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Review

# Interfacial forces used in two-phase flow numerical simulation

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ABSTRACT

High fidelity 3D computational simulation for gas–liquid two-phase flow is getting important to simulate various thermal–hydraulic phenomena in nuclear related components. Single-phase computational simulation techniques have reached to a certain level of reasonable prediction accuracy for the purposes of designs and performance analyses of industrial equipment. However, two-phase computational simulation techniques have not reached to the level of reliable prediction due mainly to the difficulty in the modeling of interfacial transfer terms. Accurate modeling of the interfacial forces including the interfacial area modeling is one of the keys to predict the distribution of gas phase in various two-phase flow systems successfully. This paper is aiming at reviewing the interfacial force modeling including recent advance of the interfacial area transport equation. This paper discusses the frame-work of bubble-wall collision force which is potentially used in place of the wall lubrication force applicable for laminar flow. This paper also discusses the frame-work of the bubble collision force considering the effect of the bubble coalescence on the bubble collision frequency. The review of existing interfacial force models including newly developed bubble-wall collision force and recent advance of the interfacial area transport equation offers the most advanced knowledge of constitutive equations necessary for improving the predictive capability of the two-phase flow computational simulation codes.



**Contents**



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**Nomenclature**

| | |
|---|---|
| $A_{base}$ | base area of group-2 bubble radius |
| $A_d$ | projection area of a bubble |
| $a_i$ | interfacial area concentration |
| $B_g$ | bubble volume |
| $C_W$ | coefficient |
| $D$ | hydraulic equivalent diameter of flow channel |
| $D_b$ | bubble diameter |
| $Eo$ | Eötvös number |
| $\boldsymbol{F}$ | interfacial force |
| $G_S$ | dimensionless velocity gradient |
| $g$ | gravitational acceleration |
| $H_{gf}$ | curvature of gas phase |
| $k$ | turbulent kinetic energy |
| $L_{wet}$ | perimeter |
| $\boldsymbol{M}$ | interfacial momentum transfer term |
| $n_b$ | number density |
| $\boldsymbol{n_W}$ | normal unit vector of wall |
| $\boldsymbol{n_Z}$ | unit vector along flow direction |
| $p$ | pressure |
| $P$ | variable of exponential law |
| $\boldsymbol{P}$ | momentum |
| $Pr_{\alpha f}$ | Prandtl number for volume fraction |
| $Re$ | Reynolds number |
| $r_d$ | bubble radius |
| $S$ | source or sink term of bubble number per unit volume |
| $St$ | Stokes number |
| $t$ | time |
| $V$ | volume |
| $\boldsymbol{v}$ | velocity |
| $\boldsymbol{v}_r$ | relative velocity |
| $\boldsymbol{v}_t$ | turbulence velocity |
| $y_w$ | distance between bubble and wall |

*Greek symbol*

| | |
|---|---|
| $\alpha$ | void fraction |
| $\alpha_{\max}$ | maximum allowable void fraction |
| $\Delta m_{12}$ | inter-group mass transfer term |
| $\Gamma$ | interfacial mass transfer term |
| $\varepsilon$ | turbulence dispersion rate |
| $\chi$ | coefficient of inter-group transfer |
| $\sigma$ | surface tension |
| $\eta$ | volume generation rate per unit volume |
| $\eta_c$ | collision efficiency |
| $\phi$ | source term of interfacial are concentration |
| $\rho$ | density |
| $\Delta\rho$ | density difference |
| $\nu$ | kinematic viscosity |
| $\nu_t$ | kinematic turbulent viscosity |
| $\nu_t^{BI}$ | bubble induced kinematic turbulent viscosity |
| $\mu$ | dynamic viscosity |
| $\Sigma$ | macroscopic bubble collision cross section |
| $\bar{\bar{\boldsymbol{\tau}}}$ | shear stress |
| $\xi$ | modification factor due to bubble deformation |

*Subscripts*

| | |
|---|---|
| 1 | group-1 |
| 2 | group-2 |
| $f$ | liquid phase |
| $g$ | gas phase |
| $i$ | value at interface |
| $j$ | *j-th* interface |
| $ph$ | phase change |
| $k$ | *k*-phase (gas or liquid) |
| $q$ | bubble group *q* (group 1 or group 2) |
| $W$ | wall |
| $\infty$ | single-bubble system |

*Superscripts*

| | |
|---|---|
| $BC$ | bubble collision force |
| $BF$ | Basset force |
| $BW$ | bubble/Wall collision force |
| $D$ | drag force |
| $IP$ | interfacial pressure force |
| $IS$ | interfacial shear force |
| $LF$ | lift force |
| $VM$ | virtual mass force |
| $SL$ | shear induced lift force |
| $TD$ | turbulent dispersion force |
| $WL$ | wall lubrication force |