GENERALIZED QUASI-ONE-DIMENSIONAL TWO-PHASE FLOW MODELS: WALL FRICTION AND HEAT TRANSFER CLOSURE RELATIONSHIPS IN QUASI STEADY STATE APPROXIMATION

Y. KORNIENKO, E. KORNIENKO
Institute for Physics and Power Engineering, SSC-RF,
Bondarenko Sq.1, Obninsk, Kaluga Region, Russia, 249033
kornienk@ippe.obninsk.ru

1 Introduction

The main question in single- and two-phase flow thermohydraulics is how to take into account the real 3-D flow characteristics in 1-D models in a simple and universal way. By performing an area average, obtained field equations become one-dimensional. In this procedure, important distributed information is actually lost on changes of variables in the direction normal to the main (axial) flow. Meanwhile, a non-adequate description of the transversal profile, being associated with space averaging of the left- and right-hand terms of the conservation law equations, could result in numeric stability problems and necessities for corrections to friction factor and heat- and mass transfer. Thus, the flow model for Lumped Parameter Analysis (LPA) code and momentum, energy and mass transfers between the wall and fluid should be specified by adequate closure relationships on the base of theoretical, semi-empirical, or empirical correlation, taking into account the effects of transversal profiles. For the complicated conditions under which several physical effects are interacting each other, the knowledge of such closure relationships leaves much room to be improved. Moreover, there is not of closure strategy for 1-D thermohydraulic model and the generalized representations of constitutive equations for distribution parameters- C_{ki}, friction factors, heat and mass transfer coefficients required in the LPA codes (both to pipe and to subchannel geometry) for nuclear reactor transient and accident regimes.

There are several approaches describing a transversal variation of the variables in the 1-D models in the literature. However, these models are either phenomenological or too general, and they fail to predict a number of experimental data with strong transversal effects.

The purpose the of this paper is to construct more complete and universal closure relationships for the distribution parameters, wall friction, heat and mass transfer coefficients and to give the representative in their integral formulations of the main effects controlling the phase parameter distribution and substance transfer, including transient flow conditions in quasi steady state approximation.

2 Conservation Laws and Distribution Parameters

Space averaging procedures of the local profile variables for each conservation law equation (in the form of the drift flux or two-fluid model) should be apply for simple (round pipe) and compound (subchannel) geometry. That is why for such quasi-1-D formulation of the left-hand conservation law equations there are distribution parameters both to pipe and to subchannel geometry due to space averaging.

The generalized hierarchically closed analytical relationships for C_{ki} have been obtained in the quasi-1-D drift flux formulation of the continuity, energy and momentum of two-phase flow equations. Main assumptions are quasi steady state approximation and power approximation of the local phase profiles for derivation of the quadratures for distribution parameters. These quadratures for C_{ki}, expressed in terms of elementary functions generalize and unify the known Zuber-Findlay method. They extend it not only to continuity but energy and momentum equations. An analogous set of analytical relationships was derived for the case of non-monotonous variable profile, including a compound channel or subchannel in the frame of two-zone model for two superimposed monotone profiles.

These integral forms of the distribution parameters make up the interrelation of the hierarchical structure between substance transfer in the conservation law equations. Moreover kinematic (simple form) distribution parameters (Zuber-Findlay-type) are a part of more compound distribution parameters for an energy transfer and momentum transfer relationships and affect in many respects the character of their behavior.

It is noted the property of the balances (or mirror symmetry) between the reciprocal products of the distribution parameter and the average void for each phases in the quasi-1-D model. These balance (or mirror symmetry) characteristics reflect the integral balances of transfer substances of each phase. In turn, it is a consequence of the unified consideration of distribution parameters for each phase through its volume fraction. These integral balances between phases are both useful and important to the quasi-1-D theories of two-phase flow modeling, as to semi-empirical applications, including verification problems for the C_{ki} closure relationship.

3 Substance Flux Distribution

For generalized and unified presentation of the shear stress and heat flux and mass flux we use general substance transfer equation in coordinate form and in boundary layer approximation and with taking in to account the number of the complementary (transversal profile) effects. Therewith, for longitudinal flows through concentric annulus and unbaffled assemblies of fuel rods with constant cross-sections, a variation of local changes of the φ-variable (by which we mean axial velocity, enthalpy, or concentration) proves to be identical at every position normal to the wall.

After scaling the variables in the substance transfer equation and having integrated it first with the variable upper limit, then up to the boundary layer and having combined the integrals obtained, we can derive the equation for the local substance flux. This relationship contains the contribution of each complementary components and form factors under the consideration (convective axial, radial and azimuthal direction transfer, sources (sinks), etc.) to the substance flux can be considered as a correction to the usual linear distribution. It is because of these form factors we have the correction to the linear flux distribution accounting for the influence of above-mentioned transversal profile terms. In the whole, it is worthwhile here to note that the local substance flux profile in the pin wall region is a function of the weighted functions and of complementary components and form factors, boundary conditions and geometry.

4 Wall Friction Factor, Heat and Mass Transfer Coefficients

Returning to momentum and energy concentration transfer equations we get the set of generalized analytical relationships for the wall friction, heat and mass transfer coefficients, taking into account of the transverse distributions of such parameters as inner sources (sink) of heat, momentum and mass, and transversal and axial substance transfer in quasi steady state approximation.

Averaging the transversal components and the source/sink terms of the right hand side of the conservation momentum and energy equation taking into account mass velocity as weighted functions both to simple channel and to compound (subchannel) geometry. Such is indeed that space averaging stipulates the origin of the correction factors for the variables profile (form factors) in the friction factor and heat and mass transfer coefficients.

5 Conclusion

The proposed approaches provide the sound analytical foundation of the quasi-1-D models of two-phase non-equilibrium transient flows. Besides, such approaches let us facilitate systematic analysis to investigate the applicability bound of the 1-D theories and quantity the error assessment, and also point out directions of 1-D transient code improvement.