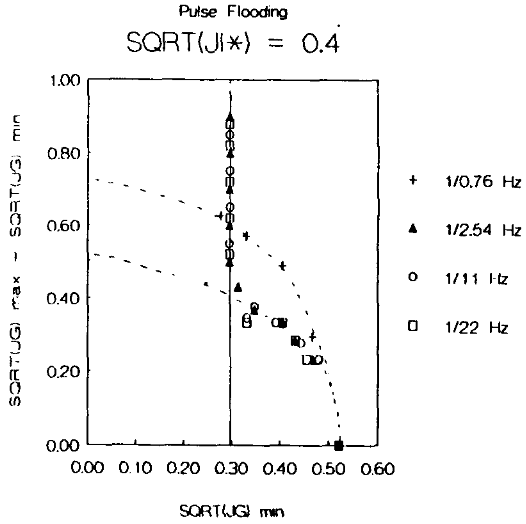

Fig.3 Oscillatory flooding in the annular flooding regime

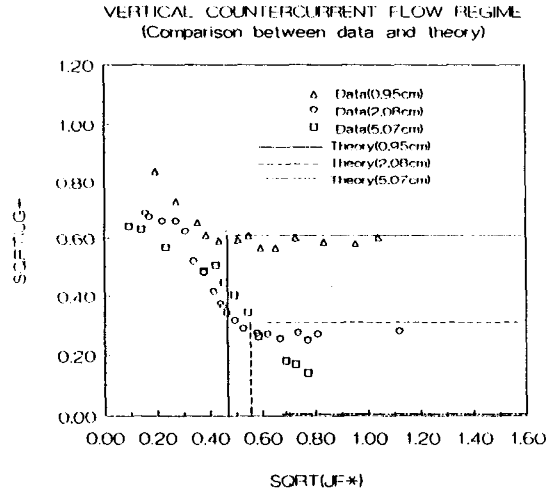

Fig.2 Flooding map with steady air flow

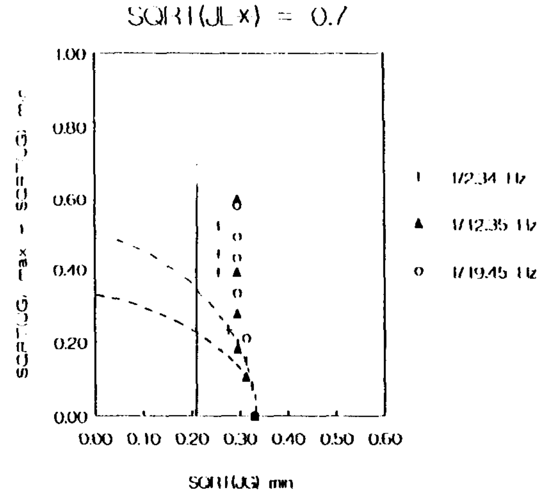

Fig.4 Oscillatory flooding in the slug flooding regime