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A NEW ASSESSMENT OF THE LARGE-TANK GENERAL ELECTRIC SWELL PROBLEM USING RELAP5-3D

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Abstract

The RELAP5-3D (version 1.5.1) computer program was used to assess a subset of the GE level swell experiments. The primary goal of this new assessment was to provide an updated evaluation of latest fluid flow modeling capability available in RELAP5-3D. In this evaluation great care was taken to faithfully represent the experimental facility and instrumentation. The GE level swell tests were performed using two vessel sizes. The vessels had nominal diameters of 0.3048 m (1 ft) and 1.2192 m (4 ft). This assessment will focus exclusively on four tests, with flow-limiting outlet venturi of different diameters, performed on the larger of the two vessels.

The new assessment highlights the sensitivity of choked-flow limited calculations to the value of the input discharge coefficients. Unlike other assessments of choked-flow phenomena, the results of this assessment are essentially insensitive to the particular choked-flow model being employed. However, the use of the optional Henry-Fauske critical flow model is recommended in lieu of the default RELAP5-3D Ransom-Trapp model for consistency with other recent assessments.

This evaluation also highlights the effect of time step size on the calculated results. The variation in results obtained using small time steps was unexpected. However, the effect of these variations on the predicted time-dependent blowdown of the system has been shown to be very small.

In addition, this assessment has examined a variety of RELAP5-3D interfacial drag correlations. It has been shown that the experimentally-determined void fraction profiles and two-phase mixture levels are best modeled using the optional Vea-Lahey interfacial drag correlation.

This paper provides the RELAP5-3D user with guidance as to which correlations to invoke for best-estimate calculations of blowdown transients similar in nature to the GE level swell experiments. Evidence is provided for chosing the interfacial drag model and the critical flow model including its corresponding adjustable coefficients.

Introduction

Many of the transients of interest to the thermal-hydraulic safety community (Loss of Coolant Accidents) are characterized by fast depressurization due to the loss of liquid inventory. This depressurization causes flashing of the liquid as the pressure falls below the saturation pressure for the fluid temperature. Accurate predictions of the time-dependent inventory and varying void distribution profiles in various system components are important for thermal-hydraulic safety programs.

Circa 1980, General Electric (GE) performed a series of experiments [1] to measure both void distribution and level swell phenomena for depressurization transients.

These tests have become standard qualification problems for reactor safety programs. Previous versions of the RELAP5 program have been assessed relative to both the small- and large-tank GE level swell tests [2]. Researchers at the Bettis Atomic Power Laboratory have recently re-evaluated a small-tank level swell test (number 1004-3) [3] with an upgraded assessment model using RELAP5-3D [4]. As was the case in the previous study [3], the latest models of the large-tank GE level swell tests were intended to represent more faithfully the test facilty and associated instrumentation, thus providing improved accuracy relative to the experimental data.

In the present paper assessments of the top-break, large-tank GE level swell tests (numbers 5801-13, 5801-15, 5801-19, and 5702-16) will be updated (see Table 1). As shown in Table 1, these tests employed blowdown venturis with throat diameters ranging in size from 54 mm (2.125 in.) to 92.1 mm (3.625 in.).

As a result of the large volume of experimental data available, as well the existence of previous RELAP5 analyses, test 5801-15 with a venturi throat diameter of 63.5 mm (2.5 in.) was chosen to study the effect of various critical flow models and discharge coefficients on the predicted evolution of the transient. In addition, this experiment was also used to determine the effect of time step size on the calculational results.

A study of the effects of various interfacial drag correlations on the predicted time-dependent void fraction profiles was also performed using test 5801-15. This study was performed using the previously obtained “best” critical flow model attributes.

Finally, the three additional experiments (with varying venturi throat diameters) were modeled with both the ‘best’ critical flow model attributes and the ‘best’ interfacial drag correlation.

Description of the Test

The large-tank GE level swell tests being analyzed were designed to measure time-dependent pressures and void fraction profiles in a large tank which was depressurized via a blowdown line consisting of a dip tube and venturi. In the top-break tests, the entrance to the centrally-located dip tube was set to be significantly above the initial liquid level. The various level swell tests can be distinguished from one another by the diameter of the associated flow-limiting outlet venturi. A schematic of the experimental facility used for the top-break, large-tank blowdown tests is shown in Figure 1.

The pressure vessel was made from carbon steel, with a volume of approximately 4.5 m^3 (160 ft^3), an inner diameter (I.D.) of 1.19 m (47 in.) and a height of 4.27 m (14 ft). For the top-break blowdown tests studied in this paper, a 0.254 m (10 in.) nominal diameter carbon steel dip tube was installed vertically within the vessel. The entrance to the centrally-located dip tube was set to a height 1.52 m (5 ft) above the initial liquid level of 1.68 m (5.5 ft). Beginning at its entrance, the dip tube extended vertically downward within the vessel to approximately the 0.76 m (2.5 ft) level after which the tube made a 90 degree bend then exited the vessel horizontally. For each of the four large-tank, top break blowdown tests studied in this paper, a gradually-tapered flow-limiting venturi was concentrically mounted within this horizontal section of the blowdown line. As presented in Table 1, the throat diameters of these venturi ranged from 54 mm (2.125 in.) to 92 mm (3.625 in.). A rupture disk assembly, used for transient initiation, was placed within the blowdown line immediately downstream of the venturi. Finally, the blowdown line/dip tube assembly exited to the atmosphere.

Figure 1 shows the locations of the strain-gage pressure transducers used to obtain absolute (e.g., P101) and differential (e.g., D103 through D109) pressure measurements within the experimental facility. The seven regions between the various adjacent differential pressure taps are referred to as levels or segments. These levels are numbered sequentially starting from the bottom. Differential pressures were used to infer the void fraction in each segment based on the assumption that hydrostatic head was the only component contributing to the pressure difference. The height of the two-phase level was determined using a two-step process. First, the segment containing the two-phase level was heuristicaly determined using the axial void profile within the vessel. Next the position of the two-phase level in that segment was calculated based on the assumption that the void fraction below the two-phase level was equal to void fraction in the segment directly beneath it.

The initial conditions for all top-break, large-tank GE level swell tests were a system filled to a level of 1.68 m (5.5 ft) with demineralized water at a pressure of 7.28MPa (1060 psia) and a fluid temperature corresponding to the saturation temperature at this pressure, 561.9K (551.7^{o}F). Before initiating the various blowdowns, the system was allowed to ‘soak’ for thirty minutes to equalize the temperature in the fluid and structural material. The blowdowns were initiated by a rupture disk assembly connected to the downstream flange of the horizontally-situated venturi section of the blowdown line.

Original Assessment Model

The input description for the original assessment is described in Volume III of the RELAP5/MOD2 Code Manual [2]. An electronic copy of the corresponding input deck was obtained from RELAP5-3D program developers, Idaho National Engineering and Environmental Laboratory (INEEL). In this model, the 4.5 m^3 (160 ft^3) pressure vessel, with dip tube in place was represented using 27 one-dimensional (1-D) volumes, 6 above the entrance to the dip tube, 20 below the entrance, and one volume associated with a branch component to which the entrance of the dip tube was connected. The blowdown line/dip tube was modeled using 6 1-D volumes, 4 in the vertical portion of piping and two in the horizontal portion of piping leading up to the venturi. The junction representing the venturi was in turn connected to a time-dependent volume representing atmospheric conditions. For the specific blowdown experiment being assessed by INEEL (experiment 5801-15) the circular venturi throat diameter of 63.5 mm (2.5 in.) was represented explicitly.

The volumes representing the vertical dip tube were connected to the bottom of the branch component within the vessel. The elevation of this connection (which allows the vertical transfer of fluid momentum from the vessel) is 3.14 m (10.3 ft), 0.061 m (2.4 in.) below the actual elevation of the top of the dip tube.

The areas of the volumes within the dip tube correspond to a pipe with an inner (rather than nominal) diameter of 0.254 m (10 in.).

All junctions at which an area change occurred were modeled using the RELAP5 smooth area change option with zero form loss factors. In addition, both the level tracking and vertical stratification models were disabled in the original model. Finally, the heat capacity and thermal conductivity of the vessel and blowdown line/dip tube walls were ignored in this model. In the original model the default Kataoka-Ishii interfacial drag model [5] was employed along with the default RELAP5 Ransom-Trapp critical flow model [6] with unity subcooled, two-phase, and superheated discharge coefficients.

Revised Assessment Model

In previous assessments of RELAP5-3D [3,7], it was concluded that faithful representations of the experimental facility including instrumentation, boundary conditions and initial conditions were required to obtain an undistorted assessment. This philosophy was used in the creation of the revised assessment model.

A slight error in the representation of the blowdown line/dip tube inner/outer diameters in the developmental assessment model was found and corrected. The blowdown line/dip tube was changed to be consistent with 0.254 m (10 in.) nominal diameter schedule 60 pipe. As a result, the dip tube internal flow area was reduced 4.9 percent relative to the developmental assessment model.

The revised model was set up to use 18 volumes, with 3 volumes each in both the upper and lower head regions. The head area volumes were calculated based upon knowledge of the stated (empty) vessel internal diameter, volume, and height. Elliptically shaped vessel heads with a minor axis dimension of 0.329 m (1.08 ft) satisfied all three of the above dimensional requirements. This geometry, although not explicitly depicted in the desciption of the present test, is commonly used in the construction of cylindrical pressure vessels. Meanwhile, the vertical flow area and volume of several volumetric components within the vessel were modified to account for the presence of the initially dry dip tube assembly within the vessel. Finally, the elevation of the center of volume 13 within the vessel was set to be 3.20 m (10.5 ft), the correct cross-flow offtake position for the dip tube assembly assuming a horizontal connection.

The blowdown line upstream of the venturi throat was modeled using 3 volumes, 2 in the vertical portion of piping and one representing the horizontal contraction portion of the venturi assembly. The single junction representing the venturi throat was in turn connected to a single volume representing the expansion portion of the venturi assembly. This volume was connected by a valve component representing the burst disk assembly to a time-dependent volume representing the catch tank at atmospheric conditions.

For the first series of comparisons, a circular venturi with a throat diameter of 63.5 mm (2.5 in.) (experiment 5801-15 in Table 1) was explicitly represented.

The lengths of the fluid volumes in the vessel which contained the taps used for differential pressure readings were adjusted such that their cell-center elevation corresponded to the correct elevation of the instruments.

The heat capacity associated with the carbon steel structural material of the vessel was modeled explicitly. The test description provides no indication of the thickness of the pressure vessel walls. Therefore, based upon ASME standards for the pressure being contained, a vessel wall thickness of 0.051 m (2 in.) was employed. The initial vessel wall temperatures were assumed to be at the saturation temperature, 561.9K (551.7^{o}F). Based upon the relatively small amount of structural material involved, the heat capacity of the entire dip tube assembly was ignored.

Non-zero form loss coefficients were applied to several of the smooth area change junctions within the revised model. Appropriate numerical values for these form losses were calculated in accordance with Crane Technical Paper No. 410 [8].

To be consistent with experiment, differential pressures are used to infer the average segment void fractions. To establish the correct static hydraulic head required to infer void fractions during the transient blowdown calculation, the model was initialized for 10 seconds with the rupture disk assembly intact.

Unlike the original assessment, the RELAP5-3D level tracking model was activated in all vertically oriented volumes in this revised assessment. Activation of the level tracking model enables the height of the two-phase level within the vessel to be calculated automatically by the version of RELAP3-3D employed in this study. The value of the variable *levhgt* for the level stack representing the vessel is used as the calculated two-phase level. A schematic of the fluid component nodalization used in the revised top-break, large-tank GE level swell test assessment model is presented in Figure 2.

At this point it may be noted that the revised RELAP5-3D model, similiar to the original assessment model, is made up entirely of one-dimensional thermal-hydraulic components. This approach is entirely appropriate given the one-dimensional nature of the experimental facility.

Comparison of Model Results

The default Kataoka-Ishii interfacial drag model [5] was employed in the first series of revised assessment calculations. In addition, both the default RELAP5-3D Ransom-Trapp [6] and optional Henry-Fauske [9] critical flow models were employed, in seperate calculations, with unity discharge coefficients. The non-equilibrium parameter for the Henry-Fauske critical flow model was retained at its default value of 0.14. As a consequence of high vapor velocities in the downstream portion of the venturi assembly, Courant limitations caused the calculational time steps in the revised model to always be small. The calculational time step sizes ranged from 1.25 msec or less for times less than 6 seconds after initiation of blowdown to 2.5 msec or less for times between 6 and 20 seconds.

Figure 3 compares the experimentally-measured system pressure response with that obtained from both the original INEEL and revised RELAP5-3D assessment models (employing first the default Ransom-Trapp then the optional Henry-Fauske critical flow model). The experimentally-measured system pressure response is characterized by a sharp pressure dip and recovery between zero and 1.5 s. The initial pressure dip occurs because steam is extracted from the upper region of the vessel which locally depressurizes the system. This sudden pressure reduction causes flashing to occur in the initially saturated liquid located in the lower portion of the vessel. During this time vapor bubbles nucleate and grow, displacing the liquid that surrounds them. This phenomenon causes the two-phase liquid level to rise. The momentum associated with the rising mixture level compresses the steam in the upper vessel volume causing the pressure to recover. This transient momentum effect, however, quickly dies out, after which the vessel depressurizes at a relatively uniform rate.

Figure 3 shows that all RELAP5-3D simulations accurately predict the initial sharp pressure drop. The original simulation (with base time step size) predicts the repressurization that occurs early in the transient, although somewhat inaccurately. However, the revised simulations greatly overstate the observed magnitude of the initial repressurization. In addition, the time scale of the initial repressurization is compressed in a manner which is not consistent with experimental observations. It should be noted that the time response of the strain-gage pressure transducers is unknown. However, it is unlikely that the transducers could detect such a sharp rise in pressure if the phenomena did in fact have a physical basis.

Finally, all RELAP5-3D simulations significantly overpredict the uniform rate of vessel depressurization beyond two seconds. The overall predicted rate of depressurization, while conservative and thus adequate from a 10CFR50, Appendix K point of view, could lead to greater than desired uncertainty allowances from a best-estimate viewpoint. This significant overprediction of depressurization will be addressed and corrected in later sections of this paper.

Figures 4 through 7 compare, respectively, the experimentally-inferred and calculated axial void fraction profiles at four times during the blowdown transient. These times include: two, five, ten, and twenty seconds after the initiation of blowdown. In these figures the void fraction profiles depicted for both the experimental data and the revised RELAP5-3D assessment models were inferred from differential pressure tap readings, in the manner previously discussed. However, the void fraction profiles for the original assessment model were merely the time-dependent average void fractions in the RELAP5-3D volumes representing the vessel. Figure 4 shows that at two seconds into the transient, with the exception of the lowest level in the vessel, all three RELAP5-3D assessments do a good job of predicting the experimentally measured void fraction profile. However, the results of the new assessments appear to better match the experimental data than do the results of the original assessment.

Figures 5, 6, and 7 show that both the original and revised assessment models tend to miscalculate the void fraction profiles at later times in the transient. In each case the RELAP5-3D models generally tend to underpredict the void fractions at lower levels in the vessel while overpredicting void fractions at higher levels. This observation is consistent with the results depicted in Figure 8, the time-dependent experimentally-inferred and RELAP5-3D predicted two-phase levels. Here the revised assessment models tend to underpredict the experimentally-determined time-dependent two-phase levels. Two-phase levels can not be obtained from the original assessment model because level tracking has been disabled.

Sensitivity studies (not included here for brevity) have shown that, although a more exact representation of the experimental facility, the inclusion of passive heat structures has almost no effect on the results calculated by the revised assessment model. This is a result of the relatively large ratio of fluid volume to surface area in the vessel and the short vessel blowdown time. This combination allows the fluid very little contact time with the vessel structure, affording almost no opportunity for heat to be transferred between the two media.

Timestep Sensitivity

Upon examination of Figure 3, one notices that the early-in-transient repressurization prediction is much larger and more abrupt in the new RELAP5-3D assessments than it was in the original assessment calculation (with base time step size). Further investigation of these similiar calculations indicates that the original assessment model employs a timestep size of 0.01 s from zero to one second into the blowdown and a timestep size of 0.0125 s in the one to twenty second time frame. Thus the timestep sizes are from five to ten times smaller in the revised assessment models than they were in the original assessment model. To quantify the effect of timestep size, the original assessment model was re-run with approximately the same size time steps as those in the revised models.

The inset to Figure 3 depicts the initial time-dependent system pressure response obtained with the original assessment model using these smaller time step sizes. The pressure trace obtained using smaller time step sizes is similiar that obtained with the revised assessment model but drastically different than that obtained using the original assessment model with base time step sizes during the repressurization. Here both the revised assessment model and the original assessment model tend to significantly overstate the observed magnitude and compress the time scale of the repressurization in a manner which is not consistent with experimental observations when small time steps are employed. Figure 9 compares the initial venturi flow rate as a function of time after blowdown for the revised assessment model and for the original assessment model using the base and small time step sizes. This figure shows that the near instantaneous repressurization incidents found in the original and revised small time-step calculations also manifest themselves in rapid rises in the rate of mass outflux from the system. A review of the sonic or choked-flow velocity at the venturi, in either small-time-step model also shows distinct, near instantaneous variations (on the order of 1.5 percent) at times which correspond to repressurization spikes appearing in Figure 9. The small relative magnitude of these variations implies that, in this case, variations in sonic velocity have a very limited effect on system mass outflow. One can therefore conclude that the near instantaneous repressurization spikes cause a near instantaneous drop in the void fraction at the orifice. This rise in the density of the exiting mixture, with no change in exit velocity, then results in the rapid upward shifts in break-flow rate.

A review of the detailed results of the small time-step calculations have shown that rapid changes in volumetric void fraction, such as those associated with a vertically-stratified two-phase level passing through the bottom of a particular computational cell, manifest themselves as rapid changes in system pressure. Thus, the difference between the sharp calculated and smooth measured repressurization is thought to be a calculational artifice and is not believed to be related to the adequacy of the instrumentation to detect a sharp repressurization.

Thus, the excessive near instantanous repressurization found in both the revised RELAP5-3D analysis and the original analysis with small steps is thought to be a calculational artifice associated with the entrance of a vertically-stratified two-phase mixture level into a computational volume.

This dependency of predicted results on calculational time step size also been seen in the previous assessments of RELAP5-3D [3]. Based on these results, users should be careful to perform a time-step sensitivity when using thermal-hydraulic codes such as RELAP5-3D to ensure that a stable solution with respect to time step size has been achieved.

Sensitivity to Choking Model Parameters

The various venturis used in the large-tank GE level swell facility are of a unique design. This design does not directly correspond to any orifice that was used to develop either the Ransom-Trapp or Henry-Fauske critical flow models. As such, sensitivity studies were performed to determine the effect of varying the discharge coefficients in the critical flow models. Figures 10 through 15 depict the optimum results obtained from these sensitivity studies performed using the revised assessment model.

Figure 10 shows that regardless of the interfacial drag correlation being used the Henry-Fauske critical flow model yields a better overall match to the experimental time-dependent post-blowdown pressure trace if the critical flow discharge coefficient was set to 0.84 and the non-equilibrium coefficient was set to 1000 or the ‘frozen’ model. The ‘frozen’ model implies that evaporation and/or condensation is disabled in the orifice. Essentially identical results were obtained using discharge coefficients of 0.84 in the Ransom-Trapp critical flow model. Similiar values for discharge coefficients and non-equilibrium parameters were also shown to produce best results in previous RELAP5-3D assessments [10].

Variations in critical flow parameters have little effect on local conditions within the vessel. Therefore, as long as the interfacial drag correlation is not altered (from the default Kataoka-Ishii formulation), the level of agreement between experimentally-measured and calculated time-dependent void fraction profiles shown in Figures 11 through 14 is essentially the same as those obtained with unity discharge coefficients (Figures 4 through 7).

Based upon the above results as well as the recommendations of previous RELAP5-3D assessments [3,7,10], the optional Henry-Fauske critical flow model with a discharge coefficient of 0.84 and a non-equilibrium coefficient of 1000 will be employed for all additional calculations within this assessment.

Interfacial Drag Study

The most outstanding deficiency of the present assessment calculations is the inability to calculate the correct experimentally-inferred time-dependent void fraction profiles and two-phase levels.

In an attempt to better model level swell, the dominant phenomena governing the prediction of both time-dependent void-fraction profiles and two-phase levels, two optional interfacial drag correlations were tested. These include: A) the Gardner correlation [11] (implemented with Card 1 option 82) and B) the Vea-Lahey correlation [12]. The use of either of these interfacial drag correlations requires the use of an alternate formulation for the drift-flux distribution parameter (Card 1 option 78). As discussed in detail in [3], the Gardner interfacial drag correlation, appropriate for large pipes (D>0.24 m), is independent of flow regime. But, its implementation in RELAP5-3D is dependent upon mass flux. The correlation is only used for low mass flux situations. For high mass flux situations the default Kataoka-Ishii interfacial drag correlation is used. The Vea-Lahey interfacial drag correlation, also appropriate for large pipes (D>0.2 m), is independent of both flow regime and mass flux as implimented in RELAP5-3D.

Both the Gardner and Vea-Lahey interfacial drag correlations were investigated separately in the 1-D RELAP5-3D model of the large-tank GE level swell experiment. The effect of these alternate interfacial drag correlations on the time-dependent pressure within the vessel can be obtained by viewing Figure 10. A comparison of these new pressure traces with the Kataoka-Ishii based traces shows that alternate interfacial drag correlations have little effect on the overall depressurization rate of the tank.

Figures 11 through 15 show that the Vea-Lahey interfacial drag correlation predicts time-dependent void fraction profiles and two-phase levels which agree much more closely with experimental values, in most cases within the stated measurement uncertainty. This is not surprising given that the Vea-Lahey correlation was based on pool swell data that simulates tank depressurization like that in the GE large tank tests. The use of the Gardner correlation, however, shows little or no enhancement in the agreement between calculation and experiment.

Finally, a study was performed in which the bubbly and slug flow regime interfacial heat transfer coefficients were modified through a developmental option (Card 1 option 61). This option which calculates bubble size from a Laplace number (independent of relative velocity) rather than a Weber number, was shown in previous assessments [3,7,10] to mitigate non-physical oscillatory behavior without affecting the character of the overall results. The time-dependent pressure within the vessel calculated using the Vea-Lahey interfacial drag correlation with and without activating Card 1 option 61 appear in the inset to Figure 10. This diagram shows that the activation of Card 1 option 61 has a distinct effect on the calculated time-dependent depressurization rate of the tank. This option causes the extent of the initial rapid depressurization to be much more pronounced, falling as much as ~70 psia below data at 1 second into the transient. Thereafter the predicted rate of depressurization slows to slightly lower than that of either the data or the previous RELAP5-3D predictions. This slower rate of depressurization enables the predicted system pressure to equal that obtained without Card 1 option 61 at 16 seconds into the transient. However, the use of Card 1 option 61 degrades the calculation of the initial time-dependent tank depressurization to such an extent that no further analysis will be performed with this Card 1 option for the remainder of this assessment.

Additional Large-Tank GE Level-Swell Problems

As noted earlier, in addition to problem 5801-15, RELAP5-3D was used to model three additional large-tank GE level-swell experiments with significantly different venturi throat diameters. Based upon the conclusions reached during the above-mentioned studies of experiment 5801-15, all three additional calculations were run with a single 'best' set of RELAP5-3D modeling parameters. These include the use of the Henry-Fauske critical flow model with a discharge coefficient of 0.84 and a non-equilibrium parameter of 1000. All models also employed the optional Vea-Lahey interfacial drag correlation without Card 1 option 61.

All three additional experiments were performed using the same facility as that used in experiment 5801-15. In addition, these three experiments employed the same initial fluid conditions, including temperature, pressure, and quiesent liquid level as did experiment 5801-15. As a result these calculations were run using essentially the same RELAP5-3D model described above. Modifications to the model included changes to the effective venturi entrance and exit diameters, venturi throat diameter, and smooth-area-change forward/reverse form losses at the venturi throat, as obtained from the formulations in Crane [8].

The available measured data for each of the additional experiments includes the time-dependent system pressure response as well as the axial void fraction profiles at four times during each transient.

Comparisons of the time-dependent system pressure obtained from the RELAP5-3D analyses of the three additional large-tank GE level-swell problems with available experimental data yielded similiar results to those obtained for experiment 5801-15. Although not explicitly presented, the results showed that, as expected, the overall rate at which the tank depressurizes is directly proportional to the area of the flow-limiting venturi. In addition, each of the experimentally-measured pressure traces is characterized by a sharp pressure dip and recovery in the very early portions of the transient. In all cases the respective RELAP5-3D models, predict this behavior, but in a manner which significantly overstates the observed magnitude and compresses the time scale of the repressurization in a manner which is not consistent with experimental observations.

Again, although not explicitly presented in this paper, comparison of the experimentally-determined versus RELAP5-3D predicted time-dependent void fraction profiles for the three additional experiments showed similar levels of agreement as those obtained in experiment 5801-15. In an effort to gain an understanding of possible deficiencies in the modeling of interfacial drag in RELAP5-3D, Figure 16 was developed. Here, at the four transient times at which axially-dependent void fraction data were measured for each of the four experiments, a data point depicting the agreement between the measured and calculated void fraction was created at each of seven axial levels.

Figure 16 shows for the most part excellent agreement between measurement and calculation (if the Vea-Lahey interfacial drag correlation is employed). The majority of the calculated void fractions agree with experiment to within the stated absolute experimental uncertainty of +/- 0.04.

One grouping of calculated data which is in obvious disagreement with measurement lies in the range of void fractions extending from 0.4 to 0.6 and originates from experiment 5702-16 which employs a 92.1 mm (3.625 in.) diameter venturi throat. Figure 17 explicitly shows the experimental and calculated void fractions as function of height at a time 10 seconds after blowdown. Here it can be seen that the void fraction at the lowest level in the vessel is signicantly underpredicted. Similiar results were observed at the three other times at which data was recorded for this experiment; 2, 5, and 20 seconds after blowdown. One can conclude from this systematic error that, for experiment 5702-16, the differential pressure transducer at the lowest axial vessel level was very likely not operating in a proper fashion.

Figure 16 shows a second grouping of calculated data in which the void fraction appears to be systematically underpredicted. This data lies in the range of void fractions extending from approximately 0.75 to 0.95. These ten data points appear to have little in common except for their relatively high void fraction. Upon further investigation it was discovered that all of these data points were for axial vessel levels which, at the time of interest, included a computational volume with a vertically-stratified two-phase level. RELAP5-3D solves a modified form of the mass, momentum and energy field equations in those volumes in which a vertically-stratified mixture level is predicted to reside. These modifications are an attempt to better represent the fluid properties which are convected from the vertically-stratified volume into its neighbors as the transient unfolds. However, the modified field equations do not appear to accurately calculate interfacial drag, which ultimately results in an underprediction of the void fraction in these computational volumes.

Conclusions

Four large-tank GE level-swell experiments with identical attributes except for the diameter of the respective flow-limiting blowdown venturis were used to perform an assessment of RELAP5-3D. Faithful representation of the experimental facility including instrumentation, the boundary conditions and the initial conditions are required in order to obtain undistorted assessments. With this philosophy in mind, a new RELAP5-3D model of the large-tank GE level-swell experimental facility was created using one-dimensional fluid components. The major differences/improvements between this model and the original RELAP5 assessment model were: 1) more accurate modeling of the dimensions of the blowdown line/dip tube, 2) more accurate modeling of the elevation of the dip tube entrance within the vessel, 3) modeling of the portion of the experimental facility beyond the venturi throat, 4) the use of heat structures to model the heat capacity of the tank structure, and 6) explicit modeling of the mechanism for obtaining volume-average void fractions from differential pressure measurements.

The net result of these model modifications/ improvements is generally improved agreement with data. Best results, with respect to measured transient vessel pressure, were obtained with the Henry-Fauske critical flow model when the discharge coefficient was set to 0.84 and the non-equilibrium parameter was set to 1000 (a ‘frozen’ model with no evaporation or condensation in the orifice).

As a result of concerns regarding the predicted magnitude and duration of the initial repressurization in the revised RELAP5-3D analyses, the original RELAP5 assessment was re-run with time steps approximately five to ten times smaller than those originally employed. Use of the smaller time step sizes in the original assessment model resulted in the emergence of the same large magnitude, short duration repressurization found in the revised RELAP5-3D analyses. The repressurization features of the original analysis with small time steps, and by analogy the revised assessment model, were most likely a calculational artifice associated with entrance of the vertically-stratified two-phase mixture level into a computational volume. This feature of the results represents a deficiency in the RELAP5-3D solution algorithm. However, the time frame during which the solution is deficient is very small in duration. This implies that the misprediction of the slight early-in-transient repressurization has little effect on the overall prediction of total mass outflow during the blowdown.

The fact that the revised RELAP5-3D models of experiment 5801-15 did not always accurately predict the differential-pressure-inferred time-dependent void fraction profiles and two-phase levels remained a cause for concern. It was believed that this misprediction may have been a direct consequence of inaccuracies in the default RELAP5-3D interfacial drag model, the Kataoka-Ishii correlation. As a result, the Gardner and Vea-Lahey correlations, both considered appropriate for use in modeling large pipes and/or tanks were tested. The Vea-Lahey interfacial drag correlation was found to predict time-dependent void fraction profiles and two-phase levels that were in much closer agreement with experimental values. The use of the Gardner correlation, however, shows little or no enhancement in the agreement between calculation and experiment.

Based upon the 'best' critical flow and interfacial drag modeling practices obtained in assessing experiment 5801-15, RELAP5-3D was then used to model the three other large-tank GE level-swell experiments appearing in Table 1. Similar levels of agreement between calculation and experiment were obtained for the time-dependent system pressure for all four venturi sizes. A comparison of experimentally-determined and calculated void fractions for all four experiments resulted in the following conclusions: 1) In general the Vea-Lahey interfacial drag correlation produces excellent agreement between measured and calculated void fraction profiles, 2) The differential pressure transducer at the lowest axial vessel level was very likely not operating in a proper fashion during experiment 5702-16, and 3) the modified field equations employed by RELAP5-3D in the perceived presence of a vertically-stratified two-phase mixture do not appear to accurately calculate interfacial drag.

References

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Table 1

Large-Tank GE Level-Swell Experiments

Experiment Number	Venturi Throat Diameter
5801-13	54 mm (2.125 in.)
5801-15	63.5 mm (2.5 in.)
5801-19	76.2 mm (3.0 in.)
5702-16	92.1 mm (3.625 in.)

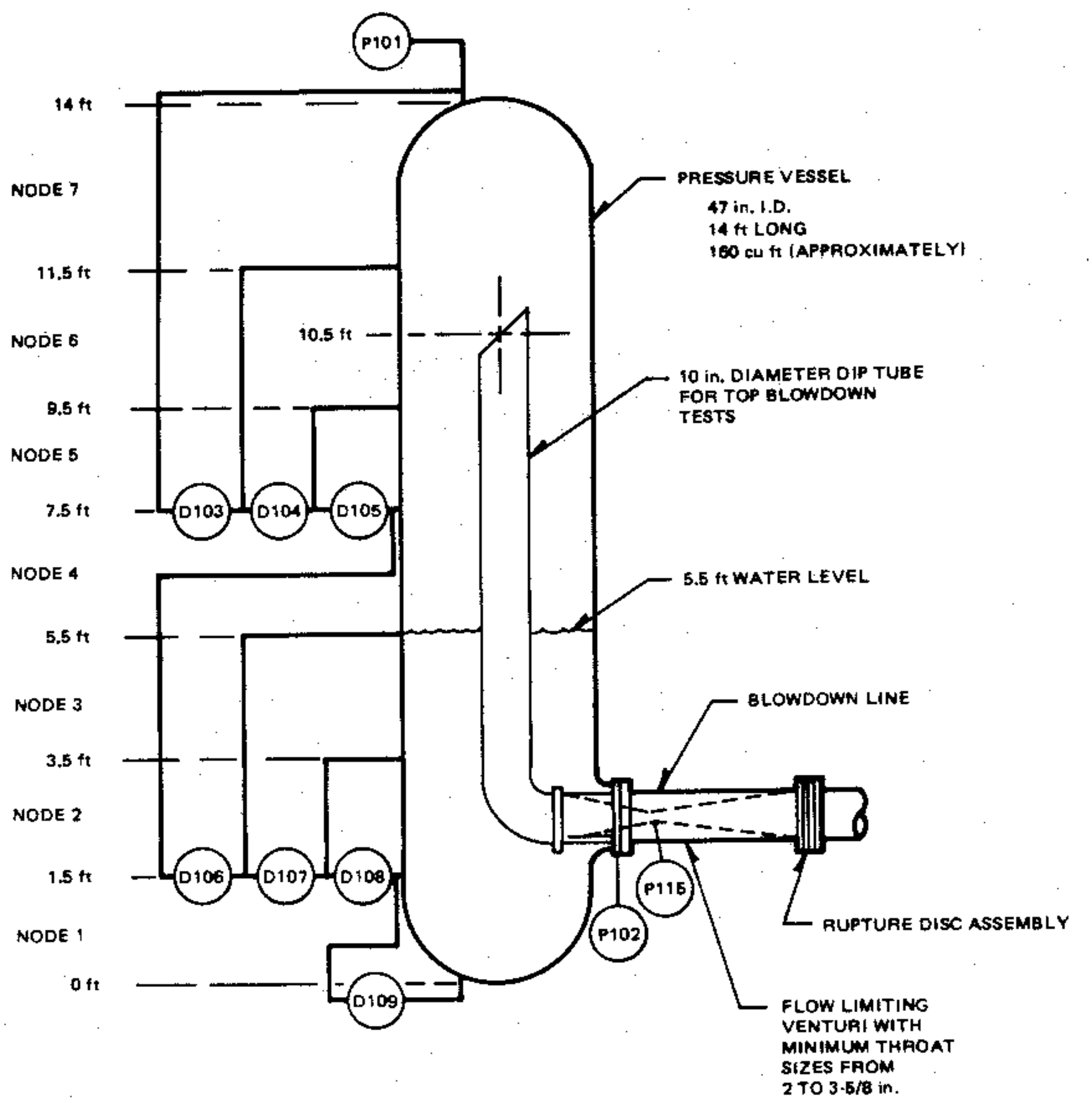

Figure 1
Schematic of the Large-Tank GE Level Swell Facility

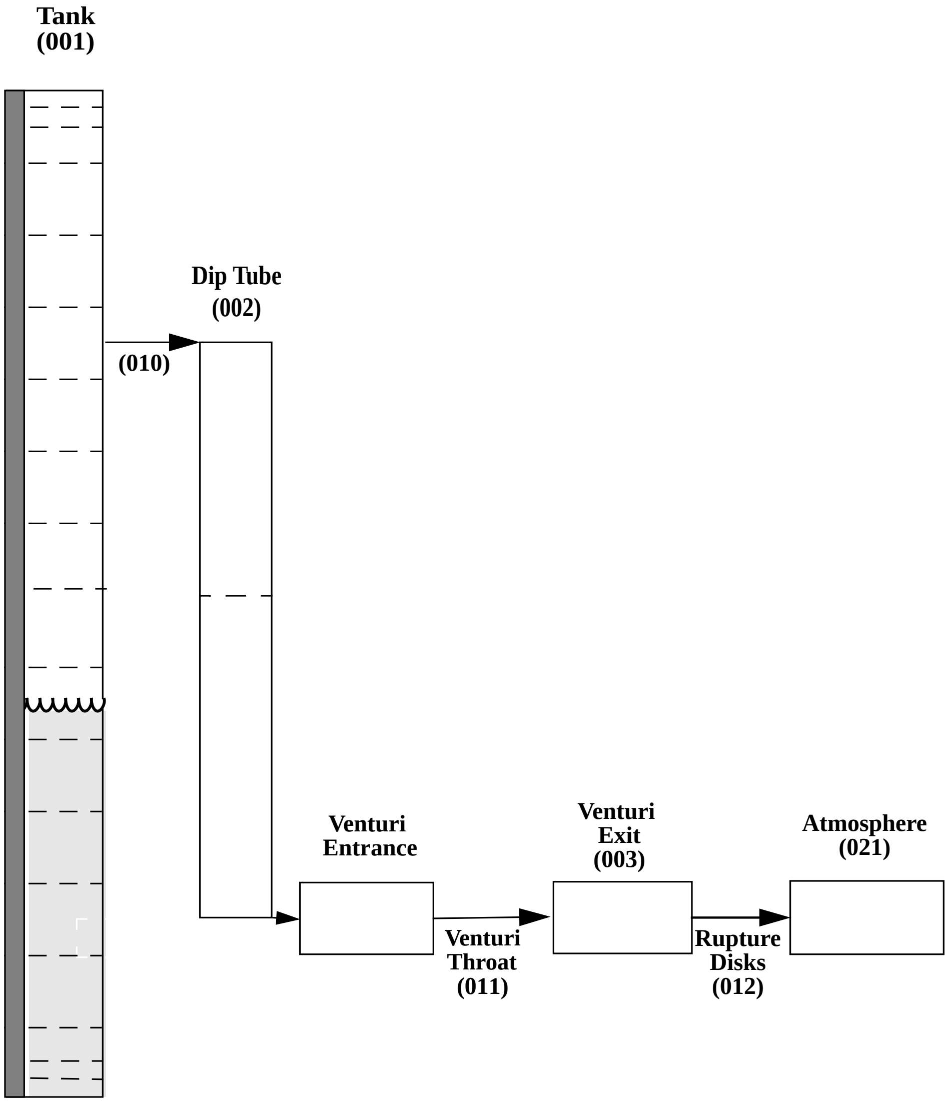

Figure 2
Schematic of RELAP5-3D Representation of Large-Tank GE Level Swell Facility

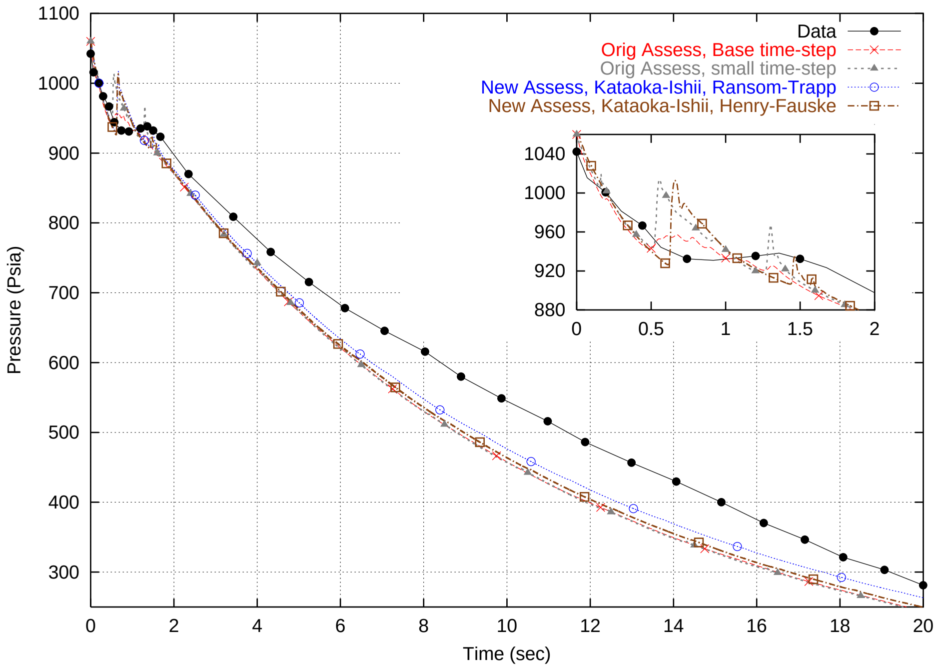

**Figure 3: Pressure at Top of Vessel
GE Level Swell Test 5801-15
w/ Unity Discharge Coefficients**

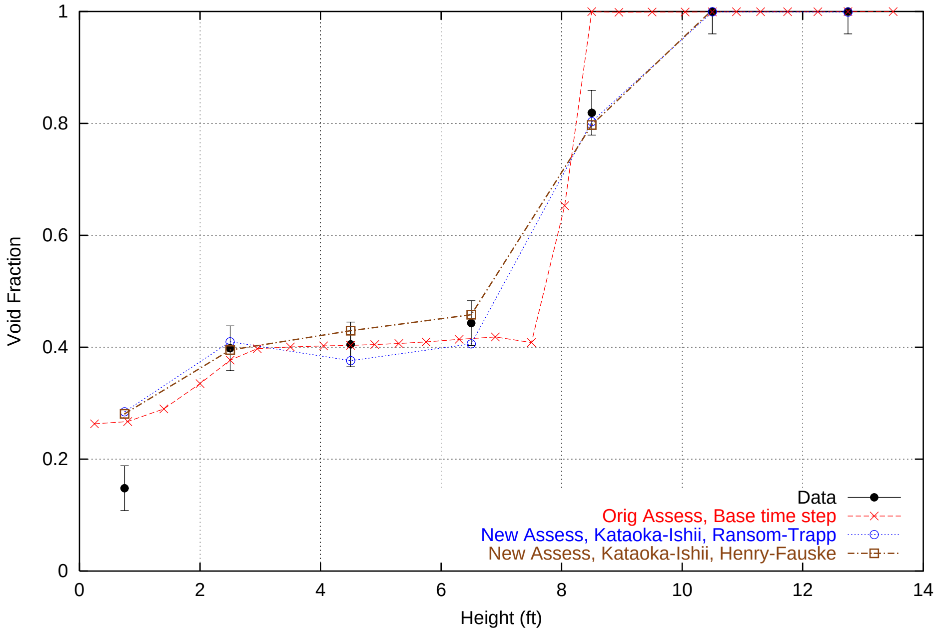

**Figure 4: Void Fraction Profile at 2 Seconds
GE Level Swell Test 5801-15
w/ Unity Discharge Coefficients**

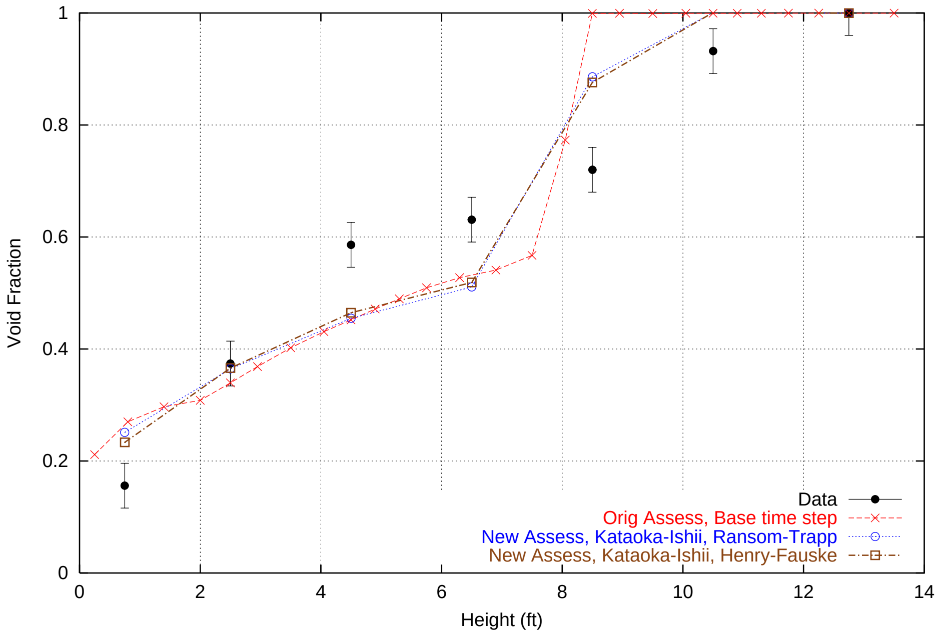

**Figure 5: Void Fraction Profile at 5 Seconds
GE Level Swell Test 5801-15
w/ Unity Discharge Coefficients**

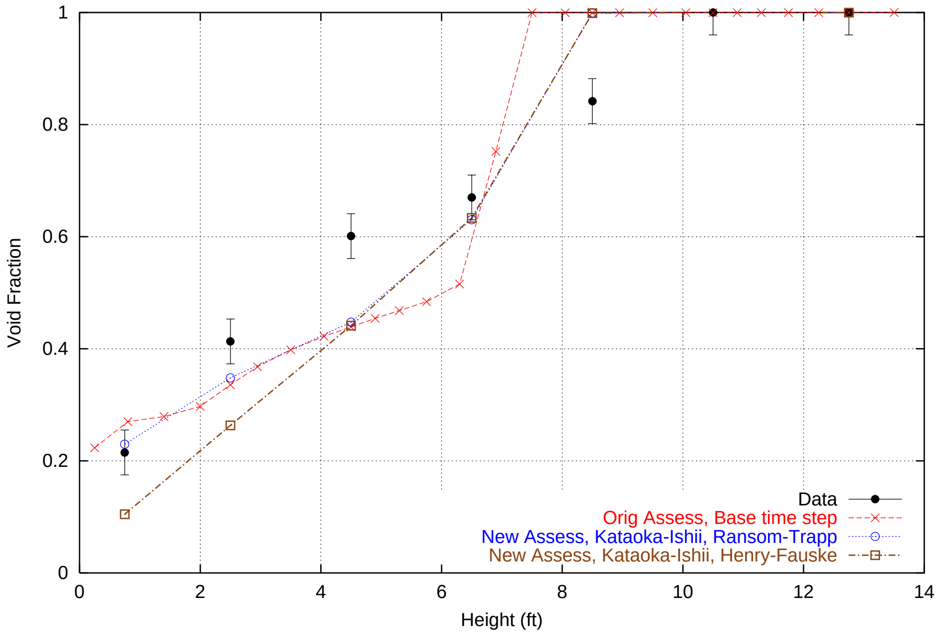

**Figure 6: Void Fraction Profile at 10 Seconds
GE Level Swell Test 5801-15
w/ Unity Discharge Coefficients**

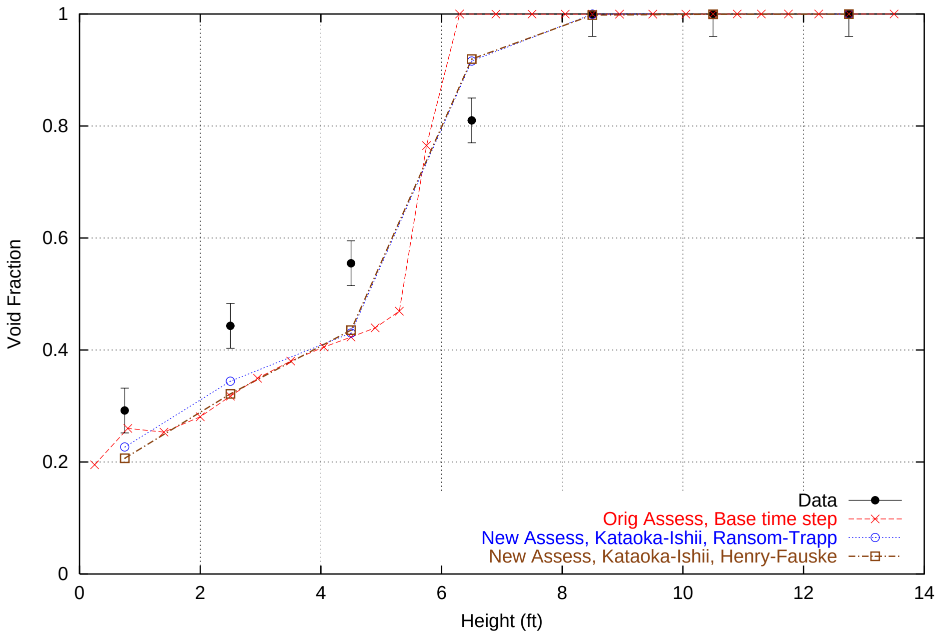

**Figure 7: Void Fraction Profile at 20 Seconds
GE Level Swell Test 5801-15
w/ Unity Discharge Coefficients**

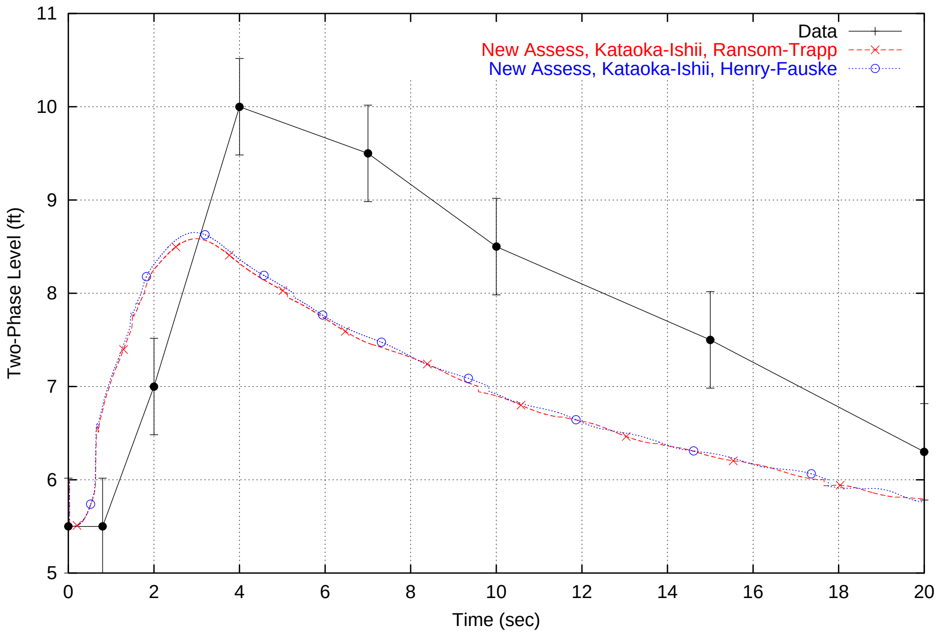

**Figure 8: Comparison of Two-Phase Levels
GE Level Swell Test 5801-15
w/ Unity Discharge Coefficients**

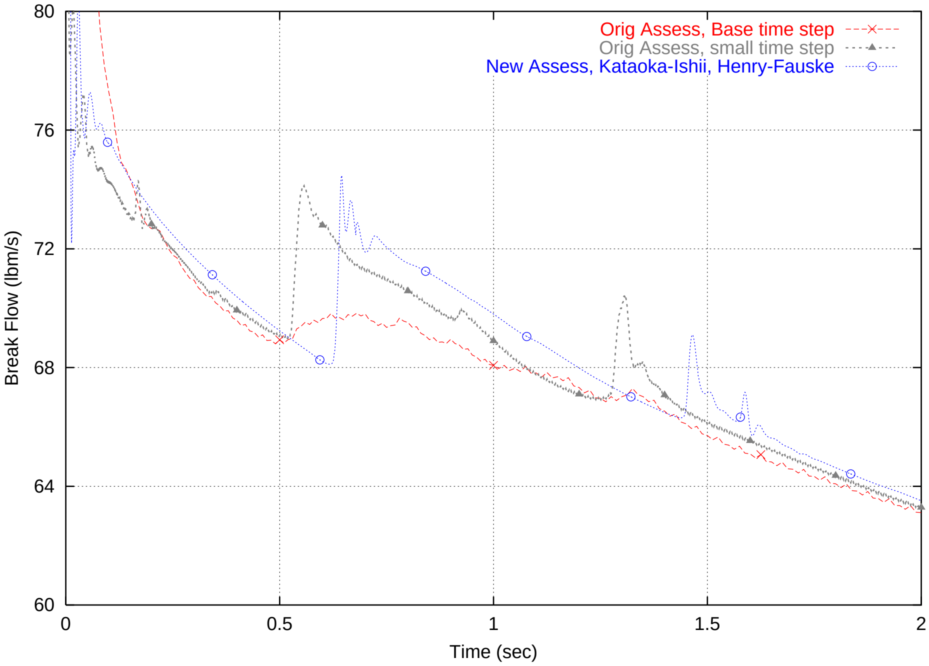

**Figure 9: Comparison of Break Flow Rate
GE Level Swell Test 5801-15
w/ Unity Discharge Coefficients**

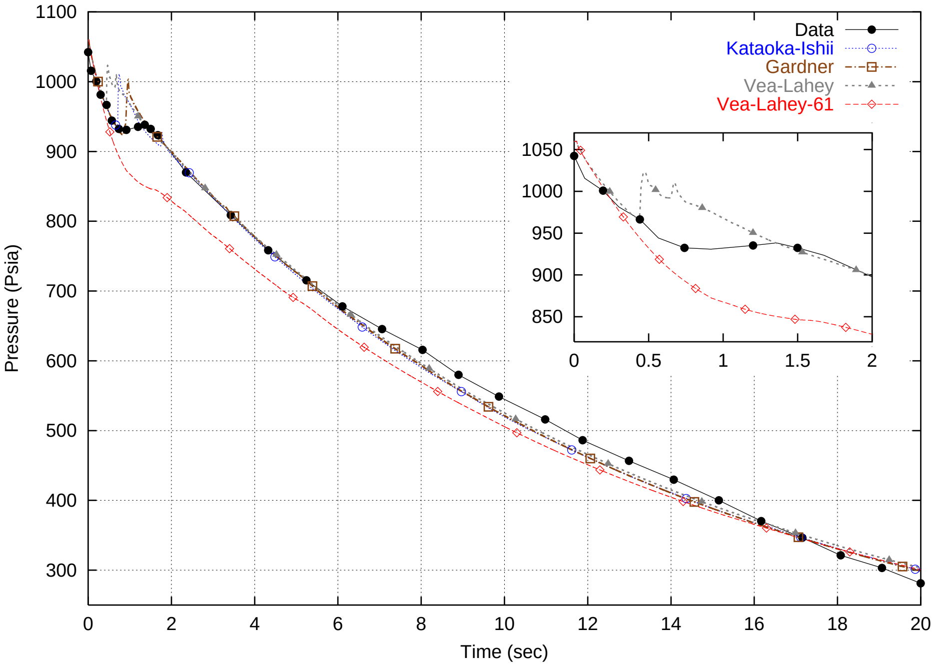

**Figure 10: Pressure at Top of Vessel
GE Level Swell Test 5801-15
w/ "frozen" Henry-Fauske Crit. Flow Model, C_D = 0.84**

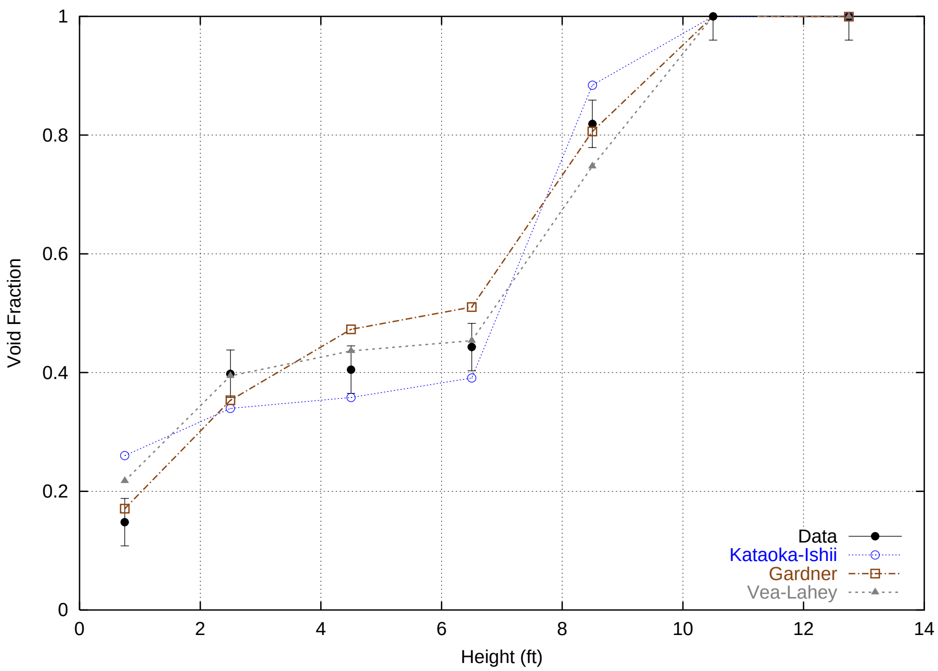

Figure 11: Void Fraction Profile at 2 Seconds
GE Level Swell Test 5801-15
w/ “frozen” Henry-Fauske Crit. Flow Model, C_D = 0.84

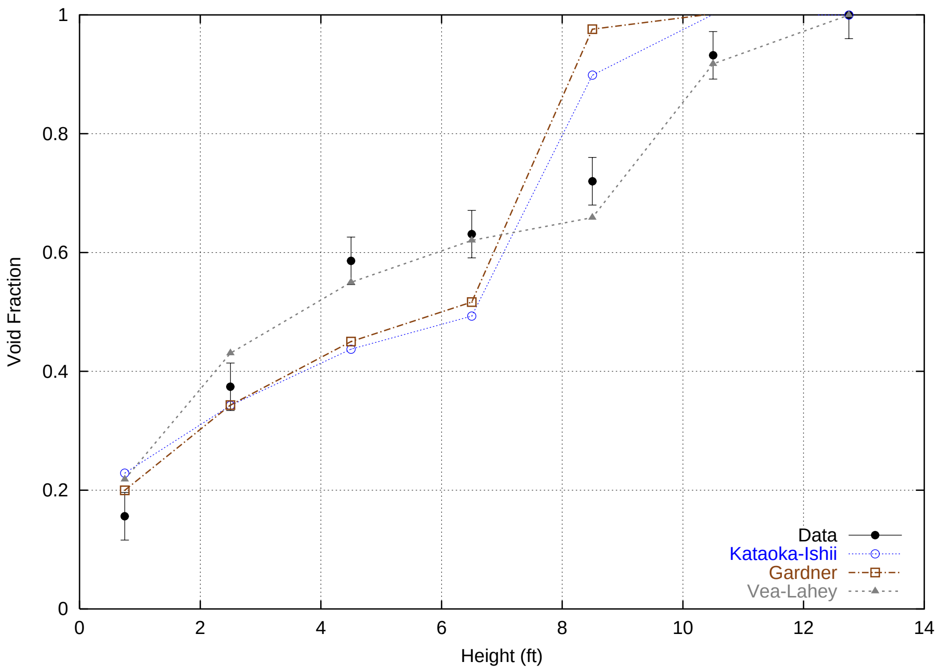

Figure 12: Void Fraction Profile at 5 Seconds
GE Level Swell Test 5801-15
w/ “frozen” Henry-Fauske Crit. Flow Model, C_D = 0.84

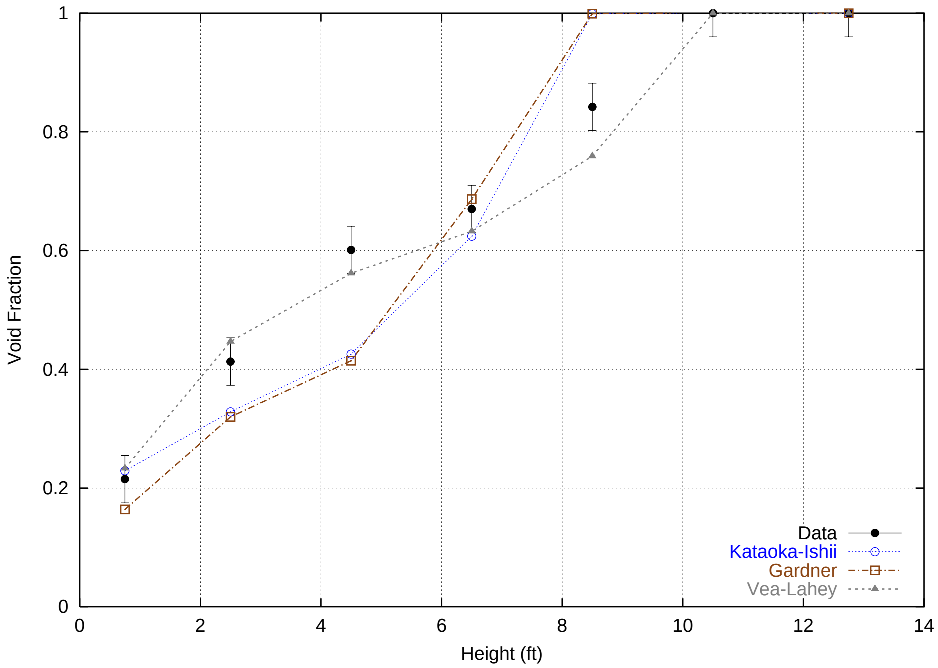

Figure 13: Void Fraction Profile at 10 Seconds
GE Level Swell Test 5801-15
w/ “frozen” Henry-Fauske Crit. Flow Model, C_D = 0.84

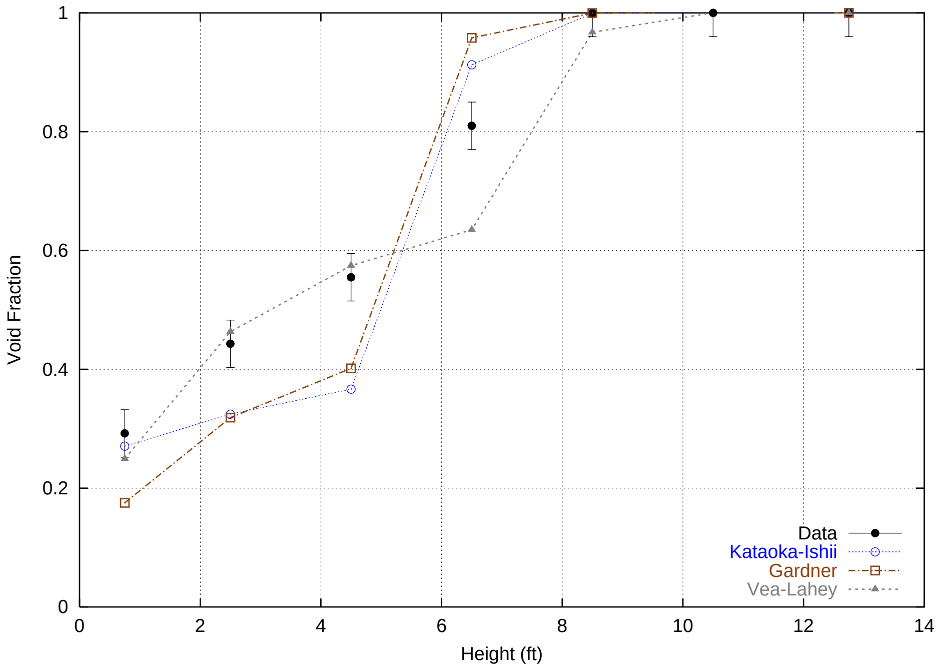

Figure 14: Void Fraction Profile at 20 Seconds
GE Level Swell Test 5801-15
w/ “frozen” Henry-Fauske Crit. Flow Model, C_D = 0.84

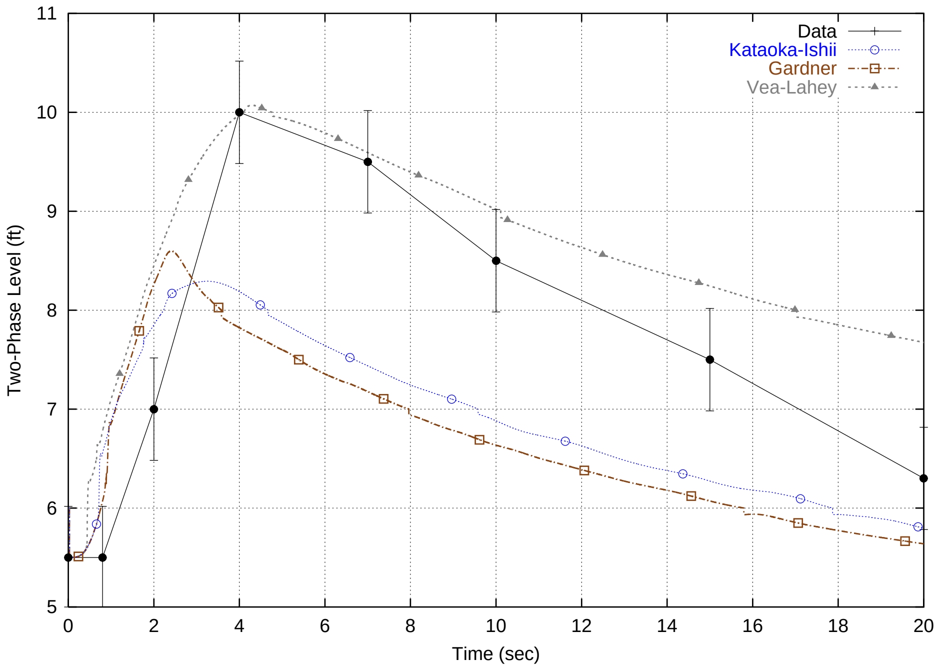

Figure 15: Comparisons of Two-Phase Levels GE Level Swell Test 5801-15 w/ “frozen” Henry-Fauske Crit. Flow Model, C_D = 0.84

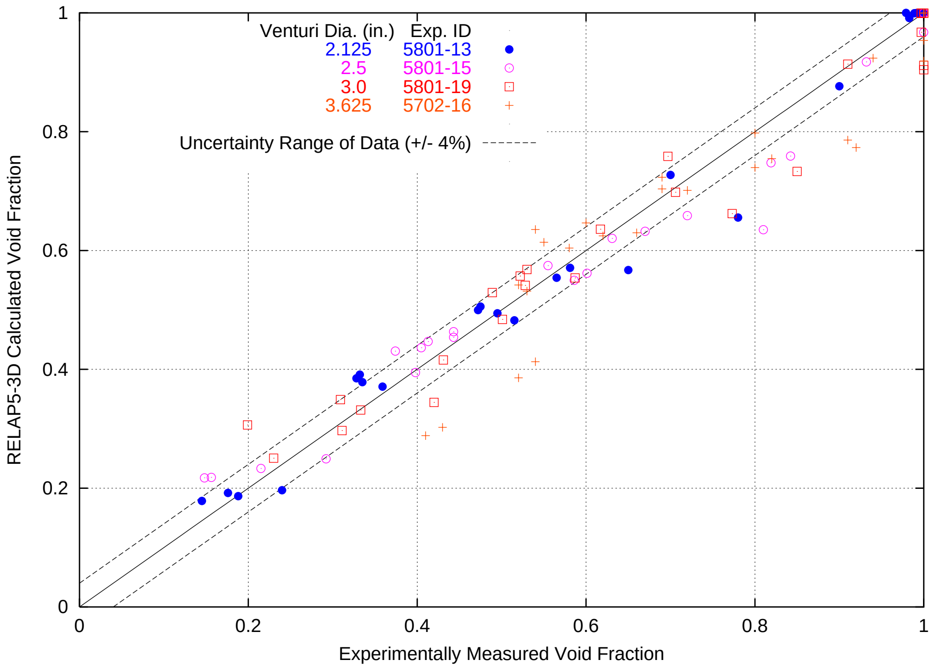

Figure 16: Calculated Versus Measured Void Fractions w/ “frozen” Henry-Fauske Crit. Flow Model, C_D = 0.84

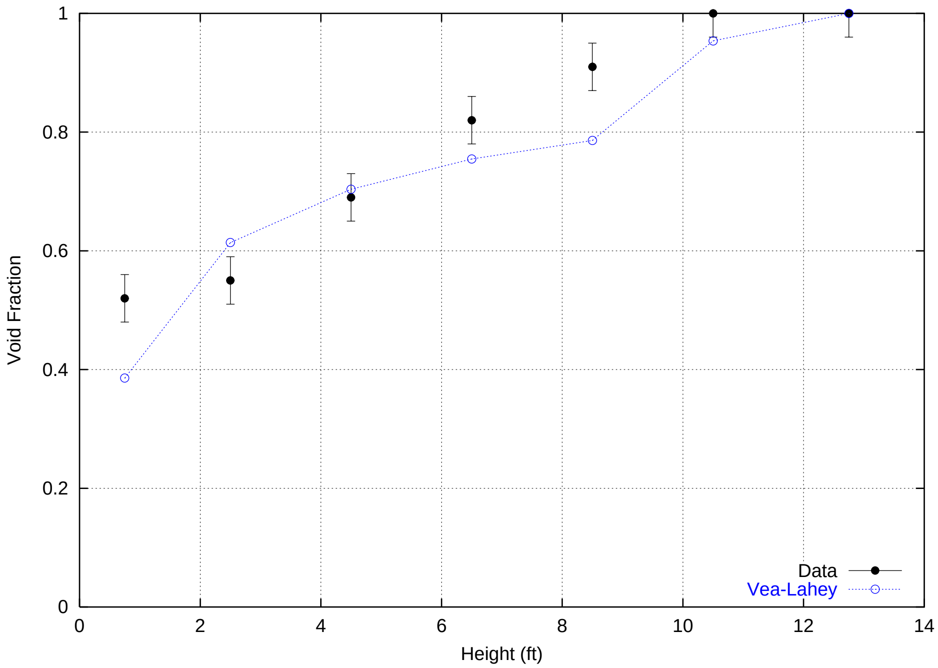

**Figure 17: Void Fraction Profile at 10 Seconds
GE Level Swell Test 5702-16 (3.625 in. Venturi)
w/ “frozen” Henry-Fauske Crit. Flow Model, C_D = 0.84**