Improved Accuracy for Two-Phase Downflow Scenarios

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Outline

- Introduction
- Method
- Results
- Conclusions

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Introduction

- RELAP5-3D selects different interphase drag correlations depending on pipe orientation, pipe size, and mass flux
  - Primary orientations are horizontal, vertical up, and vertical down
  - Pipe sizes are small ($D \le 0.018$ m), intermediate ($0.018 \le D \le 0.08$ m) and large ($D > 0.08$ m)
  - Mass fluxes are low ($G \le 50$ kg/s-m^2), medium ($50 < G < 100$ kg/s-m^2) and high ($G \ge 100$ kg/s-m^2)
- Problems have been reported for very high downflows ($G \approx 25{,}000$ kg/s-m^2) in small and intermediate pipes in the bubbly and slug flow regimes
  - The critical flow rates are about 20% lower than for upflow and horizontal flow
  - At very high flow rates the flow is expected to be nearly homogeneous and nearly independent of flow direction

Introduction

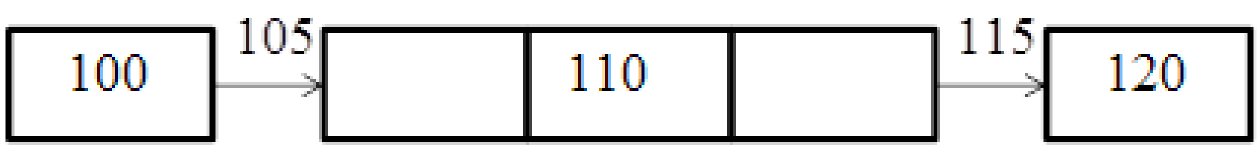
- RELAP5-3D uses the EPRI drift flux correlation for high downflow rates in small and intermediate pipes
- The EPRI correlation for downflow is based on the steam/water experiments of Petrick and several other air/water experiments
- The EPRI high downflow database is limited
  - For steam/water, $G \le 1125$ kg/s-m^2
  - For air/water, $G \le 5200$ kg/s-m^2
- Extrapolation of the EPRI correlation to very high downflow rates results in slip ratios that are judged to be too high that cause predictions of
  - gas velocities that are too high
  - void fractions that are too low
  - critical flow rates that are too low when the Ransom-Trapp model is used

Introduction

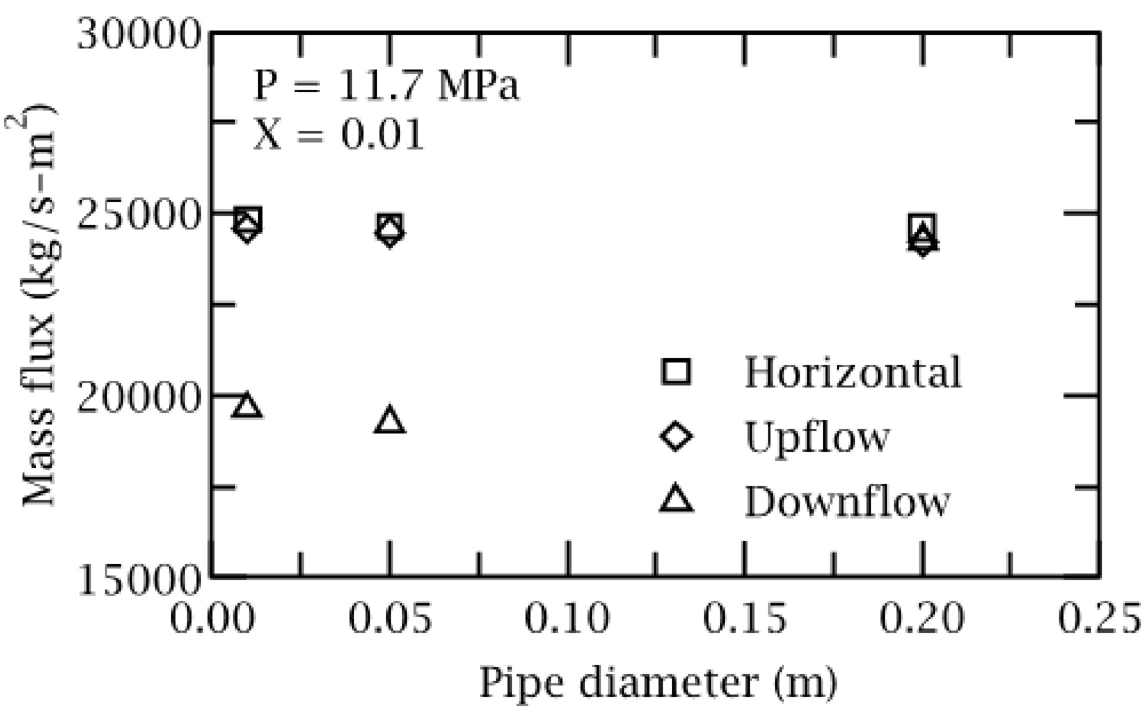
- These conclusions are based on engineering judgment because experimental data are not available for very high downflow in small and intermediate pipes
- The results presented here are judged to be sufficiently compelling to justify replacing the EPRI correlation for very high downflow
- The Zuber-Findlay and Kataoka-Ishii drift flux correlations are now used for small and intermediate pipes and rod bundles when the downflow mass flux exceeds 1500 kg/s-m^2
  - These correlations are currently used for large pipes
- No changes are made for upflow

Illustration of problem at very high mass flux

- Two-phase, steam/water flow supplied to a pipe
- Critical flow is obtained at an orifice at the exit of the pipe
- Calculations were performed for three orientations (horizontal, vertical up and vertical down) and three pipe sizes (small, intermediate, and large)
- The orifice area was adjusted so that G ≈ 25,000 kg/s-m^2 in the pipe
- The pressure and quality supplied to the pipe were 11.7 MPa and 0.01



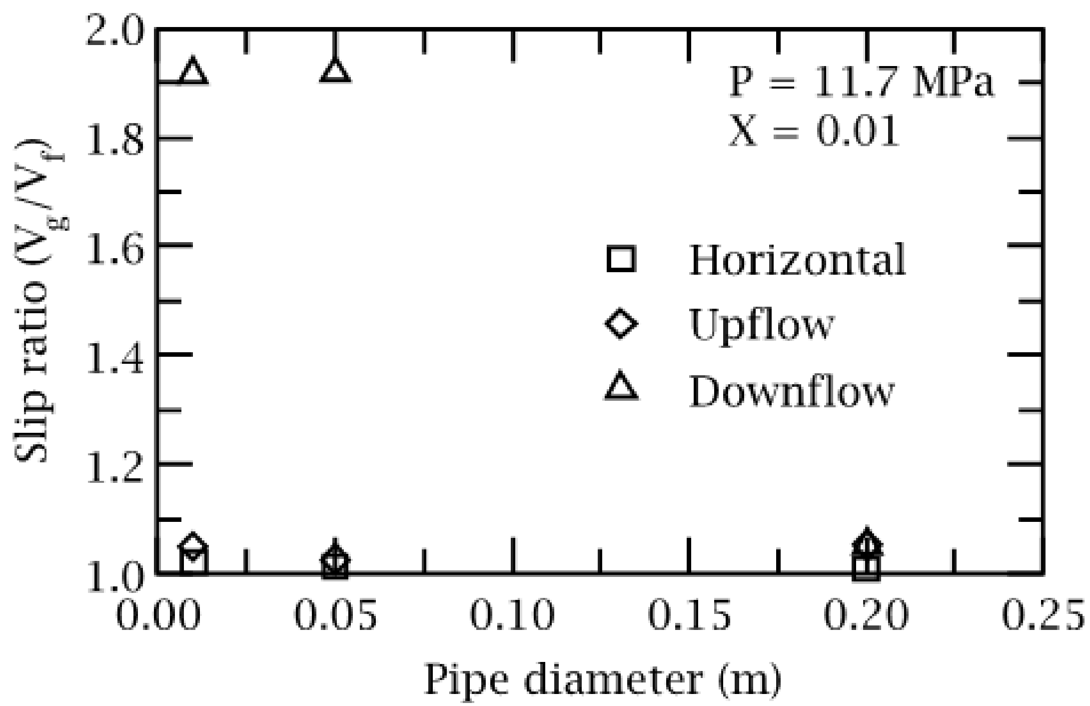
The mass flux varies significantly with orientation in small and intermediate pipes



- Mass fluxes in the horizontal and upflow cases were nearly identical for all pipe sizes

- The downflow mass flux was in excellent agreement with the other cases for the large pipe, but was only about 78% of the horizontal value for the small and intermediate pipes

The lower mass fluxes for downflow in the smaller pipes were caused by high slip ratios



- The slip ratio was about 1.9 for downflow in the smaller pipes, but was less than 1.1 for all other cases
- The large slip ratios were caused by large distribution coefficients from the EPRI correlation
- The Ransom-Trapp model predicts signficantly lower flow rates than HEM when large slip ratios are calculated

Analysis of Petrick's steam/water downflow tests

- Petrick* measured void fractions for downflow at three different pressures
- The Petrick tests were the only steam/water downflow data used to develop the EPRI drift flux correlation
- A linear regression was performed to determine best-estimate values of the drift flux parameters from Petrick's data
  - $v_g = C_0 j + v_{gj}$, where v_g is the gas velocity, C_0 is the distribution parameter, j is the total superficial velocity, and v_{gj} is the drift velocity
  - The best estimate values of $C_0 = 1.11$ and $v_{gj} = 0.417$ m/s provide a reasonable fit to Petrick's data at 4.1 MPa

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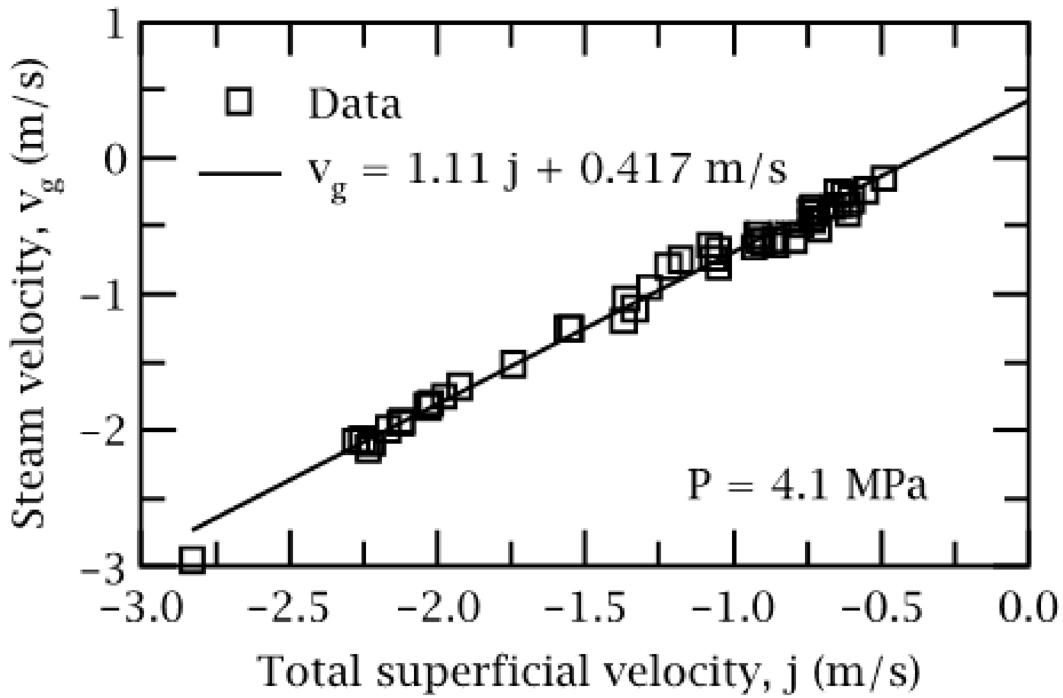
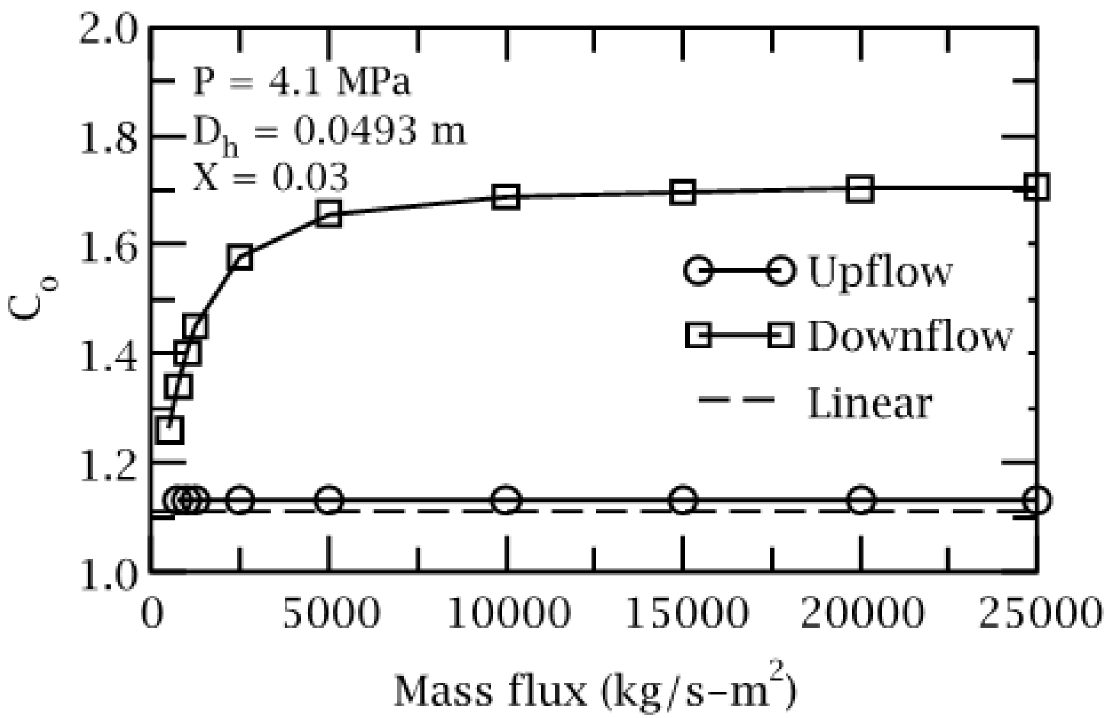
*Petrick, M., 1962, *A Study of Vapor Carryunder and Associated Problems*, Argonne National Laboratory, ANL-6581, July 1962.

The linear regression fit Petrick's steam/water downflow data reasonably well



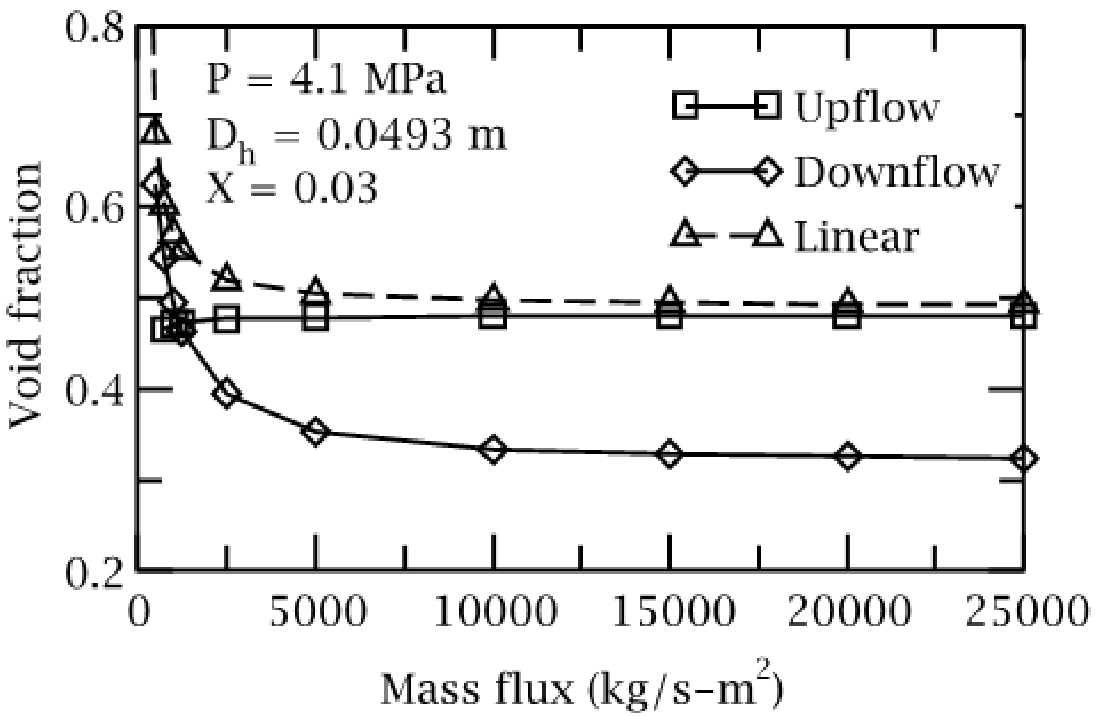
- $R^2 = 0.982$
- $C_0 = 1.11$ is the slope of the line
- $v_{gj} = 0.417$ m/s is the y-intercept

Spreadsheet calculations determined the effect of mass flux on the EPRI correlation for upflow and downflow using representative values from Petrick's experiment



- C_0 is nearly independent of mass flux for upflow, but varies significantly for downflow
- C_0 for upflow agrees closely to the linear fit, but varies significantly from the linear fit for downflow
- Similar trends were observed for v_{gj}

Void fractions versus mass flux based on representative conditions from Petrick's data



- For downflow, the void fractions from the EPRI correlation agree well with the linear fit in the range of the data, but poorly at higher mass fluxes

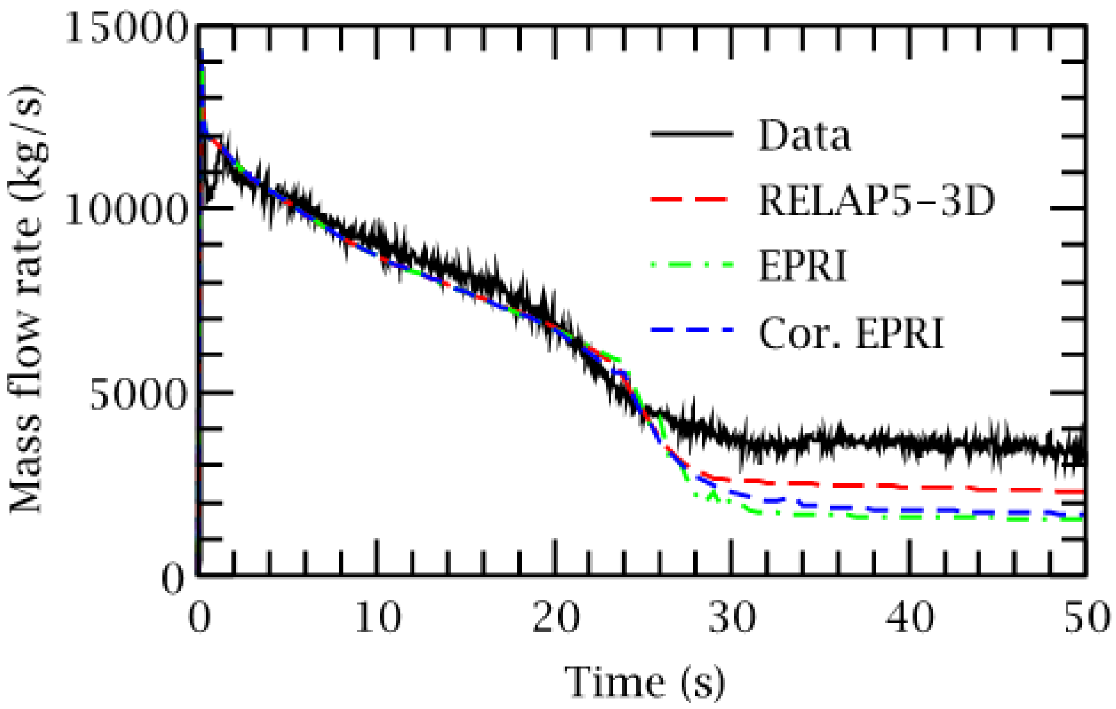
- Petrick's data are always much greater than or about the same as the void fractions from the upflow predictions; they are never significantly less

- The extrapolation of the EPRI correlation to very high downflow is judged to be incorrect

Marviken critical flow tests

- The Marviken tests simulated the blowdown of a reactor vessel through a large discharge pipe ($D_h \approx 0.75$ m)
  - Very high downflow rates were obtained in the discharge pipe
- Volume 4 of the manual describes problems that were encountered in the original developmental assessment (DA) calculations when the EPRI correlation was used to simulate the Marviken critical flow tests
  - The EPRI correlation provided poor predictions of the Marviken tests and was replaced by the Zuber-Finlay and Kataoka-Ishii drift flux correlations for large pipes
- A special version of RELAP5-3D was created that used the EPRI drift flux correlation in a large pipe
- Another special version was created that also included three error corrections that were discovered during this task
  - Two errors were related to the implementation of the EPRI correlation for downflow, and the other to an incorrect junction D_h when the abrupt area change model was used at an area reduction

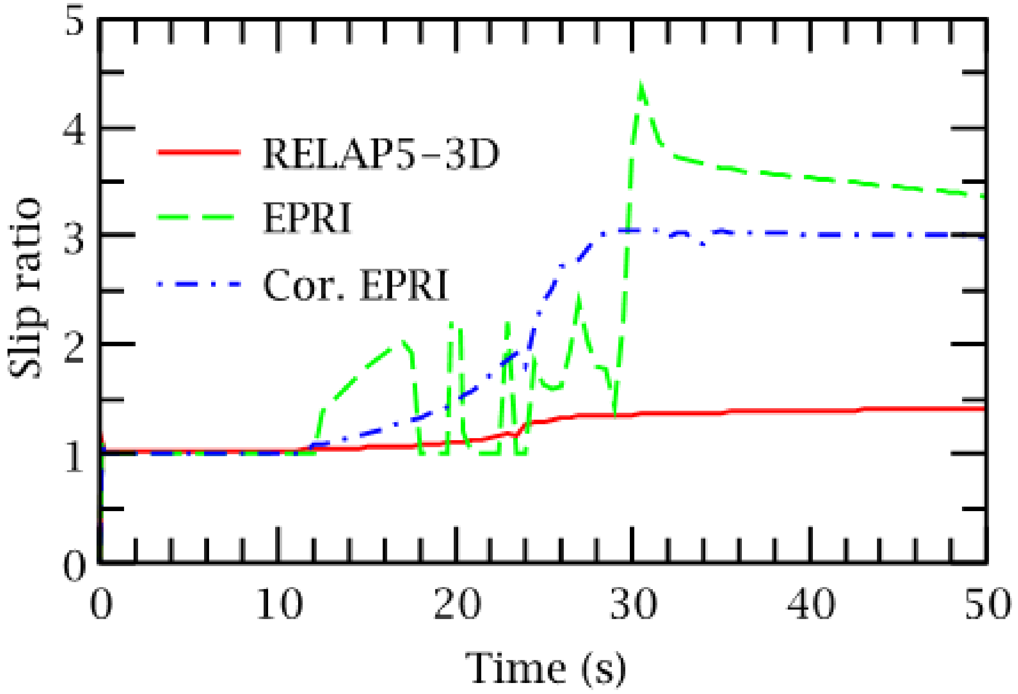
The EPRI correlation provided a much poorer prediction of the break flow in Marviken Test 24



- All three code versions calculated nearly identical results during single-phase flow (before 25 s)

- RELAP5-3D provided the best prediction in two-phase flow and was more than 30% higher than the EPRI correlation

The EPRI correlation calculated a much larger slip ratio at the break in Marviken Test 24



- More homogeneous flow was obtained when the Zuber-Findlay and Kataoka-Ishii correlations were applied

Summary

- The range of the steam/water database for the EPRI correlation is limited to G ≤ 1125 kg/s-m^2 for downflow and 2100 kg/s-m^2 for upflow
- The drift parameters from the EPRI correlation are nearly constant for upflow, so that the EPRI correlation calculates nearly homogeneous results when extrapolated to very high mass fluxes
- For downflow, the drift parameters vary significantly with mass flux resulting in unreasonably large distribution coefficients and drift velocities when extrapolated to very high downflow, which leads to the prediction of excessively high slip ratios
- Excessively high slip ratios can lead to the calculation of void fractions that are too low in very high downflow
- Excessively high slip ratios lead to the calculation of critical flow rates that are 20-30% too low when the Ransom-Trapp model is used
- Therefore, the EPRI correlation was replaced outside of the range of its database for very high downflow in a modified version of RELAP5-3D Version 302t

The new flow regime map for vertical bubbly and slug flow is

Table 6.1-1 Drift flux void fraction correlations for vertical bubbly-slug flow.

Flow rates	**Rod bundles**	**Narrow rectangular channels**	**Small pipes $D \leq 0.018m$**	**Intermediate pipes $0.018m < D \leq 0.08m$**	**Large pipes $0.08m < D$**
High upflow rates $G \geq 100\ kg/m^2 \cdot s$	EPRI (2) (eprij)	Griffith (2) (griftj)	EPRI (3) (eprij)	EPRI (9) (eprij)	Churn-turbulent bubbly flow (14) transition (15) Kataoka-Ishii (16) (katokj)
Medium upflow rates $50\ kg/m^2 \cdot s < G < 100\ kg/m^2 \cdot s$			Transition[a] (5)	Transition[a] (13)	
Low upflow, downflow, and countercurrent flow rates $-50\ kg/m^2 \cdot s \leq G \leq 50\ kg/m^2 \cdot s$			Zuber-Findlay slug flow (4) (zfslgj)	Churn-turbulent bubbly flow (10) transition (11) Kataoka-Ishii (12) (katokj)	
Medium downflow rates $-100\ kg/m^2 \cdot s < G <- 50\ kg/m^2 \cdot s$			Transition[a] (5)	Transition[a] (13)	
High downflow rates $-1250 \leq G \leq -100\ kg/m^2 \cdot s$			EPRI (3) (eprij)	EPRI (9) (eprij)	
Transition $-1250 < G < -1500\ kg/m^2 \cdot s$	**Transition[a] (17)**		**Transition[a] (21)**	**Transition[a] (25)**	
Very high downflow rates $G \leq -1500\ kg/m^2 \cdot s$	**Churn-turbulent bubbly flow (18) transition (19) Kataoka-Ishii (20) (katokj)**		**Churn-turbulent bubbly flow (22) transition (23) Kataoka-Ishii (24) (katokj)**	**Churn-turbulent bubbly flow (26) transition (27) Kataoka-Ishii (28) (katokj)**	

a. Interpolation is applied between different flow rates.

Verification testing included:

- The very high mass flux case described previously
- The code installation problems*
- The DA cases*
- Scaled Marviken tests
  - The experimental steam/water database is limited for very high downflows
  - The Marviken tests were scaled using a full-height, full-pressure scaling rationale with an area factor to produce intermediate and small discharge pipes

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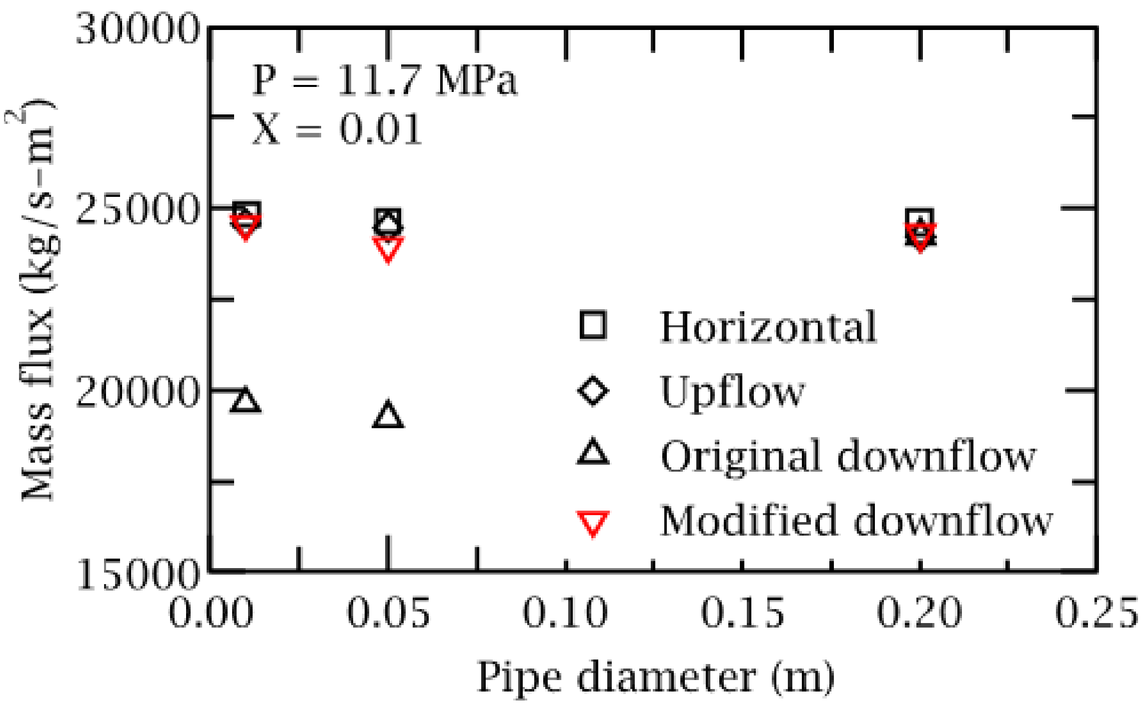
* These verification tests are described in a separate presentation

The implementation of the very high downflow regime improved the results

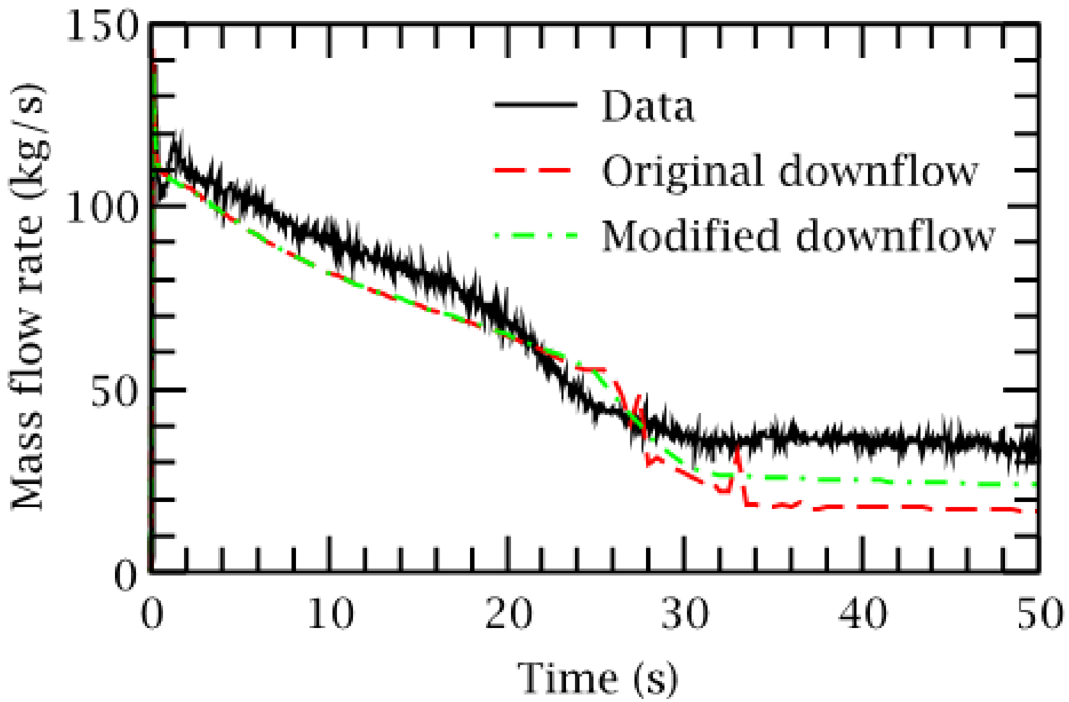


- The code modifications resulted in more nearly homogeneous flow for very high downflow in small and intermediate pipes

- The difference in mass flux decreased from more than 20% to less than 3.5%

- The slip ratio at the orifice decreased from more than 1.9 to less than 1.1

The implementation of the very high downflow regime provided reasonable results for Marviken Test 24 scaled to an intermediate pipe

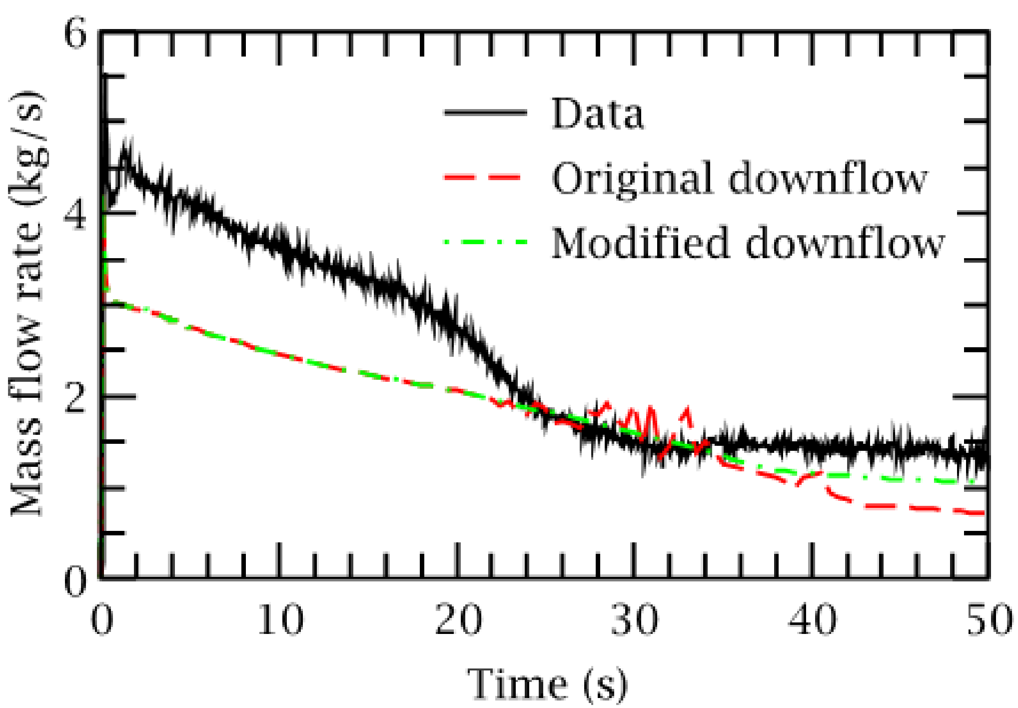


- An area ratio of 0.01 was applied to the Marviken geometry and the measured break flow rate

- The results are similar to those shown previously for the actual Marviken test

- The break flow rate with the modified logic is about 40% higher and in better agreement with the scaled data

The implementation of the very high downflow regime provided reasonable results for Marviken Test 24 scaled to a small pipe



- An area ratio of 0.0004 was applied to the Marviken geometry and the measured break flow rate

- The results are less similar to those shown previously for the actual Marviken test because of increased friction in the discharge pipe

- The break flow rate with the modified logic is higher and in better agreement with the scaled data

Conclusions

- RELAP5-3D predicts critical flow rates that are about 20% lower in downflow than in upflow or horizontal flow for small and intermediate pipes
  - The lower mass fluxes in downflow were caused by a large slip ratio from the EPRI drift flux correlation at the break orifice
- Calculated results with the EPRI correlation are judged to be incorrect when extrapolated to very high downflow
  - The Zuber-Findlay and Kataoka-Ishii correlations, which are currently used for downflow in large pipes, are judged to provide more reasonable results for small and intermediate pipes
- Therefore, a very high downflow regime, which replaced the EPRI correlation with the Zuber-Findlay and Kataoka-Ishii correlations for very high downflow in small and intermediate pipes, was created

Conclusions

- The EPRI correlation is judged to provide reasonable results when extrapolated to very high upflow
  - Therefore no changes are needed for upflow
- The code modifications that implement the very high downflow regime were extensively tested using
  - Pipes of different sizes and orientations
  - Marviken and scaled Marviken test data
  - Installation problems and DA cases
- The verification testing showed that the downflow modifications provided improved results for very high downflow, but had negligible or relatively small effects on most of the installation and DA cases