CFD Analysis of Two-Phase Flows in a Narrow Rectangular Channel withNEPTUNE_CFD and Study of the Lateral Development of the Void Fraction

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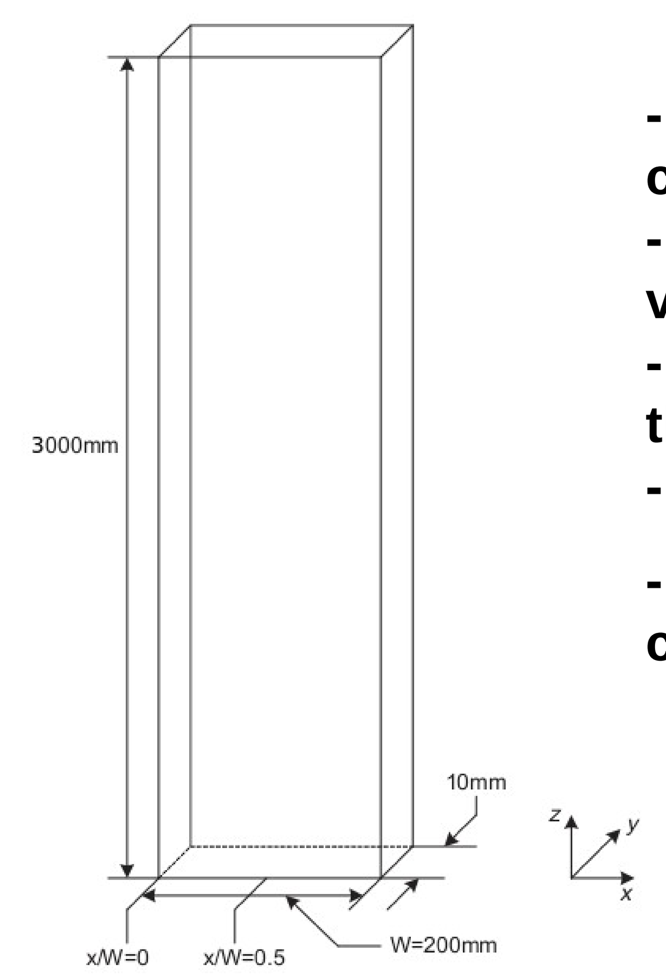
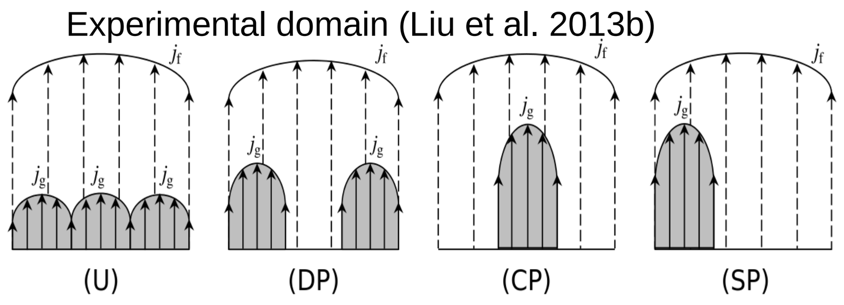
Introduction

The lateral motion of bubbles in a flat rectangular channel is a phenomenon of physical interest. As the lift, wall and turbulent dispersion forces are assumed to be the main contributors, they have to be correctly modelled for CFD codes to accurately describe this phenomenon. First a validation process of the code NEPTUNE_CFD is performed, based on experiments in narrow rectangular duct carried out by Liu et al. (2013a and 2013b) and Kim et al. 2002. A dimensional analysis of the lateral motion of bubbles is then made, and ruling parameters identified using the CFD tool.

Validation of NEPTUNE_CFD



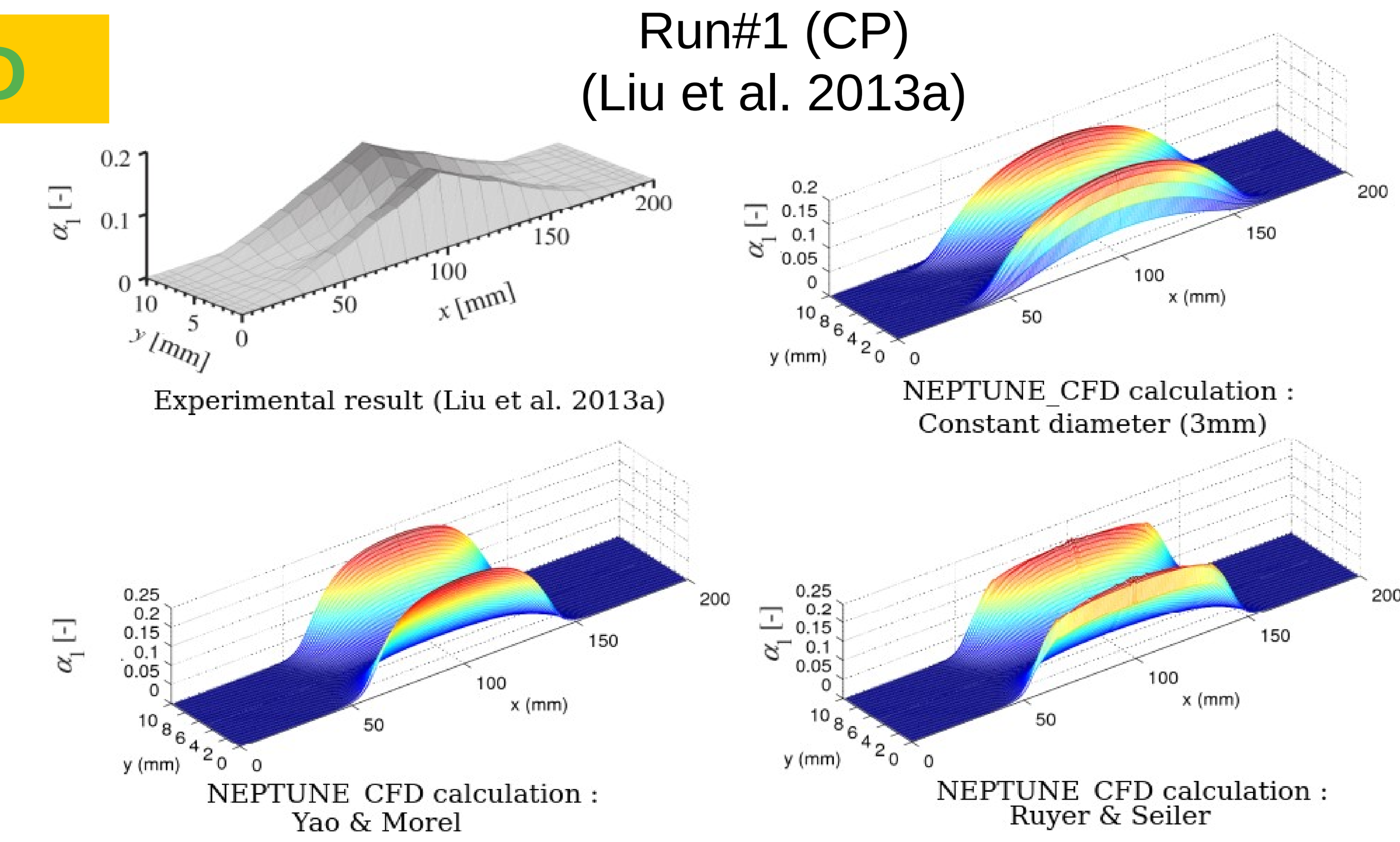
Experimental domain (Liu et al. 2013b)

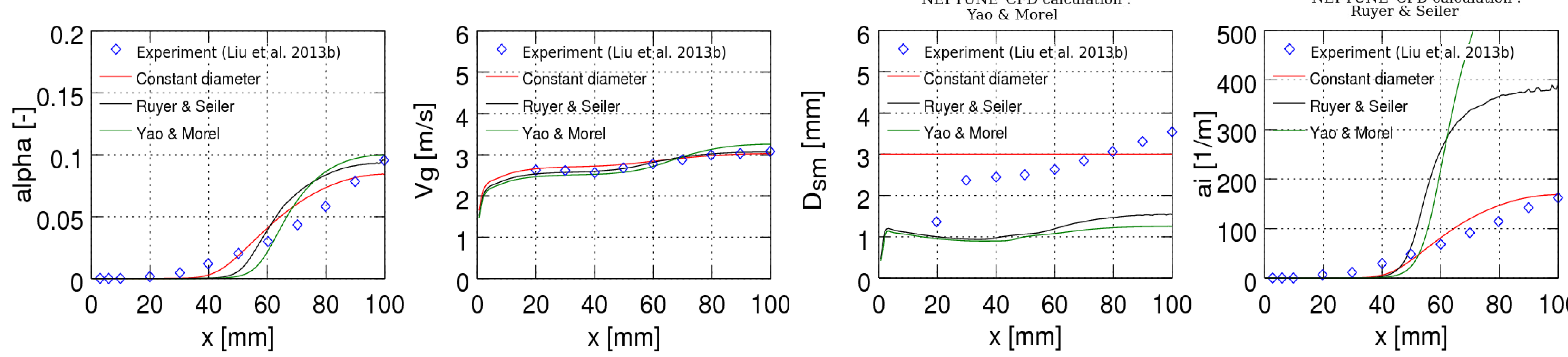


4 non-uniform two-phase profiles (Liu et al. 2013a)

- The validation process has been made over 6 bubbly flow calculations.
- Comparison to experimental data shows very good agreement for values averaged across the gap.
- Interfacial Area Transport Equation (IATE) models underestimate the mean bubble diameter.
- The lateral development is of lower amplitude in the calculations.
- The acute void fraction peak of case (CP) is never found in the calculations

Run#1 (CP)
(Liu et al. 2013a)

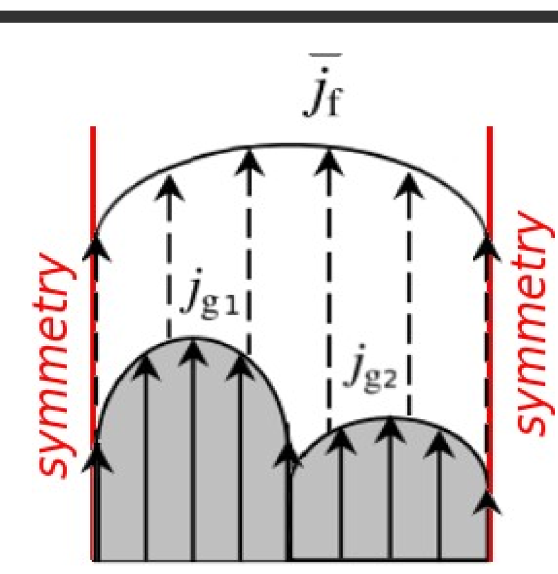




Comparison of NEPTUNE_CFD calculations to experiment of (Liu et al. 2013b). Run#1 (CP), jg=0.09m/s, jf=2.53m/s, z/Dh=142

Lateral development across the wider dimension : dimensional analysis

The Vaschy-Buckingham theorem (a.k.a Theorem Pi) is used to identify the dimensionless numbers ruling the flow in the channel.
Any variable ζ of the flow depends on the parameters through a particular function F :



Inlet conditions for the dimensional analysis with NEPTUNE_CFD

$$\mathcal{F}(\zeta, x, y, z, L, e, H, d, \rho_f, \rho_g, \mu_f, \mu_g, j_f, j_g, \sigma, g) = 0$$

The parameters appearing are then made dimensionless and the variable of interest ζ being the void fraction averaged along the gap, we obtain the following relation :

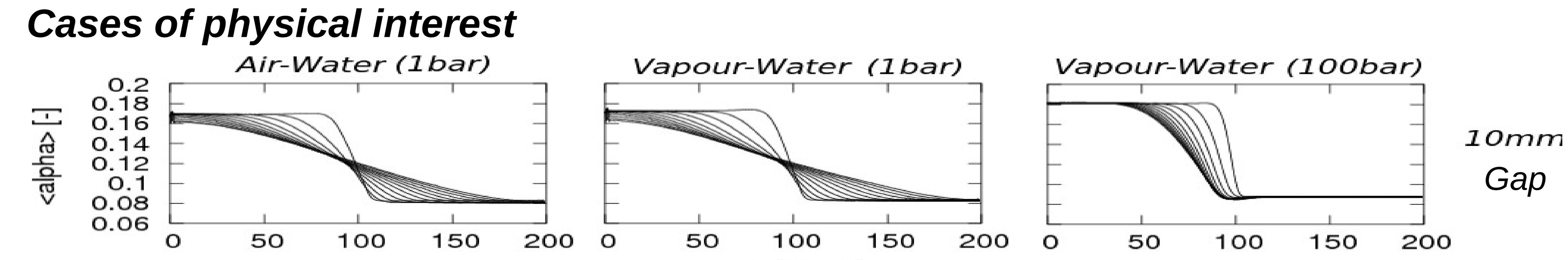
$$\alpha = \alpha\left(\frac{x}{e}, \frac{z}{e}, \frac{d}{e}, \frac{\rho_g}{\rho_f}, \frac{\mu_g}{\mu_f}, \frac{j_g}{j_f}, \overline{Re_f}, \overline{We}, Eo\right)$$

$$\overline{Re_f} = \frac{\rho_f j_{f0} D_h}{\mu_f} \qquad Eo = \frac{\Delta\rho g d^2}{\sigma} \qquad \overline{We} = \frac{\Delta\rho j_{f0}^2 d}{\sigma}$$

We then studied the effect the parameters by varying them independently from the others when possible.

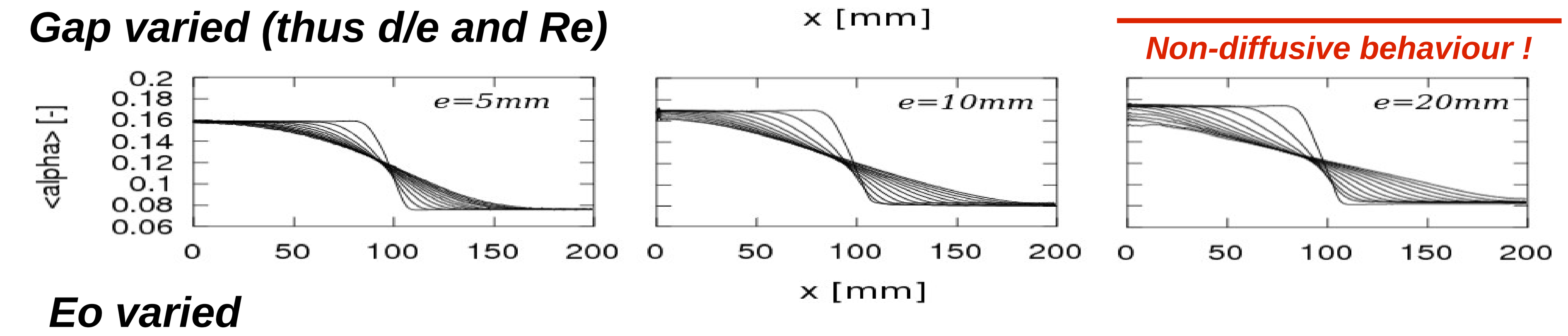
The lateral developement was observed through CFD computations with NEPTUNE_CFD. The inlet conditions induced a difference of void fraction, but a continuous velocity of both phases over the inlet section.

Cases of physical interest

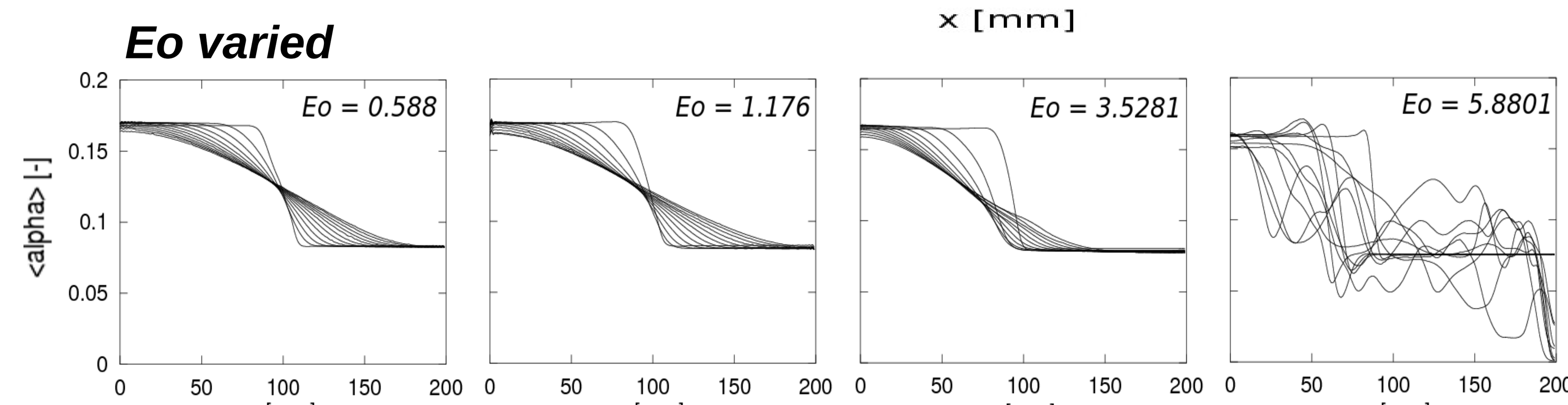


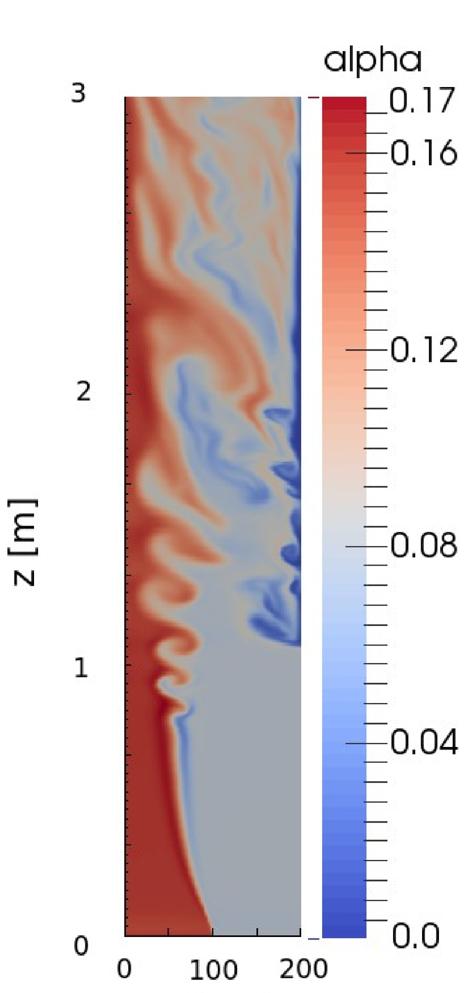
Gap varied (thus d/e and Re)

Non-diffusive behaviour !



Eo varied





The dimensionless analysis was mostly focused on the following parameters : $\frac{d}{e}, \frac{j_g}{j_f}, \overline{Re_f}, \overline{We}, Eo$

It identified the Eötvös number as most sensitive parameter. The other having minor effects on the lateral development of void fraction. It can also be noted that an important value of Eo, by changing the sign of the lift force, intensifies the disequilibrium of void fraction and induces a strong gradient of velocity, which might explain the development of instabilities in the duct.

Conclusions

- The validation study of NEPTUNE_CFD shows good agreement with experimental date provided the interfacial area is accurately. The lateral development is however underestimated. More accurate IATE models are needed.
- The lateral development has diffusive characteristics when Eo is low.
- Higher values of Eo destabilizes the flow.

References

[Kim et al. 2002] S. Kim, M. Ishii, Q. Wu, D. McCreary, and S.G. Beus. *Interfacial structures of confined air-water two-phase bubbly flow.* Experimental Thermal and Fluid Science, 26 :461–472, 2002.

[Liu et al. 2013a], Y.Liu, T.Roy, D.T.Lee, M.Ishii, J.R.Buchanan Jr., *Experimental study of non-uniform inlet conditions and three-dimensional effects of vertical air-water two-phase flow in a narrow rectangular duct*. International Journal of Heat and Fluid Flow 39, 173-186

[Liu et al. 2013b],Y. Liu, D.Y. Lee, T. Roy, M. Ishii, and J.R. Buchanan Jr. *The development of two-phase flow structures in air-water planar bubble jets.* International Journal of Multiphase Flow, 56 :25–39, 2013

[Marfaing et al, 2016] O. Marfaing, M. Guingo, J. Laviéville, G. Bois, N. Méchitoua, N. Mérigoux, S. Mimouni, *An analytical relation for the void fraction distribution in a fully developed bubbly flow in a vertical pipe*, Chemical Engineering Science, 152, 579-585, 2016.

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