FTD-MT- 63-295

TRANSLATION

64-71491

EXPERIMENTAL INVESTIGATION OF OUTFLOW OF A BOILING LIQUID THROUGH A CENTRIFUGAL INJECTOR NOZZLE

By

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NT-63-295
News of Higher Educational Institutions, Series "Aeronautical Engineering", No. 4, 1962.
Pages 139-144

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For explanation of the characteristics of the process of outflow of boiling liquid, there were set up two series of experiments on special installations.

The first series of experiments was produced with water and had as its purpose visual observation of the processes of evaporation and outflow. Initially the experiments were conducted in the installation according to the diagram given in Figure 1. Water was heated to boiling by an electric coil in the transparent, FTD-MT- 63-295

EDITED MACHINE TRANSLATION

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English Pages: 9

SOURCE: Izvestiya Vysshikh Uchebnykh Zavedeniy. Aviationnaya Tekhnika, Nr 4, 1962, pp 139-144

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S/147-062-000-004

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FTD-MT- 63-295 Date 21 May 1964

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MT-63-295
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The first series of experiments was produced with water and had as its purpose visual observation of the processes of evaporation and outflow. Initially the experiments were conducted in the installation according to the diagram given in Figure 1. Water was heated to boiling by an electric coil in the transparent,

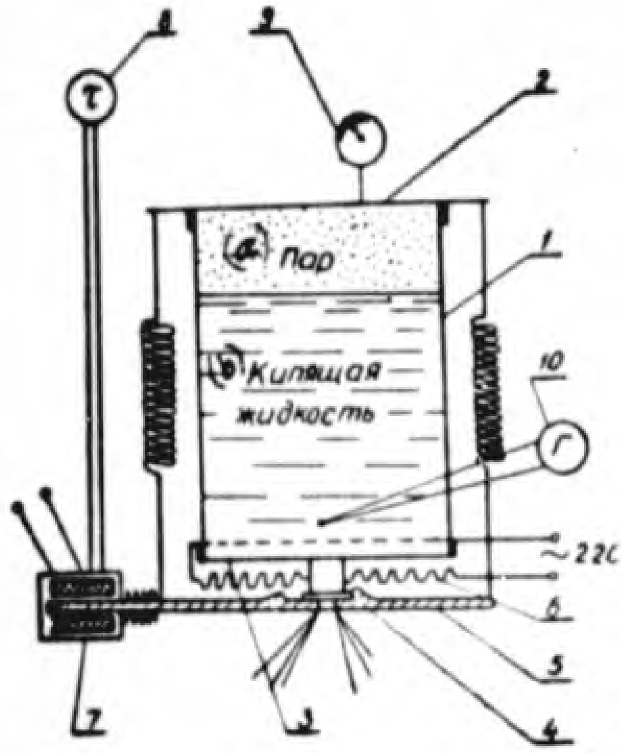


Fig. 1. Diagram of installation with transparent volume. 1—transparent volume, 2—cover, 3—bottom, 4—injector nozzle, 5—plate with drilled hole, 6—heater, 7—electromagnet, 8—electro-timer, 9—manometer, 10—galvanometer.
KEY: (a) Vapor; (b) Boiling liquid;

hermetically closed container, made from molybdenum glass. Temperature and vapor pressure were controlled according to the system "thermocouple-galvanometer" and manometer. Correctness and conformity of readings of these instruments were verified with existing tables [6]. The centrifugal injector nozzle, mounted in the metallic bottom of the container, was covered by a plate, pressed to it with springs. Through the plate was bored a hole, with the help of which, in the necessary moment the hole of the nozzle was opened.

Experiments were conducted in the following order. After attaining the planned values of temperature and pressure, heating was turned off and for some time the system was maintained while temperatures of the walls and liquid were equalized; then, with the help of the electromagnet, the plate sharply was moved toward of matching of the bored hole with the outlet of the nozzle. With the reverse motion of the plate under the pressure of the spring there was produced cutoff of the passed stream. Moments of starting and cutoff of the stream were fixed by the electro-timer, automatically connected with the electromagnet. By means of weighing of the container before and after evacuation, was determined the quantity of expended liquid during the time shown by the timer.

Thus, the method of experiment had to give a high degree of accuracy of determination of expenditure. But it turned out that the capacity of the container was 0.3 liter too small, which led to its rapid emptying (5 to 10 sec). Therefore, for obtaining stabler experimental points there was prepared another installation with a larger capacity, on which were carried out all experiments in plotting of operating points (second series of experiments).

Experiments on the installation, built according to the diagram (Fig. 1), were carried out in the range of pressures p_s = 1.5 to 5 at. and corresponding saturation temperatures. In the process of emptying of the transparent capacity there was observed violent boiling and intense evaporation of the liquid in the entire volume. With emptying, the pressure in the volume fell somewhat (by 0.2 to 0.5 at.); less noticeably, the temperature was lowered. This is explained by the fact that in the process of evaporation part of the enthalpy of the hot liquid is deteriorated.

Another cause of such a phenomenon may be the possible nonequilibrium of the process of evaporation, when the liquid constantly remains somewhat overheated, and the free space can not be filled with vapor up to the saturation pressure. However, to establish experimentally the degree of nonequilibrium was very difficult due to the inertness of the thermocouple although during manufacture of it there were taken necessary measures for decrease of its time constant to 1 sec.

For visual study of the structure of the two-phase flow, the injector nozzle was prepared by a glass blowing method from transparent molybdenum glass. Diagram of the installation with a transparent centrifugal injector nozzle is shown in Figure 2. The flow section of the nozzle had comparatively large dimensions, so that it was possible to conduct observation by the naked eye: diameter of the nozzle opening d_c = 6 mm, its length l_c = 10 mm; diameter of the swirling chamber D = 27 mm, its length L = 30 mm. Entrance of the liquid into the injector nozzle was tested with two variants: tangential hole with diameter d_e = 10 mm and three-setting screw with total area of flow section equal to $\frac{\pi d^2_{\text{вх}}}{4}$. On this installation the metal tank (boiler) had a much larger capacity (near 7 l), which was sufficient for 50 to 100 sec of work depending upon the degree of heating of the liquid.

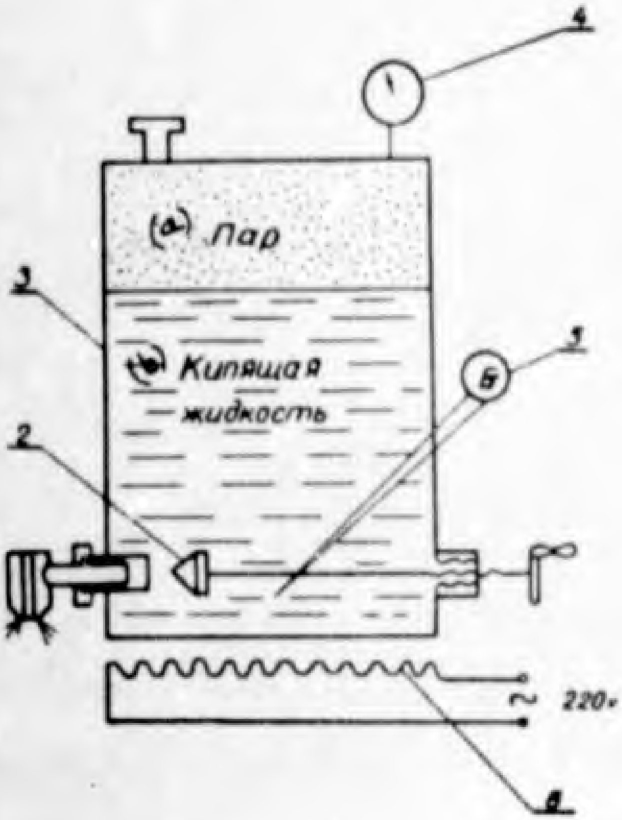


Fig. 2. Diagram of installation with transparent injector nozzle.
1—transparent injector nozzle, 2—cock, 3—tank, 4—manometer,
5—galvanometer, 6—heater.
KEY: (a) Vapor; (b) Boiling liquid;

Control of regime parameters of boiling was carried out by means of measurement of the temperature and pressure of the liquid in the tank.

Observation of the operation of the transparent centrifugal injector nozzle, the tangential, as well as the screw, showed that in the nozzle opening flow consists of two layers: a liquid peripheral layer in the form of an annular film and a vapor core. Such a picture was observed in the entire investigated range of vapor pressure of water in the tank p_t = 1.5 to 4.5 at. (Fig. 3 and 4).

The dimension of the vapor vortex depends largely on the degree of throttling of the boiling liquid, carried out here by the cock 2 (Fig. 2). With strong throttling and, thus, with large vapor content at the entrance into the nozzle an increase of the vapor vortex was noticeable (Fig. 3 and 5)..

For small pressures of the boiling liquid at the entrance into the nozzle (~1.5 at.) or with very strong throttling, there was observed a pulsating regime of outflow, which is explained by the instability of the thin liquid film in the nozzle opening, which is interrupted with a characteristic frequency. The same phenomenon, as is known, is observed during operation of injector nozzles also with a cold liquid, if the pressure drop is too small.

On the basis of the conducted experiments two conclusions can be made.

1. When boiling liquid goes into the inlet into the centrifugal injector nozzle, from the nozzle flows not only vapor as is confirmed in reference [2], but also liquid.

2. In the nozzle opening the injector nozzle there takes place separation of the phases: on the periphery is located a liquid film, in the center -- a vapor vortex.

The second series of experiments was conducted on an installation, not differing in principle from the setup shown in Figure 1. The purpose of these experiments was the plotting of experimental points for different heating (different pressure drops) of the liquid. Measurements of saturation pressure temperature were carried out and flow rate was determined. Experiments were conducted with water, mixture 1 (polymer distillate - 56%, light oil of pyrolysis--40%, tricresol--4%) and with mixture 2 (27% N_2O_4 and 73% HNO_3). Therefore in this installation the tank was made of material AK6, which is stable in the mentioned components. Quantitative investigations were carried out with injector nozzles, the geometric dimensions of the flow-sections of which are given in Figure 6.

With water, injector nozzles No 1 and No 2 were tested; with mixture 1--No 2; and with mixture 2--No 1. All these injector nozzles belong to the screwtype. Since to experiments with two-phase mixtures, bad reproducibility experimental points is peculiar, for one and the same regime experiments were repeated several times. Results of experimental investigations are considered together with the results of the theoretical calculations in [4].

Fig. 3. Picture of flow of boiling water through transparent injector nozzle with tangential inlet at various pressures at the inlet p_s.

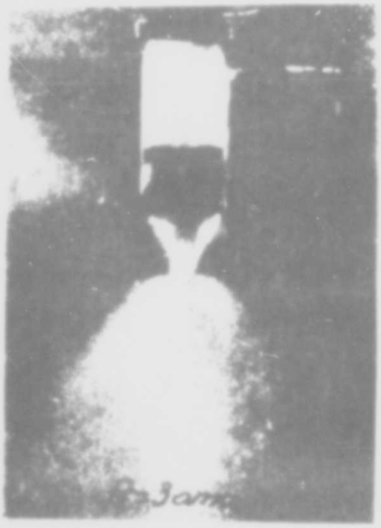
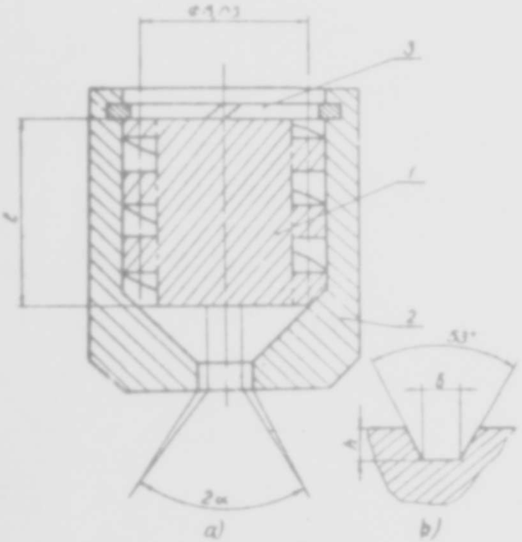


Fig. 4. Picture of flow of boiling water through transparent injector nozzle with screw at various pressures at the inlet p_s.

Fig. 5. Picture of flow of boiling water through transparent tangential injector nozzle with throttling of liquid at the inlet at various pressures P_s.



(a)

Форсунки	d_c (мм)	t (мм)	δ мм	h мм	S-tz мм	z
№1	2,2	6,5	1,8	1,6	2,5	3
№2	1,7	5	1,8	1,6	2,5	3

Fig. 6. Geometric dimensions of flow-sections of injector nozzles: a) injector nozzle; b) cross section of screw. Designations: z—number of settings, t—screw pitch, d_c—diameter of nozzle, s—movement of helical line, 1—screw, 2—body of injector nozzle, 3—ring.
KEY: (a) Injector nozzle.

Experimental data on the outflow of boiling liquids showed the following: with outflow through an injector nozzle of boiling water, which is a single chemical substance, pressure and temperature before the injector nozzle correspond to the state of saturation, and the coefficient of discharge is significantly less than with outflow of a non-boiling liquid.

A mixture of the type of kerosene flows into the discharge medium under a pressure greatly exceeding its vapor pressure. This is explained by the fact that in it are low-boiling fractions, under the pressure of which there occurs squeezing out of the main mass of the mixture. Therefore the pressure before the injector nozzles must be determined by the saturation curve of the light fractions.

During outflow through an injector nozzle of liquids which are mixtures containing a large quantity of low-boiling fractions, for example, 27% N_2O_4 + 73% HNO_3, pressure before the injector nozzles is near to the vapor pressure of the low-boiling component (in the given case N_2O_4).

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