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EXPERIMENTAL INVESTIGATION OF THE EFFECT OF LOW-FREQUENCY FLUCTUATIONS OF THE LIQUID FLOW RATE ON THE MINIMUM IRRIGATION DENSITY IN FILM FLOW

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UDC 532.52

It is shown that when low-frequency fluctuations (3-7 Hz) are imposed on a stream of liquid being fed to a channel, the minimum irrigation density in the film is reduced by a factor of 2-3 times compared with the case of non-fluctuating flow.

One of the fundamental technical characteristics of film flows and disperse-film flows is the existence of a minimum irrigation density [1]. This characteristic determines the conditions for the wetting of heat transfer surfaces by the liquid and has an important effect on heat transfer to the film, the value of the maximum wall temperature, and the critical heat flux corresponding to the occurrence of a heat transfer crisis of the second type.

A number of papers have dealt with experimental and theoretical investigations of the minimum irrigation density [2-6]. All the authors have mentioned the important effect on the value of the minimum irrigation density of the kinetic energy of the film flow and the surface tension energy at the interface. Different irrigation densities have been noted corresponding to the onset of breakup of the film, and irrigation densities at which dry spots which have formed are eliminated.

This difference, which is explained by the hysteresis of the wetting contact angle, amounts to 450-1200% or more, and depends on the temperature of the liquid at the inlet, the temperature difference at the inlet between the wall and the film, the roughness and cleanness of the material of the surface being wetted, and the construction of the distributing device.

For improving the wetting of dry surfaces by irrigation, recommendations have been made to use shaking [4] or vibration of the film equipment, or a brief considerable increase in the irrigation density [5].

It is obvious that all these measures are aimed at increasing the kinetic energy of the film flow to a value which exceeds the energy of the surface tension forces at the interface. At the same time, these methods of improving the wettability are very technologically inefficient, and often reduce the reliability of the equipment.

The present paper presents the results of an investigation of the possibility of increasing the kinetic energy of a wavy film flow by means of artificial perturbations imposed on the liquid stream by a bellows pulsator.

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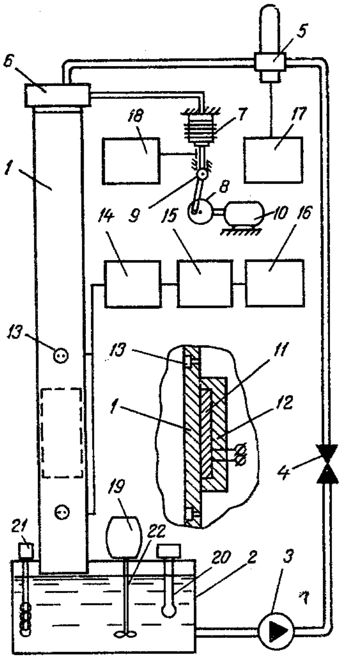

Fig. 1

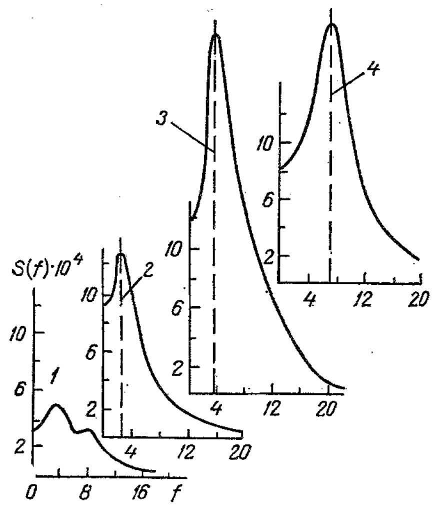

Fig. 2

Fig. 1. Experimental loop: 1) experimental channel; 2) thermostat; 3) pump; 4) control valve; 5) electric rotameter; 6) slot distributing device; 7) pulsator; 8) reducer; 9) oscillating crank drive; 10) electric motor; 11) heater; 12) thermal insulation; 13) film thickness probe; 14) electrical bridge; 15) oscillograph; 16) recorder; 17) auxiliary instrument; 18) frequency meter; 19) electric drive for agitator; 20) cooler; 21) industrial heater; 22) agitator.

Fig. 2. Spectral power densities of the film thickness perturbations (Re = 750): 1) free flow of the liquid; 2) f_n = 3.8 Hz; 2) f_n = 5.2 Hz; 3) f_n = 7.2 Hz. S(f), mm²/sec; f, Hz.

The investigations were carried out in the experimental loop shown in Fig. 1. Liquid flow rate G_0 was varied over the range $(0.2\text{-}10)\cdot10^{-5}$ m³/sec, which corresponded to a change in the irrigation density Γ_0 over the range $(0.2\text{-}10)\cdot10^{-4}$ m²/sec. The heat flux density on the heated section was not varied in the course of the experiment, and was kept equal to $1.2\cdot10^5$ W/m².

The frequency of the imposed fluctuations f_n was varied from 0 to 8.0 Hz. The amplitude of the fluctuation amounted to 0.1 G_0.

The instantaneous liquid film thicknesses were measured in the course of the experiments by means of a conductometric probe [6]. The moment at which film breakdown occurred was determined visually and by the use of cinephotography.

The investigations were carried out according to the following procedure: a liquid flow rate in the film was established in the absence of superimposed fluctuations and the heat flux density was established also. The liquid flow rate was then gradually reduced up to the moment of formation of a dry patch on the channel surface. (The flow rate corresponding to the onset of rupture of the film was determined.) Subsequently, the flow rate was gradually increased as far as the moment of disappearance of the dry patch from the surface (and the flow rate corresponding to the disappearance of the dry patch was recorded).

The measurements with the superimposition of fluctuations were carried out in this same sequence.

Measurements of the liquid film thickness δ were made at the liquid temperature corresponding to the conditions with heat transfer, but these measurements were carried out in the absence of the heat flux.

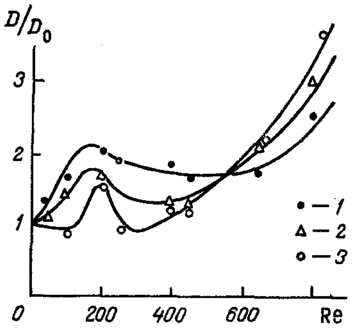

Fig. 3

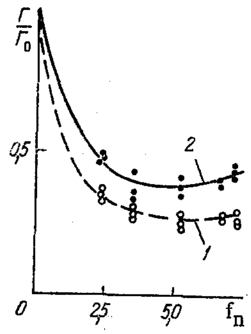

Fig. 4

Fig. 3. Relative dispersion of the film thickness fluctuations as a function of the Reynolds number Re: 1) f_n = 3.8 Hz; 2) f_n = 5.2 Hz; 3) f_n = 7.2 Hz.

Fig. 4. Relative irrigation density as a function of the frequency of the superimposed fluctuations: 1) values corresponding to the onset of dryout; 2) values corresponding to the onset of rewetting dry patches in the film. The units of f_n are sec^{-1}.

As a result of evaluating the recordings of the instantaneous liquid film thicknesses, values were obtained of the mean thickness, the three first moments of distribution, the autocorrelation function and the spectral density of the film thickness perturbations [7].

An analysis of the characteristics obtained showed that within the limits of error of the experiments and their evaluation the mean liquid film thickness did not depend on the frequency of the superimposed fluctuation; at the same time, the frequency—time and amplitude parameters characterizing the structure of the wavy motion in the film were greatly changed by the superimposition of the perturbations.

The characteristic feature of the behavior found for the spectral power density (SPD) of the film thickness perturbations (Fig. 2) was a shift in the maximum of the SPD in the direction of the frequency of the superimposed fluctuation, and also an amplification of the process of perturbation of the film thickness for all the superimposed frequencies of the fluctuations. The greatest amplification occurred when the superimposed frequency was close to the natural frequency of the wavy flow.

Figure 3 gives the dispersion D of the instantaneous liquid film thicknesses under conditions with superimposed fluctuations referred to the dispersion D_0 of the steady-state wavy flow. This quantity, which characterizes the intensity of the fluctuating processes in the film, shows a considerable effect of the fluctuation of the flow rate on the intensity of the wave motion, which increases with increase of the liquid flow rate in the film.

The overall increase in the intensity of the wavy motion reaches 200-400%, and is observed for frequencies of the superimposed fluctuations which are close to the frequency of the natural wavy flow of the film at the steady-state flow rate. It is interesting to note that in the zone of laminar flow of the liquid film (Re < 400), the greatest increase in the intensity of the wavy motion occurs at the low frequency of the superimposed fluctuations, while in the zone of turbulent flow (Re > 400) this occurs at higher frequencies of the fluctuations, which is explained by the increase in the natural frequency of the wavy film motion in the zone of turbulent flow.

This effect influences the increase of the overall level of the kinetic energy of the transverse and longitudinal fluctuating motions in the film [8] and makes it possible to expect that the superimposition of the fluctuations would significantly influence the value of the minimum irrigation density.

Investigations of the minimum irrigation density in the film which were carried out confirmed this result. Figure 4 shows values of the minimum irrigation densities corresponding to the beginning of the appearance Γ_1 and the disappearance Γ_2 of dry patches in the film referred to the value of the irrigation density Γ_0 for the steady-state fluctuation-free flow. It can be seen from the graphs that the superimposition of the fluctuations leads to a considerable decrease (by up to 2-3 times) in the minimum irrigation densities.

It is important to note that the results which have been obtained were achieved with relatively small energy consumptions for exciting the fluctuations, namely, 3-8% of the energy required for establishing the film flow.

NOTATION

G_0, liquid flow rate, m^3/sec; Γ_0, irrigation density, m^2/sec; f_n, frequency of imposed fluctuations, Hz; δ, liquid film thickness, mm; D, dispersion of the wavy flow with superimposition of fluctuations, mm^2; D_0, dispersion of steady-state wavy flow, mm^2; Γ_1, irrigation density for the beginning of the appearance of dry patch, m^2/sec; Γ_2, irrigation density at moment of disappearance of dry patch in film, m^2/sec.

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VISCOUS ISOTHERMAL MOTION OF A BINARY GAS MIXTURE THROUGH AN ORIFICE

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Motion of gases through an orifice at low Knudsen number is studied.

Motion of gas mixtures through an orifice in a thin film occurs in many technological processes. From the scientific viewpoint this process is interesting because any effect of channel walls on the gas flow is absent. However, until now experimental and theoretical studies of flows through an orifice have been limited in number and have essentially considered only single-component gases.

The present study will investigate the kinetic coefficients of isothermal motion of a binary gas mixture through an orifice at Knudsen numbers much less than unity.

1. Kinetic Coefficients of Isothermal Motion of a Binary Gas Mixture in Long Channels and an Orifice. If at the ends of a channel we create a pressure difference Δp and (or) a concentration difference Δc, then motion of the gas mixture within the channel commences.

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