

Letters to the Editor

Comments on “Level Swell Analysis of Marviken Test T-11”

The paper by Grolmes and co-workers¹ presents an analysis of level swelling, i.e., the vertical motion of the interface between the vapor space and the two-phase mixture of water vapor and liquid water in a vertical, cylindrical vessel during depressurization, achieved by venting from the top. This is an important subject for reactor safety analyses and for training simulators. It is, therefore, important that readers of this paper be cautioned as there are four serious errors in the analysis.

The authors have justifiably implied thermal equilibrium, as can be seen from Eq. (9) and from their use of Clapeyron's equation. Consequently, the following can be seen:

1. Equation (6) is wrong because it implies isochoric processes instead of processes along the saturation lines for both phases.

2. The vapor generation rate in Eq. (16) is wrong, since it implies that the net vapor volume generated by phase change below the level is discharged from the vessel. This is true only for constant pressure. In fact, the vapor generation rate is dictated by first principles. With the thermal equilibrium already implied, mass and energy balances dictate the vapor volume generation rate for adiabatic conditions:

$$\dot{V}_g = \frac{A}{\rho_g h_{fg}} \frac{dp}{dt} \left\{ H \left(1 - \rho_f \frac{dh_f}{dp} \right) + \left[\rho_f \frac{dh_f}{dp} - \rho_g \frac{dh_g}{dp} \right] \int_0^H \alpha dz \right\}, \quad (1)$$

which shows that the depressurization rate and the thermal and caloric equations of state [for densities $\rho_f(p)$, $\rho_g(p)$ and enthalpies $h_f(p)$, $h_g(p)$] determine how much vapor is being generated. In the absence of heating, vapor is only generated by depressurization, $dp/dt < 0$. Equation (16) in the paper requires constant ρ_g , which requires $dp/dt = 0$. Thus, Eq. (16) is wrong. In fact, the vapor above the level condenses during depressurization.

In passing, it should be noted that, contrary to the authors' assertion,

$$C_p - C_v = Tv\beta^2/\kappa \approx 31\% \text{ of } C_p \text{ at } p = 30 \text{ bar}$$

[$\beta = 1/v(\partial v/\partial T)_p$ and $\kappa = -1/v(\partial v/\partial p)_T$], and that the interchange of C_v and C_p leads in general to unacceptable errors in the calculation of liquid temperatures. Also, Eq. (10) is easier to derive in terms of di_f/dp , di_g/dp , dv_f/dp , and dv_g/dp . This

obviates the use of unavailable property derivatives (C_s along saturation line) and the use of composite derivatives (Clapeyron equation).

3. Equation (15) is wrong because the j_g term does not account for the motion of the level. The rate of net vapor accumulation equals the difference between accumulation and discharge through the *moving* boundary at the level elevation $H(t)$. Equation (15) of the paper can be written as the equation of motion for the level

$$\frac{dH}{dt} = \frac{\dot{V}}{A_x} - j_g(\bar{\alpha}) . \quad (2)$$

First principles, namely, mass conservation for both phases, written for the level, require that the mass jump condition be satisfied. For $\alpha^+ = 1$ above the level, it is required that

$$\frac{dH}{dt} = \frac{\langle j_g^+ \rangle - \langle j_g^- \rangle}{\langle \alpha^+ \rangle - \langle \alpha^- \rangle} = \frac{\langle j_m \rangle - \langle j_g^- \rangle}{1 - \langle \alpha^- \rangle} \quad (3)$$

and

$$\langle j_m^+ \rangle = \langle j_m^- \rangle = \langle j_m \rangle , \quad (4)$$

where $\langle j_g \rangle = \langle \alpha V_g \rangle$, $\langle j_m \rangle = \langle j_g \rangle + \langle j_f \rangle = \langle j_g \rangle + \langle (1 - \alpha) V_f \rangle$; the superscript minus designates “just below the level” and superscript plus denotes “just above the level.” It is quite clear that Eq. (2) above, and therefore Eq. (15) of the subject paper, cannot satisfy the mass balances and therefore cannot be right.

4. The authors claim in the Appendix that Eq. (21) represents the bubble rise velocity. In fact, it is the void fraction weighted, area-averaged drift velocity (pp. 23 and 36 in Ref. 2):

$$\langle\langle V_{gi} \rangle\rangle = \frac{\langle \alpha V_{gf} \rangle}{\langle \alpha \rangle} , \quad (5)$$

where

$$V_{gj} = V_g - j_m , \quad j_m = \alpha V_g + (1 - \alpha) V_f .$$

Since (see Ref. 2, p. 26)

$$\langle j_g \rangle = \langle \alpha \rangle [C_0 \langle j_m \rangle + \langle\langle V_{gi} \rangle\rangle] , \quad (6)$$

it can be seen that

$$\langle j_g \rangle = \langle j_m \rangle = \frac{\langle \alpha \rangle \langle\langle V_{gi} \rangle\rangle}{1 - C_0 \langle \alpha \rangle} \text{ only for } \langle j_f \rangle = 0 . \quad (7)$$

Thus, Eq. (A.1) in the Appendix is not valid for the level swell analysis since $\langle j_f \rangle \neq 0$, as the liquid must be lifted at first and then falls back, while the level first swells and then recedes.

The steps between Eqs. (A.1) and (A.4) are intuitive and unsupported in view of first principle evidence. The vapor generation rate is proportional to α [see local form of Eq. (1) above]; it depends on pressure (saturation properties) and on rate of change of pressure. The authors' assumptions are in conflict with these facts.

Returning to Eq. (15) of the paper, it must now be concluded that this equation is wrong for two reasons:

1. It ignores the fact that the vapor is escaping through the level interface with the relative velocity $V_g - dH/dt$, i.e., with the superficial velocity,

$$\langle j_g^- \rangle - \langle \alpha^- \rangle \frac{dH}{dt} = \frac{\langle \alpha^- \rangle}{1 - \langle \alpha^- \rangle} [(C_0^- - 1) \langle j_m \rangle + \langle V_{gi}^- \rangle], \quad (8)$$

where j_m is the volumetric mixture flux at the level.

2. It assumes that the liquid superficial velocity is zero, which it cannot be.

It has been shown^{3,4} that level swell analyses must always involve two fundamental principles. First, they must obviously involve conservation equations applied to control volumes with moving boundaries. Second, they must involve the mass jump conditions (conservation at the interface). Model formulations that contradict first principles are suspect at best.

It is interesting to note that the authors did not employ Eq. (21). Instead, they "tuned" U_∞ to fit the data. The risk is high that compensating errors keep the difference between prediction and experiment below 20% of total variation (Fig. 13). One cannot expect the model to work in general, for example at higher pressures or for bottom draining. Most importantly, however, ΔP measurements were used but are very poor for level measurements because they indicate only collapsed liquid levels.

Simplified models should not be in conflict with conservation laws; they should be shown to approximate rigorous models with necessary accuracy. Good agreement with experiments is necessary but not sufficient.

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REFERENCES

1. M. A. GROLMES, A. SHARON, C. S. KIM, and R. E. PAULS, *Nucl. Sci. Eng.*, **93**, 229 (1986).
2. M. ISHII, "One-Dimensional Drift Flux Model and Constitutive Equations for Relative Motion Between Phases in Various Two-Phase Flow Regimes," ANL-77-47, Argonne National Laboratory (Oct. 1977).
3. W. WULFF, "Lumped-Parameter Modeling of One-Dimensional Two-Phase Flow," *Proc. 2nd OECD/CSNI Specialists' Mtg. Transient Two-Phase Flow*, Paris, June 12-14, 1978, CONF-780659.
4. W. WULFF, "The Kinematics of Moving Flow Regime Interfaces in Two-Phase Flow," *Proc. 3rd OECD/CSNI Specialists' Mtg. Transient Two-Phase Flow*, Pasadena, California, March 23-25, 1981, Report No. 61, CONF-810307.

Response to "Comments on 'Level Swell Analysis of Marviken Test T-11'"

We thank Wulff¹ for pointing out an error in our paper.² Equation (6) should refer to the unnumbered equation preceding Eq. (6) on p. 232:

$$c = x \frac{di_g}{dT} + (1 - x) \frac{di_f}{dT}.$$

The following sentence, which begins with "The mixture heat capacity . . ." and ends with "(note $C_{vf} \approx C_{p,f}$)," should be ignored. Numerical calculations were based on the unnumbered equation rather than the approximation.

The other points raised by Wulff challenge the validity of the underlying analytical approach taken in the paper. The authors duly noted and are familiar with analysis that emphasizes analytical rigor.

The paper attempts to apply a semiempirical approach to level swell data obtained from the Marviken test and thereby provides a useful engineering tool for such an analysis. Due to the complex nature of the fluid behavior, a one-dimensional lumped parameter model is used, and a quasi-steady behavior is assumed for the liquid pool and the vapor phase above it. As stated in the paper, we were not attempting to present an exact solution due to its limited usefulness and complexity in implementation. Specifically, Eqs. (15) and (16) imply a first principle mass balance on the vapor phase essentially stating that the vapor mass accumulation is equal to the difference between the vapor generation rate in the pool and the rate at which vapor leaves through the vent. Under most practical conditions, the change in vapor density

$$\frac{1}{\rho_g} \frac{d\rho_g}{dt}$$

is smaller by more than an order of magnitude compared to the change in level

$$\frac{1}{H} \frac{dH}{dt}.$$

The assumption on the quasi-steady pool behavior was used to derive the general form of the relations between j_g and $\bar{\alpha}$. A reader familiar with the available data on this relation is probably aware of the large scatter in the data. Therefore, the approach of using an empirical parameter C_0 is frequently used in engineering applications and analytical studies to compensate for the actual complex pool dynamic. The value of $C_0 = 1.7$ used in this analysis is within its normal uncertainty bounds and