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Droplet Generation During Core Reflood

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The process of entrainment and disintegration of liquid droplets by a flow of steam has considerable practical importance in calculating the effectiveness of the emergency core cooling system. Liquid entrainment is also important in determination of the critical heat flux point in general. Thus the analysis of the reflooding phase of a LOCA requires detailed knowledge of droplet size.

Droplet size is mainly determined by the droplet generation mechanisms involved. To study these mechanisms, data generated in the PWR FLECHT SEASET series of experiments [1] was analyzed. In addition, an experiment was performed in which the hydrodynamics of low quality post-CHF flow (inverted annular flow) were simulated in an adiabatic test section.

In the FLECHT SEASET experiments, heated rod bundles were quenched by water, at pressures up to 0.41 MPa. Droplet sizes and velocities were observed at distances well beyond the quench front. With the photographic technique used, small, high velocity droplets could not be observed with high resolution, so that the size distributions reported may be misleading. However, from the larger-sized droplets (.3-1.5 mm) observed, droplet generation mechanisms may be examined.

Criteria for droplet disintegration have been expressed in terms of a critical droplet Weber number, such as that proposed by Hinze [2]. However, this criteria overestimates the droplet sizes observed in FLECHT SEASET. Therefore, the majority of droplets observed were generated through entrainment at the quench front, and not during the subsequent flight of droplets in the gas stream. Flow regimes at the quench front should therefore be important in determining mechanisms of droplet entrainment.

For FLECHT SEASET trial runs with high vapor flow rates, annular or annular-mist pre-CHF flow was present. Gas velocities were such that the roll wave entrainment inception criterion of Ishii and Grolmes [3] was satisfied. At these high gas flow rates, the droplet sizes observed are similar to the volume median droplet sizes predicted by Kataoka et al. [4] for roll wave entrainment:

$$d_{vm} = 0.0099 \left(\frac{\sigma}{\rho_G j_G^2}\right) Re_G^{2/3} \left(\frac{\rho_G}{\rho_F}\right)^{-1/3} \left(\frac{\mu_G}{\mu_F}\right)^{2/3} \quad (1)$$

However, for most of the FLECHT SEASET trials, lower gas fluxes were present, and Eq. (1) overestimates droplet sizes. For these conditions, churn turbulent flow occurs at the quench front. Maximum stable droplet size may then be estimated by considering the relative velocity for churn turbulent flow [5]

$$u_r = \sqrt{2} \left(\frac{\sigma g \Delta\rho}{\rho_G^2}\right)^{1/4} \quad (2)$$

and by assuming that rising particles will be stable only if they are in wake (rather than distorted) particle flow regime, where

$$u_r = \frac{d}{4} \left(\frac{(g\Delta\rho)^2}{\mu_G \rho_G}\right)^{1/3} \quad (3)$$

Combining Eqs. (2) and (3), the maximum stable droplet size is

$$d_{max} = 4 \left(\frac{2\sigma}{g\Delta\rho}\right)^{1/2} N_{\mu G}^{1/3} \quad (4)$$

Most of the FLECHT SEASET droplet size data are in close agreement with this expression for d_{max}.

In the experimental simulation of inverted annular flow, water jets were enclosed within gas annuli, and velocities, diameters and gas species were varied. Detailed information about this study may be found in Ref. [6]. At relative velocities similar to those predicted by the Ishii and Grolmes criterion [3], the dominant mechanism for liquid core break-up became roll wave entrainment, leading to transition from inverted annular to dispersed droplet flow. Roll waves first appeared on the crests of sinuous core deformations, while at higher relative velocities roll waves appeared before sinuous core deformation occurred.

Droplets were observed as they formed at roll wave crests. At high relative velocities, a modified version of the droplet size prediction of Kataoka et al. [4], taking into account the geometry of inverted annular flow,

$$d_{max} = 0.088\left(\frac{\sigma}{\rho_G(v_{rel}/\alpha)^2}\right)Re_J^{-1/6}\left(\frac{Re_{G,rel}}{\alpha}\right)^{2/3}\left(\frac{\rho_G}{\rho_J}\right)^{-1/3}\left(\frac{\mu_G}{\mu_J}\right)^{2/3} \quad (5)$$

correlated the data well (the subscript J indicates the liquid core jet). However, at lower relative velocities, Eq. (5) overestimates droplet size. It appears that a limiting droplet size is reached, as predicted by the stability criteria of Eq. (4). The droplet size data is presented in Fig. 1, along with the d_{max} predictions of Eqs. (4) and (5). Additional, limited droplet size data was taken at the test section exit, where d_{max} values similar to those predicted by Eq. (4) were observed.

The results from both FLECHT SEASET and the present experimental study indicate that, at high relative velocities, the droplet size predictions for roll wave entrainment, Eqs. (1) or (5) are valid. At lower relative

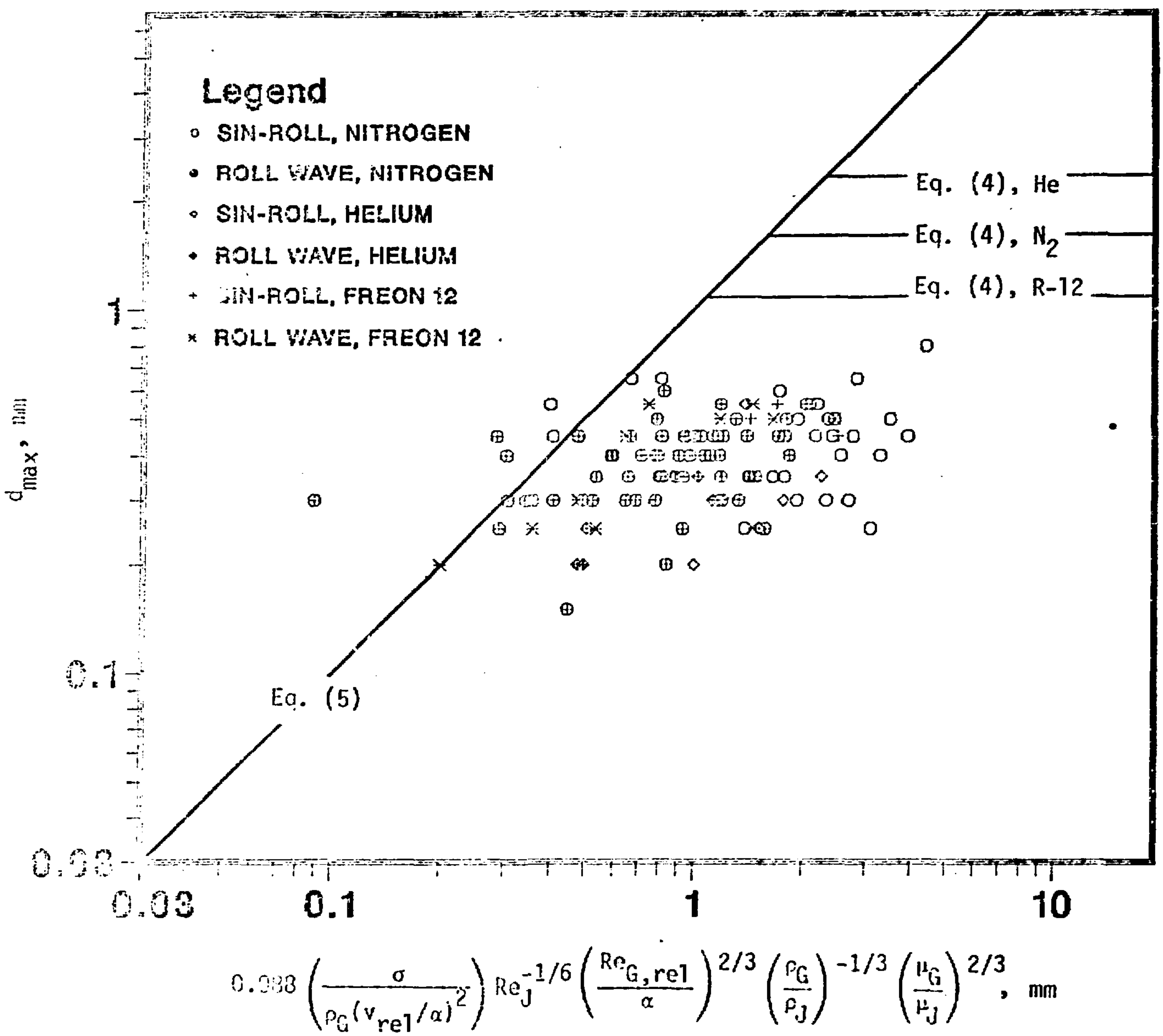

Fig. 1 Droplet Size Data from Inverted Annular Flow Simulation, Roll Wave Entrainment and Roll Wave/Sinuous Deformation Break-up

velocities, however, a maximum droplet size limit is reached, based upon the transition from wake to distorted particle flow (Eq. (4)).

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