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Boilup Transients in a Closed System*

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In analysis of certain hypothetical LMFBR accidents, it is often postulated that the core undergoes a gradual disruption leading to a boiling mixture of molten fuel and steel confined within the original core volume. The boilup behavior of such a fuel/steel mixture is an important consideration in assessing the potential for recriticalities. An experimental program is underway at ANL in order to provide a phenomenological understanding of the boilup behavior. The experiment is being conducted in a five-liter pressure vessel in which a pool of de-mineralized water is heated by volumetrically spaced electrical resistance heaters. The experimental apparatus as well as the results of steady-state tests has previously been described in Ref. 1. This paper discusses the results of transient tests on pool boilup response to varying condensation rates at the upper boundary.

The test procedure was as follows. Initially, a steady-state boilup condition was established at a given power level with the vessel pressure mainly controlled by the amount of air present in the vessel. The steady-state two-phase mixture level along with the vessel pressure was recorded. The transient was initiated either by suddenly reducing the condenser-coolant flow rate, thereby causing the pressure to increase (pressurization transient), or by suddenly increasing the condenser-coolant flow rate, thereby causing the pressure to decrease (depressurization transient). The changes in the pool pressure and temperature during the transient were continuously monitored. During the transient a motion picture was also taken through one of

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DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED the sight ports. Analysis of the motion picture film yielded data on the change in the two-phase mixture level (or equivalently, the average void fraction) during the transient.

Figure 1 shows the pressure and void-fraction changes during a pressurization transient where the power input was 8 KW and the initial pressure and average void fraction were 23.5 psia and 0.23, respectively. Similar data for a depressurization transient are presented in Fig. 2. For this transient, the power input was 8 KW and the initial pressure and average void fraction were 88.6 psia and 0.18, respectively. Note that the zero time for the pressure data does not coincide with that for the void fraction data. The zero time for the pressure data was taken during the steady-state boilup. The beginning of the transient is marked by a sharp break from the steady-state pressure. For the void fraction data, the transient began somewhere between zero and one second. (This uncertainty is due to the manner in which the transient was initiated, namely, manual opening or closing of the valves that control the flow of the condenser coolant.) For the calculations which will be discussed later (denoted by circles in Figs. 1 and 2), it has been assumed that the transient began at t = 0.5 sec.

An analysis of the transient void-fraction data has been conducted based on quasi-steady state approximation. The following steps were taken: (1) The change in the internal energy was estimated from the pressure transient data shown in Figs. 1 and 2, assuming a saturated mixture of water and steam in the boiling pool. This assumption was shown to be valid by measurements of the pool temperature. (2) The heat losses (for the pressurization transient) or gains (for the depressurization transient) at the side and lower boundaries were estimated based on transient conduction into or from the stainless steel vessel. These heat losses or gains were found to be significant. (3) The heat loss rate at the upper boundary, $\dot{Q}_L(\text{up})$, was determined from an energy balance over the boiling pool. (4) The maximum steam superficial velocity was deduced from $\dot{Q}_L(\text{up})$ by $j_{gmax} = \dot{Q}_L(\text{up})/(\rho_g h_{fg} A)$ where ρ_g is the steam density, h_{fg} is the heat of vaporization, and A is the cross sectional area of the vessel. (5) Assuming that the steady-state data on the average void fraction vs. the maximum steam superficial velocity as reported in Ref. 1 are applicable during the transient, the average void fractions at various times during the transient were estimated from the values of j_{gmax} as deduced above. (For consistency, a representative curve was drawn through the steady state data of Ref. 1 and used in all calculations.) Such estimates are indicated by circles in Figs. 1 and 2. It is seen that the estimates are in reasonable agreement with the data, indicating that the quasi steady state approximation is valid. The quasi steady state approximation would be expected to be valid for a transient significantly longer than the characteristic bubble rise time. For the present experiment, the characteristic bubble rise velocity is 20 cm/sec, so it would take about one second for the bubble to rise from the bottom to the top of the boiling pool. The experimental data seem to support the expectation. In the quasi steady state approximation, the transient boilup is solely controlled by the heat loss rate at the upper boundary. Thus, it is extremely important to model properly the heat loss process occurring at the upper boundary of a boiling pool.

Reference

1. D. H. Cho, G. A. Lambert, and S. W. Jones, "Closed-pool Boilup Experiment," Trans. Am. Nucl. Soc. 43, 510 (1982)

Figure Captions

Fig. 1. Pressure and Void Fraction Changes During a Pressurization Transient

Fig. 2. Pressure and Void Fraction Changes During a Depressurization Transient

FIG. 1

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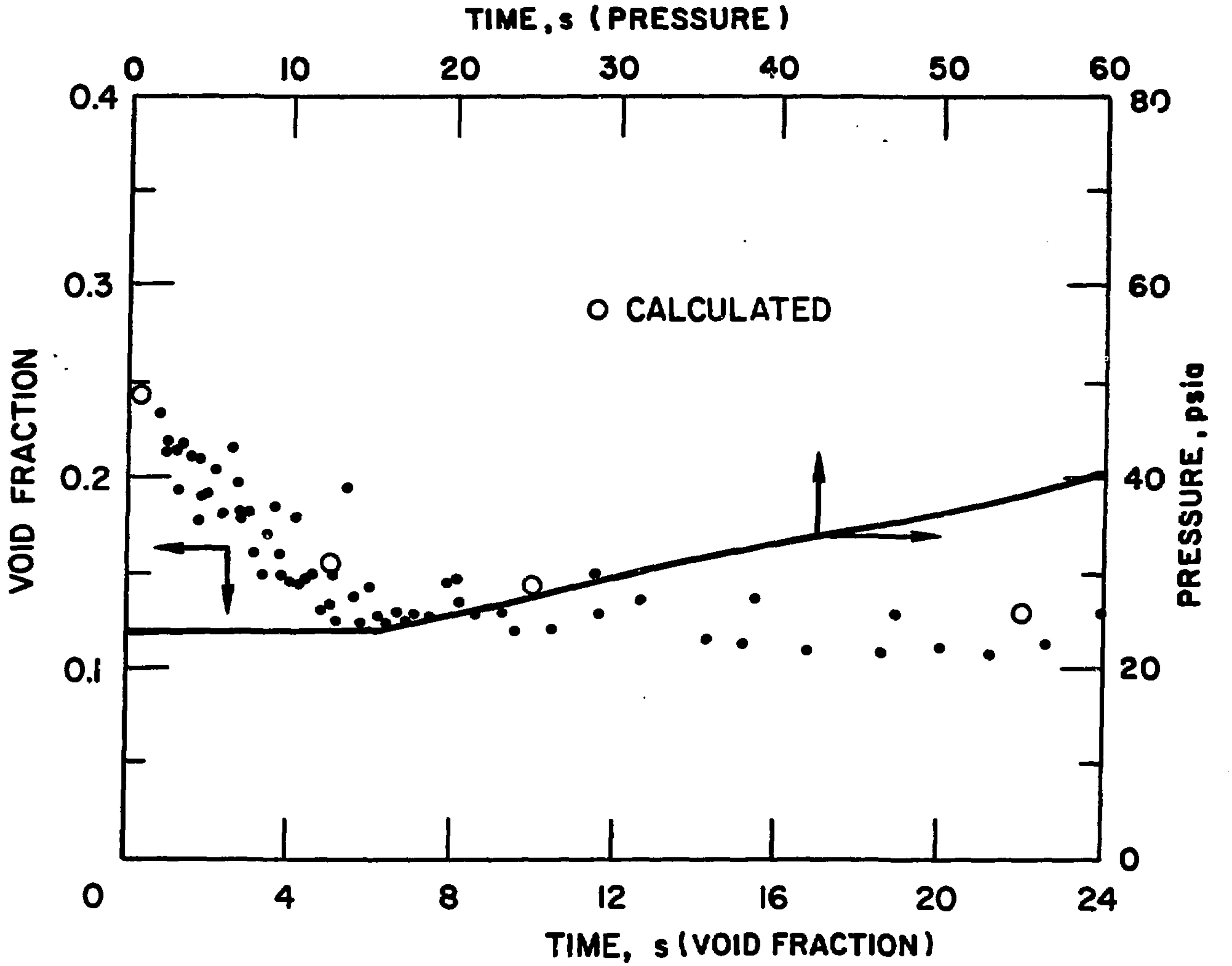

FIG. 2

CHO, LAMBERT, CHA