Formation and evolution of disturbance waves in annular flow

A.V. Cherdantsev\textsuperscript{1,2*}, M.V. Cherdantsev\textsuperscript{1}, S.V. Isaenkov\textsuperscript{1}, D.M. Markovich\textsuperscript{1,2}, S.V. Alekseenko\textsuperscript{1,2}

1: Kutateladze Institute of Thermophysics, Novosibirsk, Russia
2: Novosibirsk State University, Novosibirsk, Russia
* Correspondent author: cherdantsev@itp.nsc.ru

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HIGHLIGHTS

- Disturbance waves are formed due to coalescence of initial Kelvin-Helmholtz waves.
- The initial waves are regular and two-dimensional, but are promptly broken into a number of 3D waves.
- When disturbance waves are formed, two-dimensionality is gradually restored.
- Disturbance waves first undergo constant acceleration linearly proportional to superficial gas velocity.
- Downstream the acceleration decreases and lack of velocity increase is shown to be proportional to the rate of liquid entrainment.

ABSTRACT

Investigation of the initial stage of annular gas-liquid flow is performed in a number of configurations, including upward and downward flow in circular pipes and in a rectangular duct. In all cases the inlet was organised as a tangential slot. Field measurements of local film thickness are performed using brightness-based laser-induced fluorescence technique. Measurements were resolved along both longitudinal and transverse coordinates and in time with high spatial and temporal resolution.

It was shown that the disturbance waves are created in the very vicinity of the inlet via coalescence of initial high-frequency waves appearing due to Kelvin-Helmholtz instability. These waves are strictly two-dimensional and highly regular but they are promptly broken into small three-dimensional horseshoe-shaped waves. The length over which the initial waves are coherent decreases with superficial gas velocity. Further downstream the 3D waves undergo multiple coalescence forming large-scale quasi two-dimensional disturbance waves, able to generate fast and slow ripples on their rear slopes. Thus, degree of two-dimensionality, characterised by cross-correlation between the film thickness records in different longitudinal sections of the duct, strongly decreases in the beginning and then gradually recovers.

Once formed, the disturbance waves are accelerated by the gas shear with constant acceleration in time. Further downstream, acceleration decreases. The latter is supposed to occur due to entrainment of liquid from tops of disturbance waves, resulting in losing amplitude and, hence, velocity by the disturbance waves. Direct comparison between the underpredicted velocity and rate of entrainment was performed, confirming the above hypothesis.

Acceleration and velocities were compared for different flow configurations and analysis of influence of flow orientation and size and shape of the duct was performed. It was shown that for large enough gas velocities the effect of flow orientation and pipe diameter was small, but the corners of the rectangular duct slow down the formation and development of the disturbance waves.