ABSTRACT

This paper presents experimental and modeling approaches in characterizing interfacial structures in gas-liquid two-phase flow. For the modeling of the interfacial structure characterization, the interfacial area transport equation proposed earlier has been studied to provide a dynamic and mechanistic prediction tool for two-phase flow analysis. A state-of-the-art four-sensor conductivity probe technique has been developed to obtain detailed local interfacial structure information in a wide range of flow regimes spanning from bubbly to churn-turbulent flows. Newly obtained interfacial area data in 8×8 rod bundle test section are also presented. This paper also reviews available models of the interfacial area sink and source terms and existing databases. The interfacial area transport equation has been benchmarked using condensation bubbly flow data.

1. INTRODUCTION

In the present state-of-the-art, the two-fluid model is the most detailed and accurate macroscopic formulation of the thermo-fluid dynamics of two-phase systems (Ishii, 1975; Ishii and Hibiki, 2005). The existence of the interfacial transfer terms is one of the most important characteristics of the two-fluid model formulation. These terms determine the rate of phase changes and the degree of mechanical and thermal non-equilibrium between phases, thus they are the essential closure relations which should be modeled accurately.

The present thermal-hydraulic system analysis codes such as RELAP5, TRAC, and CATHARE use one-dimensional form of the two-fluid model equations, where the interfacial area concentration is specified by empirical correlations based on steady-state, fully developed conditions. This approach suffers following shortcomings:

1) During relatively fast transients, where the relaxation time for the development of the flow structure is similar or greater than the characteristic time of the transient itself, the dynamic nature of the transient cannot be accurately predicted. Analysis of developing flows also suffers the same drawback.

2) The correlations for interfacial area concentration are based on flow regimes which are in turn specified by constitutive equations as discrete functions of local superficial velocities of two phases. The compound errors in this approach are large. This also leads to artificial discontinuities and numerical instabilities in the numerical solutions of the field equations.

3) The flow regime transition criteria and corresponding interfacial area concentration correlations have a limited range of applicability in terms of boundary conditions, fluid properties, flow geometry and scale.

To overcome these problems, the interfacial area concentration should be specified by a transport equation which models the evolution of the geometric structure considering the physical mechanisms of local interactions between the two phases (Ishii, 1975; Ishii and Hibiki, 2005). The transport equation can capture the dynamic changes in the flow structure, especially the transitions among flow regimes. Hence the transport equation can be used for systems with wide range of scales and boundary conditions.

Following this introduction, this paper presents the basic idea behind the derivation of the interfacial area transport equation and discusses the two-group approach including modified two-
group gas momentum equation. Furthermore, the measurement technique and the available experimental data are summarized, and newly obtained data in 8×8 rod bundle test section are also presented. Finally, the evaluation of the interfacial area transport equation with respect to the database is discussed.

2. FORMULATION OF INTERFACIAL AREA TRANSPORT EQUATION

2.1 Two-group interfacial area transport equation

The Boltzmann transport equation describes particle transport by an integro-differential equation of the particle-distribution function. Since the interfacial area of the fluid particle is closely related to the particle number, the interfacial area transport equation can be formulated based on the Boltzmann transport equation (Ishii and Hibiki, 2005).

In a gas-liquid two-phase flow system, a wide range of bubble shapes and sizes exist depending on the given flow regime. Therefore, to develop the interfacial area transport equation describing the bubble transport in a wide range of two-phase flow regimes, the model must take account of the differences in the transport characteristics of different types of bubbles. These variations in shape and size of bubbles cause substantial differences in their transport mechanisms due to the drag forces as well as the bubble interaction mechanisms.

In the two-group formulation, the bubbles are treated in two groups, namely group-1 bubbles consisting of spherical and distorted bubbles and group-2 bubbles consisting of cap, Taylor and churn-turbulent bubbles. The group-1 bubbles exist in the range of minimum bubble size to maximum distorted bubble size limit, $D_{d, \text{max}}$, whereas the group-2 bubbles exist in the range of $D_{d, \text{max}}$ to maximum stable bubble size limit, $D_{\text{max}}$. The boundary bubble sizes, $D_{d, \text{max}}$ and $D_{\text{max}}$ are given by

$$
D_{d, \text{max}} = 4 \frac{\sigma}{g \Delta \rho} \quad \text{and} \quad D_{\text{max}} = 40 \frac{\sigma}{g \Delta \rho},
$$

where $\sigma$: surface tension, $g$: gravitational acceleration, $\Delta \rho$: density difference.

The two-group interfacial area transport equation can be obtained by averaging the interfacial area transport equation over the volume range of each bubble group as

$$
\frac{\partial a_i}{\partial t} + \nabla \cdot (a_i v_i) = \frac{2}{3} a_i \left[ \frac{\partial \alpha_{g1}}{\partial t} + \nabla \cdot (\alpha_{g1} v_{g1}) - \eta_{ph} \right]
$$

$$
- \chi \left( \frac{D_{sc}}{D_{\text{sm}1}} \right)^2 \frac{a_i}{\alpha_{g1}} \left[ \frac{\partial \alpha_{g1}}{\partial t} + \nabla \cdot (\alpha_{g1} v_{g1}) - \eta_{ph} \right] + \int_{V_{\text{min}}}^{V_{\text{max}}} \left( \sum_j S_j + S_{\text{ph}} \right) A dV,
$$

$$
\frac{\partial a_i}{\partial t} + \nabla \cdot (a_i v_{i,2}) = \frac{2}{3} a_i \left[ \frac{\partial \alpha_{g2}}{\partial t} + \nabla \cdot (\alpha_{g2} v_{g2}) \right]
$$

$$
+ \chi \left( \frac{D_{sc}}{D_{\text{sm}1}} \right)^2 \frac{a_i}{\alpha_{g1}} \left[ \frac{\partial \alpha_{g1}}{\partial t} + \nabla \cdot (\alpha_{g1} v_{g1}) - \eta_{ph} \right] + \int_{V_{\text{c}}}^{V_{\text{max}}} \sum_j S_j A dV,
$$

where $a_i$: interfacial area concentration, $v_i$: interfacial velocity, $\alpha$: void fraction, $t$: time, $v_g$: gas-phase center of mass velocity, $\eta_{ph}$: rate of volume generated by nucleation source per unit mixture volume, $\chi$: coefficient accounting for the contribution from the inter-group transfer, $D_{sc}$: surface equivalent diameter of a fluid particle with surface area, $A_i$, $D_{\text{sm}1}$: Sauter mean diameter, $S_j$ and $S_{\text{ph}}$: particle source and sink rates per unit mixture volume due to $j$-th particle interactions and that due to phase change, respectively, $V_{\text{min}}$, $V_{\text{c}}$ and $V_{\text{max}}$: volumes of minimum bubble, critical bubble and maximum bubble, respectively. The two-group interfacial area transport equation is simplified to a one-group interfacial area transport equation in the bubbly flow regime.
2.2 Two-group momentum equation

The two-fluid model should be modified for the two-group interfacial area transport equation (Ishii and Hibiki, 2005). In general, the pressure and temperature for group-1 and group-2 bubbles can be assumed to be approximately the same. However, the velocities of two groups of bubbles are not the same, therefore it is necessary to introduce two continuity and two momentum equations in principle. Based on the above assumption, the density of the gas phase is the same for group-1 and group-2 bubbles.

The continuity equation for group-1 and -2 bubbles are therefore given by

\[
\frac{\partial (\alpha_g \rho_g)}{\partial t} + \nabla \cdot (\alpha_g \rho_g v_g) = -\nabla \cdot \left( \alpha_g \left( \mathbf{C}_g^\rho + \mathbf{C}_g^T \right) \right) + \nabla \cdot \left( \alpha_g \left( \mathbf{C}_g^\mu + \mathbf{C}_g^T \right) \right)
\]

where \( \rho_g \): gas density, \( \alpha_g \): area-averaged quantity, \( \langle \alpha_g \rangle a \): interfacial area concentration-weighted mean quantity, \( \langle \alpha_g \rangle c \): void fraction-weighted mean quantity, \( B \) and \( C \): rates of change of interfacial area concentration due to bubble breakup and coalescence, respectively.

The momentum equation for group-1 and -2 bubbles are given by

\[
\frac{\partial (\alpha_g \rho_g v_g)}{\partial t} + \nabla \cdot (\alpha_g \rho_g v_g v_g) = -\alpha_g \nabla p_g + \nabla \cdot \left( \alpha_g \left( \mathbf{C}_g^\rho + \mathbf{C}_g^T \right) \right)
\]

where \( p_g \): pressure, \( \mathbf{C}_g^\rho \): viscous stress, \( \mathbf{C}_g^T \): turbulent stress, \( M_{ig} \): generalized interfacial drag.

2.3 One-dimensional interfacial area transport equation

The simplest form of the interfacial area transport equation is the one-dimensional formulation obtained by applying cross-sectional area averaging over Eq.(2). The exact mathematical expressions for the area-averaged source and sink terms involve many covariances that may further complicate the one-dimensional problem. In the current one-dimensional formulation for adiabatic two-phase flow, the covariance terms are neglected because of relatively uniform flow parameter distribution over the flow channel. For example, the one-dimensional one-group interfacial area transport equation is expressed as

\[
\frac{\partial \langle a_g \rangle}{\partial t} + \frac{\partial}{\partial z} \left( \langle a_g \rangle \langle v_g \rangle \right) = \left( \langle \Phi_B \rangle - \langle \Phi_c \rangle \right) + \frac{2}{3} \langle a_g \rangle \left( \frac{\partial \langle \alpha \rangle}{\partial t} + \frac{\partial}{\partial z} \left( \langle \alpha \rangle \langle v_g \rangle \right) \right)
\]

where \( \langle \rangle \): area-averaged quantity, \( \langle \rangle \rangle \): interfacial area concentration-weighted mean quantity, \( \langle \alpha \rangle \): void fraction-weighted mean quantity, \( \Phi_B \) and \( \Phi_c \): rates of change of interfacial area concentration due to bubble breakup and coalescence, respectively. However, for subcooled boiling flow, the phase distribution pattern may not be assumed uniform, resulting in many covariances in the one-dimensional interfacial area transport equation. To avoid the covariances, a simple model can be introduced to formulate the transport equation for subcooled boiling flow (Hibiki et al., 2003). In this case, the bubbles mainly exist near a heated wall, whereas almost no bubbles exist far from the heated wall. Therefore, the flow path may be divided into two regions, namely (i) boiling two-phase (bubble layer) region where the void fraction profile can be assumed to be uniform, and (ii) liquid single-phase region where the void fraction can be assumed to be zero. Thus, the one-dimensional interfacial area transport equation can be obtained by averaging the interfacial area transport equation over the bubble-layer region and applying a factor of \( A_B/A_c \).
to the interfacial area concentration in the bubble-layer region. Here $A_B$ and $A_C$ are the area of the bubble-layer region and the cross-sectional area of the boiling channel, respectively.

3. MEASUREMENT TECHNIQUE

The local time-averaged interfacial area concentration can be measured using four-sensor conductivity probe method (Kataoka et al., 1986) based on the difference in conductivity between the two phases. The probe is composed of a sensor and an electrically conductive casing. Using the casing as the common ground, the characteristic rise and fall of the impedance signals can be obtained when an interface passes through the probe sensor. With the acquired signals from the sensor, the local time-averaged void fraction can be easily obtained by dividing the sum of the time fraction occupied by the gas phase by the total measurement time. One of the most important features of the conductivity probe is that it can measure the local interfacial velocity with multiple sensors. This is of great importance because the local time-averaged interfacial area concentration can be obtained from the interfacial velocity through the mathematical relation.

The four-sensor conductivity probe is made of four sensors. With one common upstream sensor and three independent downstream sensors, three directional velocities at a local point can be obtained by measuring the time delay between the signals from three pairs of double-sensors. When the directions of the three independent probes are chosen, the equation for the time-averaged interfacial area concentration can be simplified as (Kataoka et al., 1986),

$$a_i = \frac{1}{\Omega} \sum_j \left( \frac{1}{v_{a_j}} \right)^2 + \left( \frac{1}{v_{a_j}} \right)^2 + \left( \frac{1}{v_{a_j}} \right)^2,$$

where $\Omega$: time interval, $v_{a_j}$: passing velocity of the $j$-th interface over probe $k$. In Eq.(6), no hypothesis for bubble shape is needed for calculating the local interfacial area concentration from the interfacial velocity. Therefore, the four-sensor probe can be utilized in a wide range of two-phase flow regimes where bubbles are no longer spherical in shape. If we consider spherical bubbly flow with no correlation between bubble velocity and moving direction, Eq.(6) can be significantly simplified to enable double sensor probe method to measure the interfacial area concentration (Kataoka et al., 1986; Hibiki et al., 1998).

To minimize the finite probe size effect on the measurement, a miniaturized four-sensor conductivity probe has been developed (Kim et al., 2000). A schematic diagram of the probe design and its geometrical configuration is shown in Fig.1. One of the important features of the probe design is that the four sensor probe accommodates a built-in double-sensor probe for measuring small bubbles. Therefore, the probe is applicable to a wide range of flow regimes, spanning from bubbly

Fig.1: Configuration of the four-sensor conductivity probe (Kim et al., 2000).
to churn-turbulent flow regimes. Along with the probe design, the signal processing is constructed, such that it can identify and separate the local parameters into two groups, namely: group-1 for spherical and distorted bubbles and group-2 for slug and churn-turbulent bubbles. Throughout the benchmark experiments, very few missing interfaces are observed for the group-2 bubbles unless the probe is traversed very close to the wall of the flow duct. The measurement area of the four-sensor probe used in the experiments is less than 0.2 mm² and the tip distance of the double-sensor probe for small bubbles is 2.4 mm. This allows the measurable bubble diameter to be as small as 1 mm. The diameter of the sensor electrode is 0.13 mm, however, the sensor itself has a diameter of less than 0.05 mm. The details of the double sensor and four-sensor probe techniques can be found in Hibiki et al. (1998) and Kim et al. (2000), respectively.

4. DATABASE OF INTERFACIAL AREA CONCENTRATION

4.1 Existing database
Extensive data of axial development of flow parameters in adiabatic and boiling two-phase flow have been obtained over a wide range of flow conditions including downward flow. The measured flow parameters include local void fraction, interfacial area concentration, interfacial velocity, bubble Sauter mean diameter, liquid velocity and liquid turbulence. The covered experimental conditions are

- Test section geometry: Round pipe, confined channel, annulus and rod bundle,
- Test section size: 1 mm to 102 mm,
- Flow regime: Bubbly, cap-bubbly, slug and churn-turbulent flows,
- Flow condition: Superficial gas velocity, \( \langle j_g \rangle \), up to 10 m/s and superficial liquid velocity, \( \langle j_f \rangle \), from -3.1 m/s (i.e. downward flow) to 5.0 m/s (i.e. upward flow),
- Flow direction: Vertical upward and downward flows,
- Thermal condition: Adiabatic and diabatic flows,
- Gravity condition: Normal and micro gravity conditions,
- Pressure condition: Atmospheric pressure

The extensive review of the existing database can be found in Hibiki and Ishii (2001, 2002) and Hibiki et al. (2006). In what follows, newly obtained data taken in 8×8 rod bundle test section are shown.

4.2 Database for 8×8 rod bundle geometry
Recently, axial developments of local flow parameters in air-water two-phase flow were measured in 8×8 rod bundle test facility. The test section consisted of a 3m long vertical flow channel with square cross section having sides of length 140 mm. It housed an 8×8 array of 64 rods each having a diameter of 12.7 mm arranged at a pitch distance of 16.7 mm. The rods were held in place by six spacer grids located at \( z/D_h = 31, 61, 91, 121, 151 \) and 180 where \( D_h \): hydraulic diameter of a typical subchannel (≈14.8 mm), \( z \): axial distance from the inlet of the test section. The narrowest and widest gaps in the center subchannel were, respectively, 4.0 mm and 10.9 mm. The measurement ports were located at the axial distances of \( z/D_h =7, 86, 94, 116, 124, 137 \) and 200. The detailed information on the experimental facility and instrumentation can be found in Paranjape et al. (2008).

Figure 2 shows the measurement grid for local flow data. At each axial location in the flow channel, the local flow data were taken at the center of the sub-channels and the narrowest gap between the rods. The local data were taken in 5 axial locations in the flow channel under 20 superficial gas and liquid velocity conditions which covered bubbly, cap bubbly, cap-turbulent and churn-turbulent flow regimes. Figure 3 shows flow visualization in various flow regimes.
The representative data at \( \frac{z}{D_H} = 200 \) in two bubbly and one cap-turbulent flow regime conditions are shown in Figs.4-7. In Figs.4-6, the data are shown along the center line of the rod bundle from the bundle center, \( x \). The distance in the figures is normalized by the half width of the rod bundle casing designated by \( W \). In Fig.7, the data is also plotted along the diagonal line of the rod bundle from the bundle center, \( d \). The distance in the figure is normalized by the half width of
the bundle diagonal length designated by $S$. The flow conditions in Figs.4 and 5 are $\langle j_g \rangle = 0.02$ m/s and $\langle j_l \rangle = 0.02$ m/s, and $\langle j_g \rangle = 0.02$ m/s and $\langle j_l \rangle = 1.0$ m/s, respectively, corresponding to bubbly flow regime where only group-1 bubbles are observed. The flow condition in Figs.6 and 7 is $\langle j_g \rangle = 0.5$ m/s and $\langle j_l \rangle = 0.2$ m/s, corresponding to cap-turbulent flow regime where two groups of bubbles are observed. Comparing Figs.4 and 5, the effect of increased superficial liquid velocity on the spatial distribution and magnitude of flow parameters can be clarified, whereas the comparison between Figs.4 and 6 provides some insights on the effect of increased gas velocity and flow regime transition on the spatial distribution and magnitude of flow parameters.

Open and solid symbols in Figs.4 and 5 indicate local flow parameter measured at subchannel center and rod narrowest gap, respectively. As the superficial liquid velocity increases, the bubble size becomes smaller due to bubble breakup and the bubbles tend to migrate toward the rod narrowest gap, which is similar to wall peaking observed in a round pipe test section (Hibiki and Ishii, 1999). This can be explained as follows.

The lift force acting on a bubble is generally enhanced by increased velocity gradient. The increased liquid velocity enhances the gas velocity gradient between the subchannel center and rod

![Graphs showing void fraction, interfacial area concentration, gas velocity, and Sauter mean diameter.]

Fig.4: Local parameter data along center line in bubbly flow at $z/D_H = 200$.

Flow condition: $\langle j_g \rangle = 0.02$ m/s and $\langle j_l \rangle = 0.2$ m/s.
narrowest gap, which may also indicate the augmented liquid velocity gradient. In addition to this, the lift force direction is flipped over around the bubbles size of 5 mm. If the bubble size is smaller than 5 mm, the lift force tends to push the bubbles toward a wall. For the bubble size smaller than 5 mm, the absolute value of the lift coefficient decreases with increased bubble size (Hibiki and Ishii, 2007). Thus, the increased superficial liquid velocity decreases the bubble size resulting in the increased absolute value of the lift coefficient. Such combined effects enhance the void fraction at the rod narrowest gap.

As the bubbles migrate toward the rod narrowest gap, the interfacial area concentration near the rod narrowest gap is increased. The gas velocity at the subchannel center is higher than that at the rod narrowest gap, since the liquid velocity is bound to be zero at the rod surface. For the lower liquid velocity condition, the bubble Sauter mean diameter is comparable to the rod narrowest gap (4 mm).

Open and solid symbols in Fig.6 indicate local flow parameter measured at subchannel center and rod narrowest gap, respectively. Circle and triangle symbols indicate local flow parameter for group-1 and -2 bubbles. As can be seen from Fig.6, as the superficial gas velocity increases, group-2 bubbles, namely cap bubbles are formed. Unlike the low superficial gas velocity condition shown in Fig.5, the difference in flow parameter distribution between the subchannel center and rod narrowest gap.

Flow condition: $\langle j_y \rangle = 0.02$ m/s and $\langle j_f \rangle = 1.0$ m/s.
Fig. 6: Local parameter data along center-line in cap-turbulent flow at $z/D_h = 200$.

Flow condition: $\langle j_g \rangle = 0.5$ m/s and $\langle j_f \rangle = 0.2$ m/s.

gap is insignificant, which means that the flow parameter distribution is influenced by the presence of the bundle outer casing.

Since the size of the group-1 bubble exceeds 5 mm, the bubbles around the rod narrowest gap may be squeezed by rods. Since large bubbles tend to rise in the center of the channel, the void fraction at the subchannel center becomes higher. The gas velocity shows the power-low distribution over the whole bundle test section in a global sense. The gas velocity of group-1 bubble is slightly higher than that of group-2 bubble. This can be explained by the difference in drift-velocity in group-1 and -2 bubbles. In the tested condition, the Sauter mean diameter of group-2 bubble exceeds the hydraulic diameter of the subchannel. Due to the presence of the rods, the drift velocity may be reduced considerably. This can be understood by the fact that the drift velocity of a slug bubble is in proportional to the square root of channel diameter. For air-water pipe flow at room temperature and atmospheric pressure, the drift velocities for small and slug bubbles becomes equal at $D_h = 50.8$ mm. In the channel smaller than 50.8 mm, slug bubble rising velocity is smaller than small bubble rising velocity.

Figure 7 shows the local flow parameter measured at subchannel center along the diagonal line of the bundle test section. Interestingly the void fraction of group-1 bubbles has a slight peak near the bundle outer casing. The distributions of flow parameters along the diagonal line are consistent with those along the subchannel center line.
5. SINK AND SOURCE TERM MODELING AND THEIR EVALUATION

To close the interfacial area transport equation, extensive efforts to model various sink and source terms of the interfacial area transport equation have been made. Major modeled sink and source terms are summarized in Table 1. To demonstrate the capability of the interfacial area transport equation, the one-dimensional one-group interfacial area transport equation is evaluated in condensation systems using

\[
\frac{\partial}{\partial z} \left\langle \left\langle \alpha_i \right\rangle \right\rangle \left\langle \left\langle v_i \right\rangle \right\rangle_a = \left\langle \Phi_{TT} \right\rangle - \left\langle \Phi_{RC} \right\rangle - \left\langle \Phi_{CD} \right\rangle + \frac{2\left\langle \alpha_i \right\rangle}{3\left\langle \alpha \right\rangle} \frac{\partial}{\partial z} \left\langle \left\langle v_i \right\rangle \right\rangle.
\]

In Eq.(7), the bubble breakup and coalescence terms are calculated by Hibiki and Ishii’s model (2000a), whereas the bulk condensation term is computed by Park et al. model (2007).

Figure 8 compares the interfacial area transport calculation with condensation data taken in a vertical concentric annulus (Park et al., 2007). The flow condition is \( p_0 \) (inlet pressure) = 0.103 MPa, \( T_{J0} \) (inlet liquid temperature) = 98.0 °C and \( G \) (total mass flux) = 139 kg/m²/s (Zeitoun, 1994).

As can be seen from Fig.8, the interfacial area concentration changes due to bubble coalescence, bubble breakup and void fraction change are negligibly small in the tested condition. The condensation in heat transfer-controlled region without bubble number density change, \( \Phi_{HC} \), is the
Table 1: Major modeled sink and source terms of the interfacial area concentration.

<table>
<thead>
<tr>
<th>Category</th>
<th>Investigator</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-group Bubble</td>
<td>Wu et al. (1998)</td>
<td>One-group bubble coalescence and breakup</td>
</tr>
<tr>
<td>Bubble Interaction</td>
<td>Hibiki and Ishii (2000a)</td>
<td>One-group bubble coalescence and breakup</td>
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<td>Hibiki et al. (2001)</td>
<td>One-group bubble coalescence and breakup</td>
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<td></td>
<td>Yao and Morel (2004)</td>
<td>One-group bubble coalescence and breakup</td>
</tr>
<tr>
<td>Two-group Bubble</td>
<td>Hibiki and Ishii (2000b)</td>
<td>Two-group bubble coalescence and breakup</td>
</tr>
<tr>
<td>Bubble Interaction</td>
<td>Fu and Ishii (2003)</td>
<td>Two-group bubble coalescence and breakup</td>
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<tr>
<td></td>
<td>Sun et al. (2004)</td>
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<td>Phase Change</td>
<td>Park et al. (2007)</td>
<td>Bulk condensation</td>
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<td>Situ et al. (2008)</td>
<td>Bubbly departure frequency</td>
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Fig. 8: Contribution of bubble coalescence, breakup, void transport, and condensation to interfacial area transport (Park et al., 2007).

6. CONCLUSIONS

In relation to the modeling of the interfacial transfer terms in the two-fluid model, the concept of the interfacial area transport equation has been proposed to develop a constitutive relation for the interfacial area concentration. The interfacial area transport equation can replace the traditional flow regime maps and regime transition criteria. The changes in the two-phase flow structure can be predicted mechanistically by introducing the interfacial area transport equation. The effects of the boundary conditions and flow development are efficiently modeled by this transport equation. The successful development of the interfacial area transport equation can make a significant improvement in the two-fluid model formulation and the prediction accuracy of three-dimensional two-phase flow simulations.

This paper reviewed the current status of the interfacial area transport equation development and presented newly obtained interfacial area concentration data in 8×8 rod bundle test facility. Although much efforts have been done to develop it, further modeling and experimental work are required to establish the interfacial area transport equation.
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