Formation of disturbance waves in annular gas-liquid flow

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Keywords: annular flow, disturbance waves, spatio-temporal evolution, LIF technique

An annular flow in pipes is a simultaneous flow of liquid film along the pipe walls and gas stream in the pipe core. Part of liquid can be entrained from film surface and travel as droplets in the core of gas stream. Film surface is covered by a complex system of waves of different scales. The disturbance waves are characterized by large values amplitude, velocity and lifetime. They carry the most part of liquid and they are the source of liquid entrainment. Crests of disturbance waves and the base film between them are covered by small-scale ripple waves, which contribute to the pressure drop in the pipe and play important role in the entrainment process (Woodmansee & Hanratty 1969, Azzopardi 1983).

Dynamics of disturbance waves is studied for a long time. Many papers are devoted to measurements of the average characteristics of disturbance waves such as velocity, passing frequency, amplitude, etc. Disturbance waves travel with high constant velocity over large distances (Hall Taylor et al. 1963). When one disturbance wave overtakes the other, coalescence occurs. Due to multiple coalescence events, frequency of disturbance waves decreases downstream (Hall Taylor & Nedderman 1968). Disturbance waves appear not far from the inlet. Upstream the point of inception of disturbance waves small-amplitude high-frequency wavelets exist on film surface (Zhao et al. 2013). But the process of disturbance waves formation is not yet investigated.

In present work, wavy structure of downstream annular gas-liquid flow in 15 mm pipe is studied using high-speed laser-induced fluorescence (LIF) technique. Measurements are performed near the inlet, which was organized as a tangential slot. Spatio-temporal records of film thickness were obtained over the first 100 mm below the liquid inlet in order to investigate formation of the disturbance waves.

![Fig. 1 Fragment of film thickness matrix at the distance of 3-103 mm below the inlet. Brightness of the image is directly proportional to film thickness.](image)

As it was recently shown by Alekseenko et al. (2009), disturbance waves are covered by the fast ripples, which are generated at the rear slopes of disturbance waves and travel with higher velocity towards the front of disturbance wave. In present work we define a disturbance wave as a wave with fast ripples on it. Using this criterion, it was found that for high gas and liquid flow rates disturbance waves appear and start to dominate in the wavy structure of liquid film within the area of interrogation. Disturbance waves were found to be formed due to coalescence of small high-frequency wavelets appearing at the inlet (Fig. 1).

This mechanism was investigated quantitatively using spectral analysis. Energy transfer from high-frequency to low-frequency modes with increasing downstream distance was observed. Significant growth of waves' velocity was found for flow regimes where disturbance waves dominate in the wavy structure.

With the algorithm of identification of individual disturbance waves (developed in Alekseenko et al. 2014), properties of disturbance waves at the initial stage of their evolution were investigated. It was found that the velocity distributions of disturbance waves are essentially asymmetric in contrast to the distributions obtained far downstream. Comparison of the distributions obtained at different distances below the inlet indicates that acceleration of existing disturbance waves and formation of new ones should be expected downstream the area of interrogation.

Similar mechanisms of waves' formation were observed far downstream for waves near transition to entrainment and for ephemeral waves (see Wolf et al. 1996) in flow regimes with liquid entrainment. In both cases waves with fast ripples on their crests are formed due to coalescence of small-scale waves.


Acknowledgements

The work was supported by Russian Foundation for Basic Research (project 13-08-14040a) and by the Grant Council of the President of Russian Federation (project MK-5997.2014.1)