Study of Formation and Evolution of Disturbance Waves in Annular Flow Using Brightness-Based Laser-Induced Fluorescence (BBLIF) Technique

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Abstract : In annular gas-liquid flow, liquid flows as a film along pipe walls sheared by high-velocity gas stream. Film surface is covered by large-scale disturbance waves which affect pressure drop and heat transfer in the system and are necessary for entrainment of liquid droplets from film surface into the core of gas stream. Disturbance waves are a highly complex and their properties are affected by numerous parameters. One of such aspects is flow development, i.e., change of flow properties with the distance from the inlet. In the present work, this question is studied using brightness-based laser-induced fluorescence (BBLIF) technique. This method enables one to perform simultaneous measurements of local film thickness in large number of points with high sampling frequency. In the present experiments first 50 cm of upward and downward annular flow in a vertical pipe of 11.7 mm i.d. is studied with temporal resolution of 10 kHz and spatial resolution of 0.5 mm. Thus, spatiotemporal evolution of film surface can be investigated, including scenarios of formation, acceleration and coalescence of disturbance waves. The behaviour of disturbance waves' velocity depending on phases flow rates and downstream distance was investigated. Besides measuring the waves properties, the goal of the work was to investigate the interrelation between disturbance waves properties and integral characteristics of the flow such as interfacial shear stress and flow rate of dispersed phase. In particular, it was shown that the initial acceleration of disturbance waves, defined by the value of shear stress, linearly decays with downstream distance. This lack of acceleration which may even lead to deceleration is related to liquid entrainment. Flow rate of disperse phase linearly grows with downstream distance. During entrainment events, liquid is extracted directly from disturbance waves, reducing their mass, area of interaction to the gas shear and, hence, velocity. Passing frequency of disturbance waves at each downstream position was measured automatically with a new algorithm of identification of characteristic lines of individual disturbance waves. Scenarios of coalescence of individual disturbance waves were identified. Transition from initial high-frequency Kelvin-Helmholtz waves appearing at the inlet to highly nonlinear disturbance waves with lower frequency was studied near the inlet using 3D realisation of BBLIF method in the same cylindrical channel and in a rectangular duct with cross-section of 5 mm by 50 mm. It was shown that the initial waves are generally two-dimensional but are promptly broken into localised three-dimensional wavelets. Coalescence of these wavelets leads to formation of quasi two-dimensional disturbance waves. Using cross-correlation analysis, loss and restoration of two-dimensionality of film surface with downstream distance were studied quantitatively. It was shown that all the processes occur closer to the inlet at higher gas velocities.

Keywords : annular flow, disturbance waves, entrainment, flow development
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