TWO-WAY-COUPLING USING DYN3D-SP3 AND SUBCHANFLOW

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Drift-flux model in a sub-channel of rod bundle geometry

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A R T I C L E I N F O

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A B S T R A C T

In view of the practical interest of the drift-flux model for two-phase flow analysis, the distribution parameter and drift velocity constitutive equations have been obtained for subcooled boiling flow in a sub-channel of rod bundle geometry. The constitutive equation of the distribution parameter for subcooled boiling flow in a sub-channel is obtained from the bubble-layer thickness model. In this derivation an existing constitutive equation for subcooled boiling flow in a round pipe is modified by taking account of the difference in the flow channel geometry between the sub-channel and round pipe. The constitutive equation of the drift velocity is proposed based on an existing correlation and considering the rod wall and sub-channel geometry effects. The prediction accuracy of the newly developed correlations has been

Aim

Showing new constitutive equations development for the drift-flux model in a sub-channel of rod bundle geometry.

Overview

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- Drift-flux model

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- Distribution parameter

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    - Comparison of drift velocity model with data
- Conclusions

Drift-flux model

The drift-flux is defined as the flux of the gas phase relative to a plane moving to the total flux.

- The basic concept of the drift-flux model is to consider the mixture as a whole, rather than two phases separately.

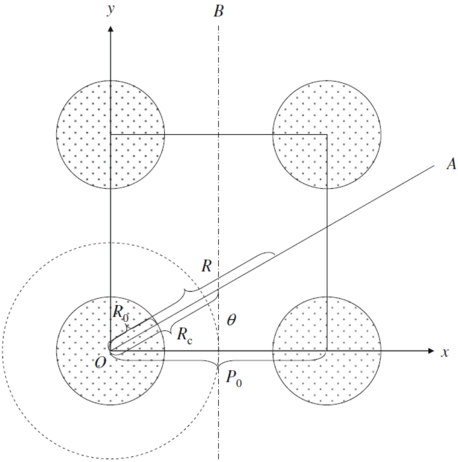
The one-dimensional drift-flux model can be in terms of the distribution parameter, C_0, and the void-fraction-weighted as

$$\langle\langle v_g \rangle\rangle \equiv \frac{\langle j_g \rangle}{\langle \alpha \rangle} = C_0 \langle j \rangle + \langle\langle v_{gj} \rangle\rangle,$$

$$C_0 \equiv \frac{\langle \alpha j \rangle}{\langle \alpha \rangle \langle j \rangle}.$$

Distribution Parameter

To get the distribution parameter C_0 the analytical forms of the j and alpha void fraction distributions, are needed.
The modeled sub-channel, including the coordinate system, is given by



Distribution Parameter

The mixture volumetric flux, j, is assumed by

$$j(r,\theta) = j_c(\theta)\left\{1 - \left(1 - \frac{2r_0}{R - R_0}\right)^n\right\} \quad (0 \leqslant r_0 \leqslant R_c - R_0;\ 0 \leqslant \theta \leqslant \pi/4)$$

where

$$R = 2R_c - R_0$$

$$R = \frac{P_0}{\cos\theta} - R_0 \qquad \cos\theta = \frac{P_0}{2R_c}.$$

substituting R in j(r,theta)

$$j(r,\theta) = j_c(\theta)\left\{1 - \left(1 - \frac{2r_0\cos\theta}{P_0 - 2R_0\cos\theta}\right)^n\right\}$$

Distribution Parameter

the mixture flux j_c at a point on the line B is

$$j_c(\theta) = j_{c0}\left[1 - \left\{1 - \frac{P_0 - 2R_0\cos\theta}{(\sqrt{2}P_0 - 2R_0)\cos\theta}\right\}^n\right]$$

joint these two equations of flux results the

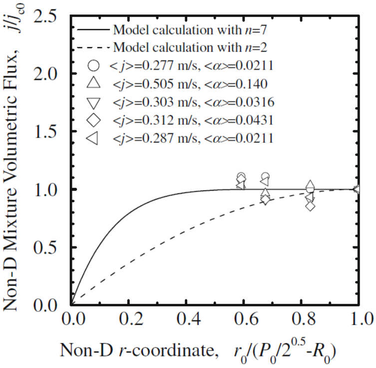
$$j(r,\theta) = j_{c0}\left[1 - \left\{1 - \frac{P_0 - 2R_0\cos\theta}{(\sqrt{2}P_0 - 2R_0)\cos\theta}\right\}^n\right] \times \left\{1 - \left(1 - \frac{2r_0\cos\theta}{P_0 - 2R_0\cos\theta}\right)^n\right\},$$

In a similar way, the void fraction distribution flow in the sub-channel can be defined as

$$\alpha(r,\theta) = \alpha_{c0}\left[1 - \left\{1 - \frac{P_0 - 2R_0\cos\theta}{(\sqrt{2}P_0 - 2R_0)\cos\theta}\right\}^m\right] \times \left\{1 - \left(1 - \frac{2r_0\cos\theta}{P_0 - 2R_0\cos\theta}\right)^m\right\}.$$

Distribution Parameter

the the comparisons of modeled j/j_{co} at a maximum point on the line B is



Distribution Parameter

In order to obtain the complete C_{co} distribution, the Ishii's equation for boiling flow in a round pipe, is modified in order to take into account the flow channel geometry difference.

$$C_0 = \left\{ C_{0,\infty} - (C_{0,\infty} - 1)\sqrt{\rho_g/\rho_f} \right\} \left(1 - e^{A\langle\alpha\rangle}\right) \quad (6)$$

The results obtained by the use of the results have been fitted to a equation with a similar function

$$C_0 = \begin{cases} \left(1.03 - 0.03\sqrt{\frac{\rho_g}{\rho_f}}\right)\left(1 - e^{-26.3\langle\alpha\rangle^{0.780}}\right) & \text{for} \quad D_0/P_0 = 0.3 \\ \left(1.04 - 0.04\sqrt{\frac{\rho_g}{\rho_f}}\right)\left(1 - e^{-21.2\langle\alpha\rangle^{0.762}}\right) & \text{for} \quad D_0/P_0 = 0.5 \\ \left(1.05 - 0.05\sqrt{\frac{\rho_g}{\rho_f}}\right)\left(1 - e^{-34.1\langle\alpha\rangle^{0.925}}\right) & \text{for} \quad D_0/P_0 = 0.7 \end{cases} \quad (29)$$

Drift velocity

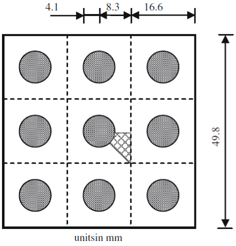
The drift velocity of a gas phase, $\mathrm{v_{gj}}$, is he velocity of the gas phase, $\mathrm{v_g}$, with respect to the volume center to the mixture flux, j
In this work, the expression developed by Ishii has been modified, considering the flow in the sub-channel, is given as

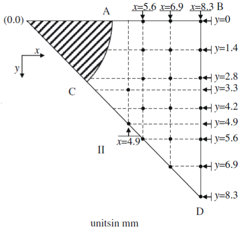
$$\langle\langle v_{gj}\rangle\rangle = B_{sf}\sqrt{2}\left(\frac{\sigma\Delta\rho g}{\rho_f^2}\right)^{1/4}(1-\langle\alpha\rangle)^{1.75}, \qquad (30)$$

Results

Experimental data

- Using a Pitot tube and a double-sensor conductivity probe they obtain the flow parameters in liquid and gas phases;
- The high void fraction considered is 0.2
- The measurements were performed at 20 different locations in one of the sub-channels,





Experimental facility	Type	Length (m)	Rods (heated)	D_H (mm)	D_0 (mm)	Axial power distribution	ΔT_{sub} (K)	p (Mpa)	G (Kg/m^{2}s)	q (kW m^{-2})	No. flow cond.	Measured parameters
Yun (1996)	BWR	1.7	9 (9)	18.4	8.2	Uniform	3.5–11	0.12	250–522	25–185	53	α, a_i, v_g, D_{Sm}, v_f

Results Distribution Parameter

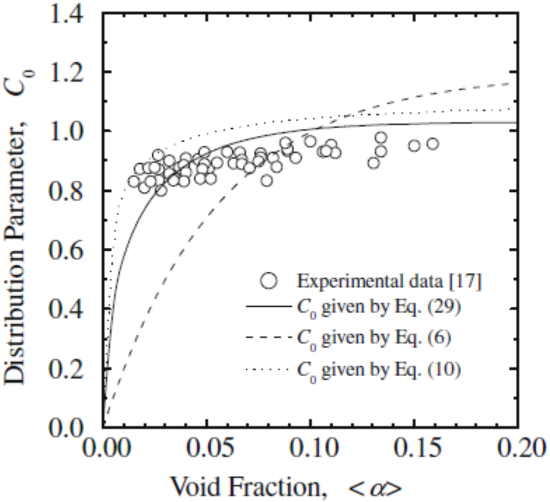


Fig. 7. Comparison of distribution parameters and experimental data.

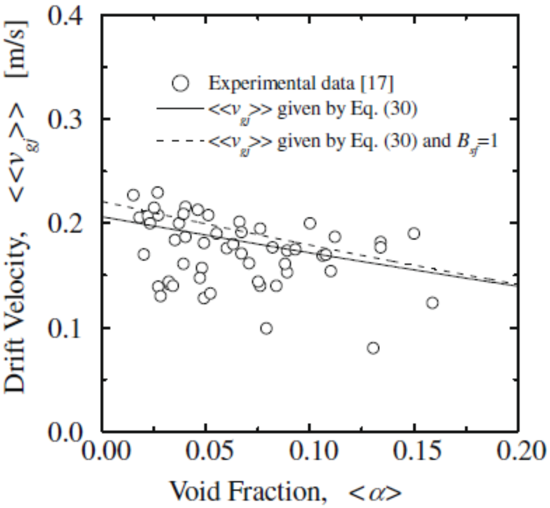


Fig. 8. Comparison of area-averaged drift velocity with experimental data.

Results Model

Prediction accuracy of drift-flux models.

Models	Averaged error C_0	Averaged error $\langle\langle v_{gj} \rangle\rangle$	Averaged error $\langle \alpha \rangle$
Disctribution parameter			
Eq. (29) with $D_0/P_0 = 0.5$	±8.01%	–	–
Drift velocity			
Eq. (30) with $B_{sf} = 1$ (Ishii's Eq.)		±19.6%	
Eq. (30)	–	±13.1%	–
Drift-flux model			
Eq. (29) with $D_0/P_0 = 0.5$ and Eq. (30) with $B_{sf} = 1$			±20.4%
Eq. (29) with $D_0/P_0 = 0.5$ and Eq. (30)	–	–	±14.4%
Bestion (1990)	–	–	±23.8%
Inoue et al. (1993)	–	–	±35.1%
Chexal–Lellouche (1992)	–	–	±38.6%
Maier and Coddington (1997)	–	–	±67.6%

Conclusions

- Distribution parameter: The averaged relative prediction error by the newly developed correlation presents a remarkable low prediction error of $\pm 8.01\%$.
- Drift velocity: the best prediction results are provided by the Ishii's correlation modified in order to take into account the wall effect with an averaged prediction error of $\pm 13.1\%$. If this effect is not considered the prediction error is $\pm 19.6\%$.