Analysis of spatial and temporal spectra of liquid film surface in annular gas-liquid flow

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Gas-liquid flow regime when liquid travels as a film along channel walls, and gas travels along the core of the tube, is termed as annular flow. At high gas and liquid flow rates third phase – liquid droplets, entrained from the film surface into the core of gas stream, appear. It is well known that wavy structure of liquid film in entrainment conditions consists of large-scale disturbance waves and small-scale ripple waves. Flow regimes without liquid entrainment are less studied. Normally it was supposed that only the ripples exist on the film surface in such conditions.

In [1] laser-induced fluorescence technique was applied to investigation of the wavy structure of liquid film in annular flow. Excitation of fluorescence was performed using green continuous laser sheet, aimed at one longitudinal section of the pipe. Local brightness of red fluorescent light was measured by high-speed digital camera, equipped with low-pass orange filter. Such experimental system is able to obtain instantaneous distribution of local film thickness along the longitudinal section of the pipe with high sampling frequency (several thousand distributions per second).

In [1] it was observed for the first time that the wavy structure in no-entrainment conditions is also presented by two types of waves, which are characterized by essentially different velocity, height, lifetime, etc. Their evolutionary behavior is similar to that of disturbance waves and slow ripples in entrainment conditions, which causes additional interest to no-entrainment regimes, since these regimes might provide the key information for better understanding the entrainment regimes.

In present work, the results of spectral analysis of wavy structure are presented. Experimental technique allows us to perform such analysis in both spatial and temporal domains. Power spectra in both domains are characterized by one-humped shape with long exponential tail. Increase in the gas velocity leads to the increase in frequency of maximum power, and to decrease in total power of the spectrum (see the upper part of Figure 1). Temporal frequency shows parabolic dependence on $V_{g}$, spatial frequency shows linear dependence on $V_{g}$. Influence of liquid viscosity, liquid Reynolds number and pipe diameter on the main properties of primary waves was also investigated.

The most interesting thing here is the similarity of power spectra at different gas velocities. Power spectra, linearly normalized along vertical axis by total power, and linearly normalized along horizontal axis by frequency of maximum power, show identical shape independently on $V_{g}$ (bottom part of Figure 1). Deviations from this universal shape become essential at high gas velocities, where gravity effect is not negligible in comparison to the shear stress. Thus, wavy structure of liquid film in annular flow at high gas velocities is characterized by the universal spectrum.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{fig1.png}
\caption{Example of power spectra of film thickness records in temporal domain. $Re=20$, working liquid – water. $V_{g}=27$ m/s (1), 36 m/s (2), 44 m/s (3), 52 m/s (4), 58 m/s (5).}
\end{figure}

Frequency of generation of the secondary waves by the primary waves was also studied. Combination of spectral analysis and automatic algorithm of waves’ detection allowed measuring the generation frequency in the reference system, moving with the primary wave.

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References