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BWR POOL PENETRATION AND SCALING STUDY

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ABSTRACT

An analysis of water and air injection depths into the wetwell pool during blowdown for a vertical vent BWR is presented. The Bernoulli theorem is applied to both air and water jets. The results indicate that air injection depths presented in JIM-4-75 arc conservative and that vent submergence is the critical parameter that should be considered for scaling purposes.

I. INTRODUCTION

A previous letter[1] discussed the question of the penetration depths of the air injected into the wetwell pool during blowdown of vertical vent systems such as MARK I and II or Marviken. This discussion considered only air and ignored the penetration into the wetwell of the slug of water initially contained within the vents. Recent discussions have resulted in speculation that this water slug might penetrate into the wetwell much farther than would a simple air slug. This behavior could then initially lead to the formation of a "pocket" behind the water slug which would, in turn, result in deeper air penetration depths than predicted by the analysis[1].

This report analyzes this problem and presents suggestions concerning important scaling factors that should be accounted for in experimental investigation of blowdown phenomena.

II. ANALYSIS OF INJECTION DEPTHS

The analysis is made by assuming that the slug of water expelled from the vents during blowdown behaves as a homogeneous jet, of finite length λ, impinging upon a fixed target represented by the wetwell pool. For this purpose, λ is equal to the length of the water slug initially contained in the vent and, therefore, to the vent submergence.

The liquid slug initially penetrates the wetwell pool with a velcity v_j. At maximum penetration, the system becomes analogous to a jet impinging on a stationary target. Then, the length of the jet will begin to diminish as the jet collides with the target and the flow pattern is reversed.

The length of the jet will, upon collision with the fixed target, diminish with some rate $v_j - u$, where v_j is the impingement velocity and u is the penetration velocity into the target. It should be noted that v_j is dependent upon the mass flow rate and u is strictly a function of the interaction between the jet and the pool. Relative to an observer moving with the penetration velocity u, the phenomenon could be viewed as one where the target and jet approach a common stagnation point with velocities u and v_j-u, respectively. Figure 1 illustrates the final configuration where the maximum penetration depth has been obtained.

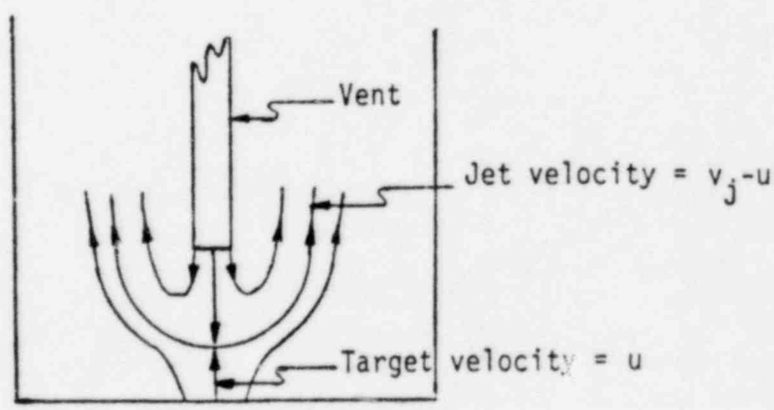

Figure 1. Maximum Jet Penetration

The interface, illustrated in Figure 1, between the jet and the wet-well pool is a stagnation point at maximum penetration. Bernoulli's theorem applies in both media, and equating pressures at the stagration point, the following relationship is established;

$$1/2\ \rho_j(v_j - u)^2 = 1/2\ \rho u^2 \tag{1}$$

where

ρ_j = density of jet

ρ = density of wetwell pool

$(v_j - u)$ = rate of change of jet length

u = rate of penetration

Now, the ratio of the rate of penetration, u, to the rate of change of length of the jet is from Equation (1) equal to:

$$\sqrt{\frac{\rho_j}{\rho}} \tag{2}$$

Assuming that there is a moment when the jet is just stopped, before it diminishes from length λ; then Equation (2) is also equal to the ratio of the absolute depth of penetration to the initial length of the jet. Therefore,

$$\frac{\text{depth of penetration}}{\text{length of jet}} = \sqrt{\frac{\rho_j}{\rho}} \tag{3}$$

Equation (1) was applied to shaped charges, was quite well confirmed experimentally[2], and it should apply equally well to the problem being discussed in this report.

The densities of the water slug, contained within the vent, and the wetwell pool are equal and therefore Equation (3) may be written as:

$$\text{depth of penetration} = \text{length of jet} \tag{4}$$

Therefore, the maximum depth of penetration of the vent water slug into the wetwell pool will be equal to the vent submergence. Assuming incompressible flows, the initial configuration and the final configuration (after vent clearing) of the vent and water slug can be illustrated as in Figure 2.

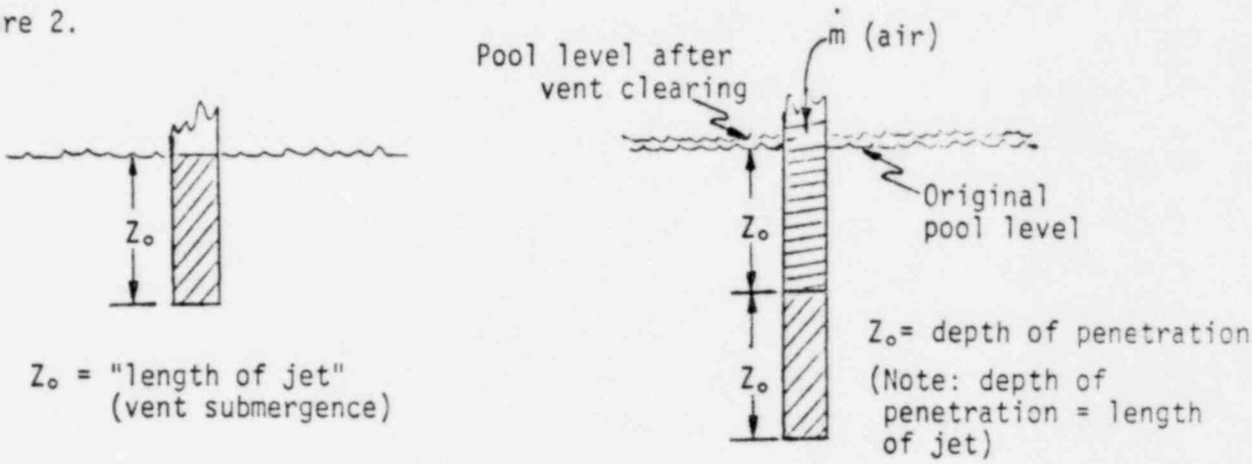

Figure 2. Water Slug Penetration

From Figure 2, it is seen that the maximum penetration depth is equal to the length of the vent submergence. Therefore, the air will "see" a system that could be modeled as an air-filled vent resting on the surface of a pool of water. Then, the air penetration can be calculated and, based upon the previously described model, it is seen that these depths are negligible.

Realizing that these conclusions are based upon idealized, steady-state models, it is speculated that actually a "bullet" effect might result in observations that differ from the above description. The "bullet" effect is simply a result of the probability that the jet will deform during penetration due to the influence of the floor of the pool and the motion of the

pool free surface. Figure 3 illustrates this "bullet" effect.

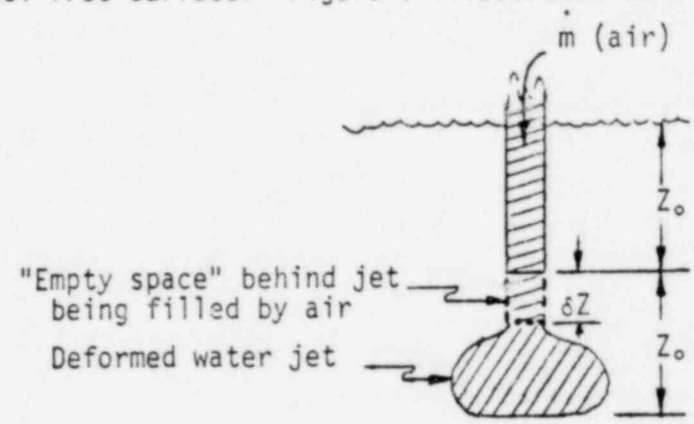

Figure 3. Bullet Effect

Therefore, the total penetration of the air jet would be given by:

$$\sqrt{\frac{\rho_{air}}{\rho_{water}}} + \delta Z \qquad (5)$$

Depending on δZ, the pool thickness used in the pool swell model could become a non-negligible value. However, two points are important and must be considered:

(1) The additional penetration, δZ, would only hold during the initial vent clearing transient. A steady-state situation would quickly develop (a model to estimate the response time could be developed) and then the penetration depths predicted by Equation (3) would again be valid.

(2) The additional pool thickness, δZ, would result in added conservatism because of greater hydrostatic forces ($\rho_1 gh$) acting upon the expanding air volume; lower pool velocities and lower surface heights would result. However, the corresponding momentum associated with the pool would be approximately the same. Momentum has

a linear dependence upon mass and velocity. An increase in mass results in a corresponding decrease in velocity and vice versa.

One more application of Equation (3) is possible. By making suitable adjustments of density, it is possible to approximate the injection depth of air into the wetwell pool and thus supply a check of earlier results. The results of this exercise indicate that:

$$\text{penetration depth} = (\text{vent submergence})\ (0.038) \qquad (6)$$

Densities used for air and water were 0.088 lbm/ft^3 and 62.4 lbm/ft^3 respectively. These values were taken from a Marviken test of the pool swell model, and the maximum density of air observed in this test was used for conservatism. The vent submergence for Marviken was 9.2 feet and therefore the maximum predicted air injection depth is 4.2". This compares to an injection depth of approximately 6" predicted previously.

III. SCALING

Equation (3) furnishes insight into those parameters that are important when scaling experimental systems. The equation indicates that the vent submergence depth is a critical determinant of injection depths. Thus, if a system is, for example, one-third scale, it is important to reduce the submergence depth accordingly. Also, to insure that effects due to the proximity of the vent system to the bottom of the wetwell pool are accurately predicted, it is necessary to scale the distance between vents and wetwell pool bottom by the appropriate amount (i.e., one-third for a one-third scale system).

IV. CONCLUSIONS

The results of this study indicate that the maximum depth of penetration of the liquid slugs contained within the vents prior to blowdown is limited to the vent submergence depth.

The assumption of negligible air penetration depths is conservative, although experimental investigations may demonstrate, at least at the onset of air penetration, greater penetration depths than predicted due to the "bullet" effect.

The results of Equation (3) also indicate that vent submergence is the critical parameter to consider when experimentally modeling the air injection phenomena.

V. REFERENCES

1. JIMills, "BWR Pool Swell Model Applicability Study", ANC Letter Report JIM-4-75 (June 30, 1975).

2. GBirkhoff and EHZarantonello, Jets, Wakes and Cavities (New York: Academic Press, Inc., 1957), pp. 15-17.