Steady and Unsteady Computational Results of Full Two Dimensional Governing Equations for Annular Internal Condensing Flows

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Abstract

This paper presents steady and unsteady computational results obtained from numerical solutions of the full two-dimensional governing equations for annular internal condensing flows in a channel. This is achieved by active integration of our own home grown codes and utilization of COMSOL Multiphysics® CFD and Heat Transfer modules. This has allowed for an accurate wave simulation technique for the highly sensitive, shear-driven, annular condensing flows.

The simulation capability uses an approach of separately solving (via COMSOL) the unsteady liquid and vapor domain governing equations over their respective fixed domains resulting from an assumed "sharp" interface location, tracking the interface (by solving its evolution equation in MATLAB®) using a moving grid, and then iteratively re-solving the unsteady liquid and vapor domain governing equations while satisfying the remaining interface conditions. Here liquid and vapor domain unsteady equations are solved on fixed grids and suitable boundary conditions are imposed with the help of COMSOL's CFD and Heat Transfer Modules. Interface evolution equation is a wave equation which is solved (with the help of the well-defined characteristics equation underlying this problem) with 4th order accuracy in time. The resulting accurate prediction of interface location is used to iteratively redefine the liquid/vapor domains with COMSOL Multiphysics®. The approach ensures accurate prediction of interface location and interface variables towards accurate satisfaction of all the time-varying interface conditions. For example, at any point on the interface, the mass flux values computed from three different methods - one using predicted kinematics of vapor velocity and local interface profile, one using predicted kinematics of liquid velocity and local interface profile, and one based on the energy balance - show excellent agreement with one another.

Figure 1 highlights the difference in the streamlines patterns and film thickness variations for a shear driven steady condensing flow in a horizontal channel and its analogous gravity driven condensing flow in an inclined channel. The horizontal flows exhibit much thicker films (and poorer heat-transfer rates) with the liquid tending to lift upwards from the condensing-surface. The basic features of the flows as well as their stability (see Figure 2) are obtained for the case of negligible externally imposed fluctuations. The computational simulation results agree with experimentally measured values of heat-flux and the length of the annular regime. This unsteady wave simulation capability is able to capture the destabilizing wave growth tendencies that

govern the transition from the annular regime of a shear-driven steady flow to its non-annular regime.

This unsteady wave simulation capability is used to predict the heat transfer rates and length of annular regimes for condensing flows. It is also being used to track the transition from the annular regime of a shear-driven steady flow to other non-annular regime. In addition, results obtained for inclined, horizontal, and zero-gravity cases (with and without surface-tension) bring out the differences between shear driven and gravity assisted/driven flows. This accurate simulation capability leads to significant improvements over our previous simulation capabilities and over other existing fixed grid solution techniques.

Figures used in the abstract

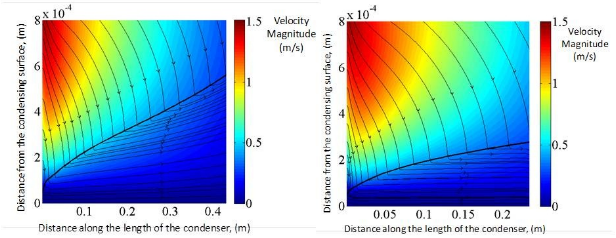

Figure 1: Fig. 1: (a) Shear driven flow streamlines and film-thickness variations for a steady condensing flow simulation in a horizontal channel. (b) Analogous results for gravity driven flows in a 2deg downward titled channel. (Flow conditions- fluid = FC-72, inlet pressure = 101 kPa, channel height = 2 mm, inlet mass flow rate = 0.4 g/s, and ΔT = 17.5 oC).

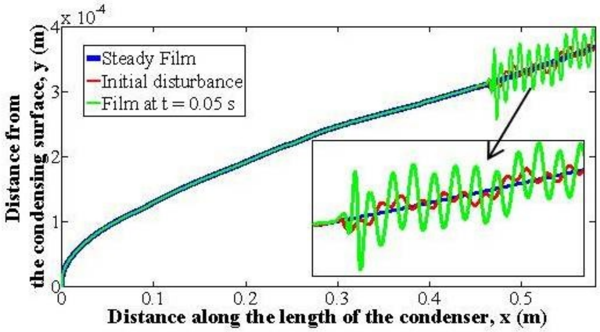

Figure 2: Fig. 2: The 0 m ≤ x ≤ 0.57 m steady and unsteady simulations in this figure are for an experimental case (Flow conditions- fluid = FC-72, inlet pressure = 101 kPa, channel height = 2 mm, inlet mass flow rate = 1.0 g/s, and experimental wall temperature variation). The initial disturbance at t = 0 s (with three different wavelengths) and its unsteady evolution at t = 0.05 s are shown. The steepening and growing wave front around x = xA has been assessed to indicate transition from annular to non-annular regimes.