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Experimentally investigating pulsations of a two-phase flow in a narrow microchannel

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Abstract. Today, there is a revolutionary development of microchannel systems. In such systems, it is extremely important to determine the two-phase flow regime, depending on the gas and liquid flow rates. The two-phase flow in the microchannel is affected by many factors, such as the parameters of the initial section, the geometry and dimensions of the channel, the properties of the channel surfaces and liquid. In the present study, we have investigated a two-phase flow in a microchannel with a height of 50 μm and a width of 20 mm. It is shown that, with an increase in the size of the liquid nozzle, the film regimes are replaced by pulsating ones in the investigated range of gas and liquid flow rates. The characteristic frequencies of pulsations, their duration and delays are studied, depending on the superficial velocities of the gas and liquid. It is shown that the duration of the pulsation is mainly influenced by the gas flow rate, and the delay between them – by the liquid flow rate.

1. Introduction
One of the current problems of thermal physics of interest today is the problem of cooling microelectronic equipment. Microelectronic components and microelectromechanical systems (MEMS, microsystems, micromachines) are designed. These are three-dimensional mini- and microobjects with characteristic dimensions of the elements being measured in millimeters or microns, where high heat fluxes (up to 1 kW/cm²) are observed. The use of microchannels can reduce the average thickness of the liquid film in two-phase flows, which leads to intensification of heat transfer of evaporation [1,2]. Such systems are more energy efficient than free-flow systems [3,4]. In this regard, for a wide range of technical applications, it is important to understand hydrodynamics in microchannels, providing the most efficient processes of heat and mass transfer. A review of publications on the two-phase flow in microchannels is contained in [5,6]. The structure of the two-phase flow in microchannels is not fully understood. Analysis of the studies shows that the following main parameters influence the structure of the two-phase flow: the geometry and dimensions of the channel, the parameters of the input section [7], the surface characteristics (roughness, wettability) and fluid properties, such as viscosity and surface tension [8]. In channels of larger channels (minichannels), the flow regime is significantly affected by gravity [9]. In microchannels, there is no effect of gravity on the two-phase flow regime [5].

The purpose of this study is to show how the size of the liquid nozzle affects the boundaries between the two-phase flow regimes in the microchannel with a height of 50 μm and a width of 20
mm, and to study the characteristics of pulsations of the two-phase flow regimes depending on the superficial velocities of the gas and liquid.

2. Test section design
The test section is a microchannel with a height of 50 μm and a width of 20 mm. The scheme of the test section is shown in figure 1. The microchannel consists of a top plate made of glass and a bottom plate made of stainless steel with a length of 160 mm, between which a foil is clamped. The thickness of foil is 50 μm. A nozzle for the injection of liquid is made in the stainless steel plate at an angle of 11°. The height of the nozzle was set using constantan foil. An antireflective coating is applied to the glass. The stainless steel plate is polished. The height of the microchannel after the assembly is measured by the confocal method. It is 50±5 μm in the investigated region. The parameters of the test section and the experimental setup are close to work [10]. The size of the liquid nozzle differs. In the present study, it is 100 μm, while in work [10] it was equal to the channel height of 50 μm. Milli-Q® water was used as the liquid, and high purity nitrogen was used as the gas. The gas was supplied from a balloon, and the flow rate was monitored by a Bronkhorst flow regulator. The liquid was fed using a Cole-Parmer syringe pump. The registration of the two-phase flow was carried out by the schlieren-method, which is described in [10]. The schlieren method is used to register and visualize surface deformations in a thin liquid film. To study the pulsation frequency, movies are recorded and the number and duration of the pulsations is studied using a special program.

3. Results and discussion
The following flow regimes are observed experimentally: bubble, churn and jet ones. At very low superficial liquid velocities, a jet regime is observed when the gas moves in the central part of the microchannel, and the bulk of the liquid moves along its periphery along the side walls. As the superficial liquid velocity increases, stable horizontal liquid bridges between side walls begin to form, and the transition from the jet to the bubble regime occurs. In this regime, a liquid containing many small gas bubbles flows through the channel. As the superficial gas velocity increases, the bubbles coalesce, and a transition to the churn regime takes place. This regime is characteristic for vertical channels, where it is caused by gravity [11]. It is also observed in wide horizontal channels with less than 1 mm height, where capillary forces are responsible for this regime [12]. It is characterized by the existence of broken horizontal bridges. The existence of the churn regime is due to the development of

![Figure 1. Scheme of the test section.](image-url)
instability of the jet regime and an increase in the frequency of pulsations of the fluid moving at the side walls of the channel under the action of the gas flow.

Figure 2 shows a regime map for the same channel with a liquid nozzle of 50 μm [10]. In this case, at high superficial gas velocities, stratified and annular regimes are observed, when liquid film moves along the channel. In the present work, instead of these regimes, a pulsating churn regime is observed. At superficial gas velocities $U_{SG} > 6.67$ m/s periodic pulsations of the flow appear. The liquid is accumulated in the nozzle, retained by capillary forces, and then ejected into the channel, forming the churn regime. Figure 3 shows the characteristic schlieren images of the churn regime at $U_{SL} = 0.333$ m/s, $U_{SG} = 13.3$ m/s. In the channel, the presence of both continuous horizontal liquid bridges and ruptured ones is observed. Then the channel dries out, and the process is repeated.

Figure 4 shows the dependence of the pulsation frequency $\nu$ on superficial velocities of the gas $U_{SG}$ and the liquid $U_{SL}$. The dependence of the flow pulsation frequency on the superficial gas velocity at the superficial liquid velocity $U_{SL} = 0.333$ m/s is shown in figure 4a. It can be seen that pulsations appear when the superficial gas velocity reaches $U_{SG} = 6.67$ m/s. The pulsation frequency is $\nu = 0.12$ Hz. With an increase in the superficial gas velocity, the pulsation frequency grows monotonically. Figure 4b shows the dependence of the flow pulsation frequency on the superficial liquid velocity at a fixed superficial gas velocity $U_{SG} = 16.7$ m/s. It can be seen that pulsations exist at the minimum investigated superficial liquid velocity $U_{SL} = 0.033$ m/s and its frequency is $\nu = 0.06$ Hz.

Figure 2. Flow regime map of two-phase flow in the microchannel cross section of 0.15×20 mm$^2$ [10].

Figure 3. Schlieren images of the churn regime in time.
In this case superficial gas velocity is much larger than superficial liquid velocity, so the pulsation velocity is very low. With an increase in the superficial liquid velocity, the pulsation frequency increases monotonically.

The growth of the pulsation frequency of the flow with increasing superficial velocities of the gas and liquid is due to a decrease in the duration of flow pulsations and the time between them. Figure 5 shows the dependence of the pulsations duration (2) and the delay between them (1) on superficial velocities of the gas $U_{SG}$ and liquid $U_{SL}$. Figure 5a shows the dependence of the duration of pulsations and delays between them on the superficial gas velocity at a superficial liquid velocity $U_{SL} = 0.333$ m/s. It can be seen that the duration of pulsations significantly decreases with increasing superficial gas velocity. In this case, the delay between pulsations decreases insignificantly. As can be seen from figure 5b, at the fixed gas superficial velocity ($U_{SG} = 16.7$ m/s), the superficial liquid velocity has almost no effect on the pulsation duration. And the delay time between pulsations significantly decreases with increasing superficial liquid velocity.

4. Conclusions

Thus, it can be concluded that the duration of pulsation is mainly influenced by the gas flow rate, and the delays between them is mainly influenced by the liquid flow rate. This can be explained by the fact that at high gas flow rates, the pressure in the channel also increases. In this case, when the liquid is

Figure 4. The dependence of the flow pulsation frequency (a) on the superficial gas velocity at the fixed superficial liquid velocity $U_{SL} = 0.333$ m/s; (b) of the superficial liquid velocity at the fixed superficial gas velocity, $U_{SG} = 16.7$ m/s.

Figure 5. The dependence of the delays between pulsations (1) and their duration (2) (a) on the superficial gas velocity at the fixed superficial liquid velocity $U_{SL} = 0.333$ m/s; (b) of the superficial liquid velocity at the fixed superficial gas velocity $U_{SG} = 16.7$ m/s.
injected into the nozzle, the pressure more rapidly drops down to the pressure level in the channel. As
the flow rate of the liquid increases, the pressure in the liquid nozzle quickly reaches the pressure in
the channel, which significantly shortens the duration of the delays between pulsations. And both these
effects lead to an increase in the frequency of pulsations.

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