UDC 532
DOI: 10.15587/1729-4061.2024.310140

# THE INFLUENCE OF THE ROTOR SHAPE ON THE EFFICIENCY OF THE HYDRODYNAMIC HEATER

**Bekbolat Nussupbekov**
Professor, Candidate of Technical Sciences*
**Yerlan Oshanov**
Senior Lecturer, Master of Transport**
**Mihail Ovcharov**
Full Professor, Candidate of Technical Sciences**
**Moldir Duisenbayeva**
*Corresponding author*
Doctoral Student*
E-mail: m_o_l_d_i_r_89@mail.ru
**Adilzada Sharzadin**
Candidate of Pedagogical Sciences**
**Aitkul Kongyrbayeva**
Doctoral Student*
**Makpal Amanzholova**
Master of Technical Sciences, Teacher**
*Department of Engineering Thermophysics named after professor Zh. S. Akylbayev***
**Department of Transport and Logistics Systems***
***Karaganda Buketov University
University str., 28, Karaganda, Republic of Kazakhstan, 100024

***The paper discusses issues related to the design of a hydrodynamic throttle type heater. The maximum angular velocities for cylindrical and conical shapes are determined from the condition of non-spilling of liquid from a rotating vessel.***

***Theoretical studies have shown that the conical shape of the skirt is more optimal, since with an increase in the liquid level in the vessel within 0.02–0.09 m, the angular velocity decreases from 37.566 rad/s to 17.709 rad/s, respectively. In addition, with a taper of the vessel walls of 5° and a liquid level height of 0.02 m, the volume of the liquid is $11.0 \cdot 10^{-5}$ m$^3$. If to increase the liquid level to 0.09 m, then the volume of liquid will increase to $55.0 \cdot 10^{-5}$ m$^3$. At a taper of 10°, respectively, there is also an increase in the volume of liquid from $6.0 \cdot 10^{-5}$ m$^3$ to $42.0 \cdot 10^{-5}$ m$^3$.***

***To establish a small increase in the temperature of the liquid when it is forced through the throttle holes, a transparent mock-up was made. Experimental studies have shown the locking of air during the formation of a ring of liquid in the rotor cavity. In addition, it was found that the smaller the inner radius of the liquid ring, the higher the temperature of the pressed liquid through the throttle openings. For this purpose, a system for removing air from its rotor was provided in the hydrodynamic heater.***

***When the rotor is running, the lateral outer walls of the conical skirt interact with the liquid, forcing it to rotate. The rotating liquid, rising along the walls of the housing, begins to interact with the lower part of the rotor, which negatively affects the operation of the hydrodynamic heater as a whole. For this purpose, a special flow directing cylinder was provided in the housing.***

***When the liquid is forced through the throttle opening, there is a decrease in pressure and an increase in the velocity of the liquid. This leads to an increase in its kinetic energy, which is then converted into thermal energy due to friction between the liquid molecules. This principle is used in various systems such as heating systems, industrial processes or laboratory research. However, creating pressure in front of the throttle openings using the inertial forces of a rotating mass of liquid is a promising direction***

***Keywords: rotor drum, liquid temperature, cylinder rotation, liquid level, thermal energy***

*Received date 11.06.2024*
*Accepted date 15.08.2024*
*Published date 28.08.2024*

***How to Cite:*** *Nussupbekov, B., Oshanov, Y., Ovcharov, M., Duisenbayeva, M., Sharzadin, A., Kongyrbayeva, A., Amanzholova, M. (2024). The influence of the rotor shape on the efficiency of the hydrodynamic heater. Eastern-European Journal of Enterprise Technologies, 4 (8 (130)), 42–49. https://doi.org/10.15587/1729-4061.2024.310140*

## 1. Introduction

One of the main advantages of vortex heaters is the high efficiency of heat transfer, since the vortex movements and turbulence created inside the device contribute to more intensive mixing of the liquid, which increases the efficiency of heat transfer. However, vortex heaters have some disadvantages, as the main elements may be subject to wear and require regular maintenance and replacement. In addition, the use of vortex heaters may require higher initial investments compared to traditional methods of heat generation.

Heating the liquid by pushing through the throttle openings is one of the methods of controlled heating. This process is based on the well-known principle of creating a narrowing channel or installing a throttle through which a liquid flow is passed, which requires a significant amount of energy.

The growing interest in the research of liquid throttling in a rotating vessel is due to its importance both for studying their hydro-thermodynamics and for optimizing industrial processes such as separation, purification, mixing and heating in the chemical, food, pharmaceutical and thermal power industries. These studies also help to develop new models and theories that are used in a wide variety of fields of engineering and industry. This is due to the fact that the use of inertial forces of a rotating mass of liquid to create pressure in front of the throttle openings allows the use of external low-power sources.

However, it is worth noting that the effectiveness of throttling also depends on the parameters of the throttle, such as its size, shape and material, as well as the velocity and pressure of the liquid. In this regard, research in the field of throttling of rotating fluid remains relevant.

## 2. Literature review and problem statement

In hydrodynamic heaters, thermal energy is generated by activation by external sources of internal energy of the liquid. These include vortex [1], cavitation-vortex and throttle



Copyright © 2024, Authors. This is an open access article under the Creative Commons CC BY license

types of heaters. The optimal modes in which the coefficient of conversion of electrical energy into thermal energy will be maximum are not fully described.

The work [2] studies the dynamics of vortex cavitation under various conditions, including the pressure and orifice number, and their effects on the nozzle flow and spray characteristics using a modified cavitation model considering the swirling flow. Its validation against experimental data has demonstrated a high precision of the code in terms of vortex cavitation inside the nozzles. This paper does not show the application of this method or mathematical modeling. The work fully reveals the potential of the cavitation effect. The results show that increased inlet pressures gradually reduce the influence and intensity of vortex cavitation structures.

Vortex liquid heaters are a type of heat exchange devices that use the Ranque effect [3] to heat or cool liquids. The vortex effect, or the Wound effect, manifests itself in a swirling flow of a viscous compressible liquid and is realized in a very simple device called a vortex tube. When a liquid passes through a vortex tube, vortices and turbulent flows are created. This contributes to a more intensive mixing of the liquid and a more efficient heat exchange between the heated liquid and the environment. The paper does not consider the practical application.

In [4], a solution is considered for studying the characteristics of heat transfer in a pipe with a turbulent damped swirling flow using an integrated boundary layer circuit. The influence of the Reynolds number at the inlet, the intensity of the turbulence at the inlet and the Prandtl number on the thickness of the thermal boundary layer and the Nusselt number is also studied. The paper does not consider the practical application.

The work [5] shows patented devices that allow the use of vortex and cavitation effects to provide heating of premises: a hydrodynamic heater, includes a pump with an electric motor, an inlet pipeline, a vortex energy converter, a device for forming a vortex installed at some distance from the vortex shaper, a confuser at the outlet of the vortex tube. When the device is in operation, the number of rotations of the rotor reaches 6800 rpm. Under these conditions, the bearing bearings wear out. The work does not describe the actions for the wear of the part.

In [6], the authors proposed a cavitation vortex heat generator that includes a vortex chamber with two injection nozzles that are positioned at an angle of 45–90° to each other and have different heights inside the chamber. The bottom of the chamber is made in a curved shape for the lower injection nozzle. The housing of the device is a cylindrical tube, and a bypass connects the vortex chamber to the base of the housing. At the base of the housing, opposite the vortex chamber, there is a braking device, as well as an additional braking device in the bypass. Both braking devices include fins with parallel holes along the body axis and the bypass axis. At the entrance to the injection nozzles of the vortex chamber, devices for twisting the flow are installed, which are cylindrical bushings with an internal screw surface. The housing is connected to the vortex chamber by means of a pipe with a curved profile.

The work [7] shows an energy conversion system that converts hydraulic wind energy directly into thermal energy. When using wind energy, the throttle valve is considered as a source of heat generation to convert wind energy into thermal energy. The use of a throttle valve allows to calculate heat dissipation using Matlab (USA) modeling and calculate the physical and mathematical model of the heating system. This process shows that heat can be obtained by pushing through. A fully mathematical model is considered, but its application in industry is not described.

In [8], cavitation heating of a liquid is shown, which is based on the use of a physical phenomenon where, due to a local decrease in pressure, tiny vapor bubbles form in the liquid and burst at the moment they enter the high-pressure zone, which leads to heating. However, these bubbles in large concentrations can create powerful explosions, and this in turn will lead to the exit of the engines.

In [9] shows throttling of a liquid rocket engine, which have the ability to independently adjust thrust. A liquid-fueled guided rocket engine can be used to enter and descend from the planet, space rendezvous, orbital maneuvering, including orientation and stabilization in space, as well as to hover and prevent hazards during landing on the planet. But the effect of variable thrust on the mechanics and dynamics of a liquid rocket engine, as well as the difficulties and problems associated with the throttling process, are important aspects of regulation. The problems associated with each method are considered and the advantages and disadvantages are compared.

In [10], the heat generator consists of an electric motor, a housing with a cylindrical inner cavity, inside which a rotor with many recesses and holes is rigidly mounted on the shaft of the electric motor, it is equipped with a container covering the electric motor and communicating through holes with the inner cavity of the housing. The work fully describes the application of hydrodynamic cavitation. The results obtained are used to study the influence of the main design parameters of the separator-throttle valve assembly on the flow capacity of the control valve and are relevant for stochastic modeling of the hydrodynamic cavitation process.

In [11], energy losses (reduction of hydraulic pressure) in a moving fluid are considered. As described in the work, pressure losses are distributed along the length of the pipeline – these are linear losses; in others they are concentrated on very short sections, the length of which can be neglected – on the so-called local hydraulic resistances: valves, all kinds of rounding, constrictions, expansion, etc., that is, wherever the flow is subjected to deformation. The source of losses in all cases is the viscosity of the liquid.

The paper [12] presents the results of a study of the main characteristics of the liquid throttling process in a control axial valve, taking into account the dependence of the simulated coefficient of hydraulic resistance on design and operating parameters. The calculation of the throughput and throughput characteristics of the separator of the specified valve is performed from the standpoint of varying the degree of its opening. In the course of the work, the main factors influencing the change in these axial valve performance indicators were identified.

In this article [13], dynamic mesh and UDF technology are used to investigate the dynamic evolution of cavitation and the axial force for the entire valve disc during the opening and closing of an inclined ball valve. The results show that the development of cavitation during the opening process is divided into three stages, including the occurrence of cavitation, its development and the complete development of cavitation. The paper does not provide mathematical modeling of the process.

In this study [14], the efficiency of heat transfer of Galinstan liquid flowing through an immersion heater was analyzed using computational fluid dynamics. The calculation was carried out under different conditions with a different number of partitions, mass flow and constant heat flow values.

In [3], the dynamics of vortex cavitation is studied under various conditions, including pressure and hole number, as well as their effect on the characteristics of sputtering. The higher the inlet pressure, the higher the mass flow rate and discharge coefficient, but the weaker the vortex cavitation. While the intensity of vortex cavitation decreases, the flow coefficient increases, and the mass flow remains almost constant with increasing back pressure. Under the action of vortex cavitation, the spreading angle of the liquid of the primary jet, the penetration of the jet, and the volume coefficient of the jet first increase and then decrease with increasing inlet pressure. As is known, the phenomenon of cavitation in the nozzle, especially vortex cavitation, strongly affects the flow dynamics and spray characteristics. The paper describes in detail the influence of pressure conditions (inlet and return pressure) and the number of holes on the internal vortex cavitation and the dynamics of its sputtering.

There is also a method for generating thermal energy, where heated water is given a rotational motion, causing centrifugal forces and pressure that move water in a radial direction and simultaneously create an increasing reusable pulsation of this pressure, followed by its drop to atmospheric pressure. But these methods are shown only in existing patents. And they are not fully implemented.

Currently, hydrodynamic heaters are rarely used in everyday life and in industrial enterprises. This is due to insufficient knowledge about this type of equipment and the amount of information and research.

## 3. The aim and objectives of the study

The aim of the study is to select the shape of the rotor for optimal operation of the hydrodynamic heater. This allows to explore ways to heat the liquid using special chokes.

To achieve this aim, the following tasks were set:

– to determine the position of the coordinate of the paraboloid vertex of the free surface and the volume of liquid in the vessels, from the height of the liquid level;

– to determine the temperature of the liquid by the rotation velocity of the rotor.

## 4. Materials and methods

The object of the study is the design of a hydrodynamic heater and the physical processes in a liquid during the production of thermal energy. The assumption is made that the conical shape of the skirt contributes to a better filling of the rotor cavity and the creation of liquid pressure in front of the throttle openings. To confirm the shape of the skirt considered the behavior of a liquid in a rotating vessel around a vertical axis with a constant angular velocity. The rotating walls of the vessel will cause the layers of liquid closest to the walls to rotate, and then, due to the viscosity of the liquid, its entire mass. After some time, all the particles of the liquid will rotate at the same angular velocity. The equilibrium of the liquid relative to the vessel will be established. In this case, the liquid is at rest relative to the vessel in a non-inertial coordinate system $x$, $y$, $z$. When writing equilibrium equations in a non-inertial coordinate system, it is necessary, in addition to surface forces, mass gravity, to introduce a portable force of inertia of rotational motion [15]. For this case, the portable force of inertia is the centrifugal force directed along the radius and equal to:

$$F=\Delta m\omega^2 r, \quad (1)$$

where $\Delta m$ – the elementary mass of the liquid; $r$ – the distance from the vertical axis to the elementary mass.

Projections of the density vector of the distribution of mass forces from gravity and the portable force of inertia have the form:

$$F_{x_1}=0;$$

$$F_{y_1}=0;\ F_{z_1}=-g;$$

$$F_{x_2}=\omega^2 x;\ F_{y_2}=\omega^2 y;\ F_{z_2}=0,$$

where $x$ and $y$ are the horizontal coordinates of an arbitrarily selected point of the liquid.

Using the equal pressure surface equation:

$$F_x dx+F_y dy+F_z dz=0, \quad (2)$$

let's define the shape of its surface. To do this, let's substitute expressions into the equation $F_x$, $F_y$ and $F_z$ then the equation will take the form:

$$\omega^2 x dx+\omega^2 y dy-g dz=0.$$

Integrating:

$$\frac{\omega^2}{2}\left(x^2+y^2\right)-gz=C,$$

since $x^2+y^2=r^2$ the equation can be written as follows:

$$\omega^2 r^2/2-gz=C. \quad (3)$$

Find the value of an arbitrary constant $C$ for a paraboloid with vertex coordinates $x=0;\ y=0;\ z=z_0$. By substituting these coordinates into expression (3):

$$C_0=-gz_0.$$

The equation of the free surface:

$$z_{fs}-z_0=\frac{\omega^2}{2g}\left(x^2+y^2\right)\Rightarrow \omega^2 r^2/2g. \quad (4)$$

To determine the cause of a slight increase in the temperature of the liquid, a transparent mock-up was made (Fig. 2), where a tinted liquid was used as a coolant.

Any particle of liquid (Fig. 2), which is in a state of relative rest in a rotating vessel, located at a distance from the axis of rotation, has a linear velocity. The height of the point of the free surface of the paraboloid is equal to:

$$h'=z_{fs}-z_0=\omega^2 r^2/2g=u^2/2g. \quad (5)$$

To determine the advantage of the conical shape of the skirt compared to the cylindrical one, the forces in the rotating fluid were determined in Fig. 1.

The ordinate of the vertex of the paraboloid of the free surface at a given angular velocity depends on the volume of liquid in the vessel. Before the vessel rotates, the liquid level has a horizontal position and is at a height $h$ with a volume of liquid equal to $\pi R^2 h$. When the vessel rotates, the shape of the liquid surface changes, but its volume remains unchanged:

$$\int_0^R \left(z_0 + \omega^2 r^2/2g\right) 2\pi r \mathrm{d}r = \pi R^2 h.$$

After integration, the free surface equation has the form:

$$h = z_0 + \frac{\omega^2 r^2}{2g} \text{ or } z_0 = h - \omega^2 R^2/2g. \quad (6)$$

To establish the advantage of the conical shape of the skirt in comparison with the cylindrical shape, it is possible to determine to what maximum angular velocity the vessel can be spun so that the liquid does not spill out of it. At the same time, let's change the taper of the vessels, as well as the liquid level in them. Next, let's write down the necessary formulas for calculating the parameters of the cylindrical and conical shapes of the vessel, based on the condition that the liquid should not spill over the edge of the conical vessel [16].

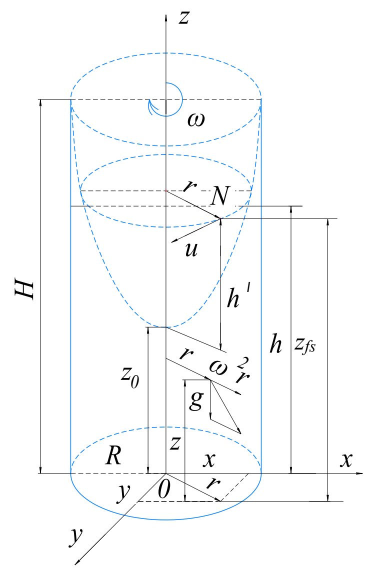


Fig. 1. Forces in a rotating fluid

The temperature increase during throttling can be determined by equating the energy given by the liquid flowing out of the throttle openings to the energy spent on heating it [2].

The temperature of the liquid can be determined by the following formula [17]:

$$\Delta t = 2.37 \cdot 10^{-7} \Delta p. \quad (7)$$

However, when the installation was started within 20 minutes, the coolant temperature reached only 36–37 °C. To determine the reason for the small increase in liquid temperature, a transparent mock-up was made (Fig. 2), where a tinted liquid was used as a coolant.

During rotation, tinted water, lifted by the conical skirt of the rotor, rushed along the bottom of the drum to the throttle holes, which caused an air cavity to form in its upper part, as shown in [18]. The trapped air in the rotor reduces the fluid pressure at the throttle openings:

$$p = \frac{\gamma \omega^2 \left(R^2 - r_i^2\right)}{2g}, \quad (8)$$

where $\gamma$ – the specific gravity of the liquid, N/m$^3$; $R$ – the outer radius of the ring of liquid in the rotor, m; $r_i$ – the inner radius of the ring of liquid in the rotor drum, m; $g$ – acceleration of gravity, m/s$^2$; $\omega$ – the angular velocity of rotation of the rotor, rad/s and, accordingly, the increase in its temperature.

Also, it is provided (Fig. 3) a special cylinder, which was mounted in the casing of a hydrodynamic installation to accommodate a rotor with a conical skirt.

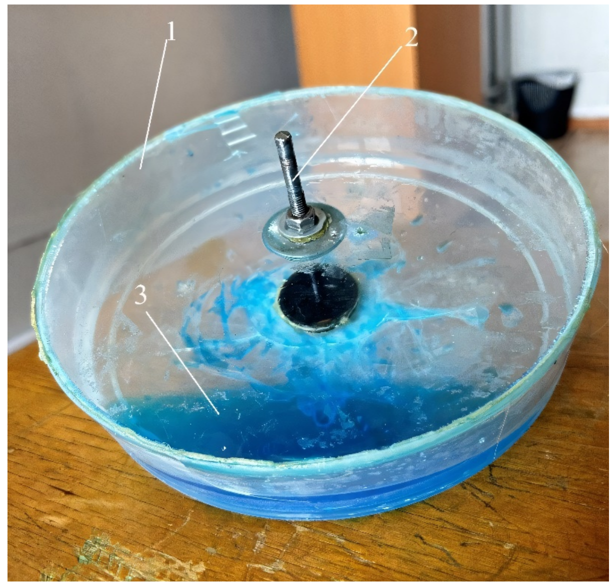


Fig. 2. Transparent rotor layout:
1 — conical rotor; 2 — axial fitting; 3 — tinted liquid

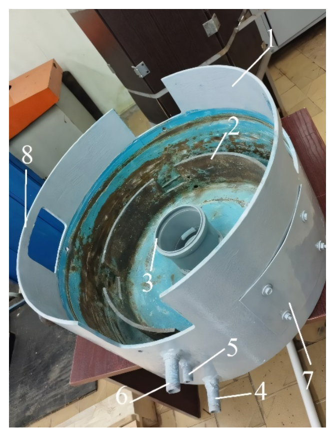


Fig. 3. Housing of a hydrodynamic installation for placing a rotor with a conical skirt: 1 — body of the hydrodynamic installation; 2 — separator of liquid flows (cold and hot); 3 — special guiding cylinder for liquid flow; 4 — fitting for liquid supply; 5 — connector for mounting an electronic digital thermometer; 6 — fitting for hot liquid discharge; 7 — viewing window; 8 — grippers for transportation installations

During operation of the rotor 2, the lateral outer walls of the conical skirt 3 interact with the liquid, forcing it to rotate (Fig. 4, *a*). When the liquid rotates, its surface forms a parabola 4 (Fig. 4, *b*), the surface of which, rising along the walls of the housing 1, begins to interact with the lower part of the rotor drum 2.

To eliminate dynamic surface contact, it is installed motionlessly in the center of the body of the hydrodynamic installation, covering the conical skirt of the special guiding cylinder 6, made with holes for supplying liquid flow (Fig. 5).

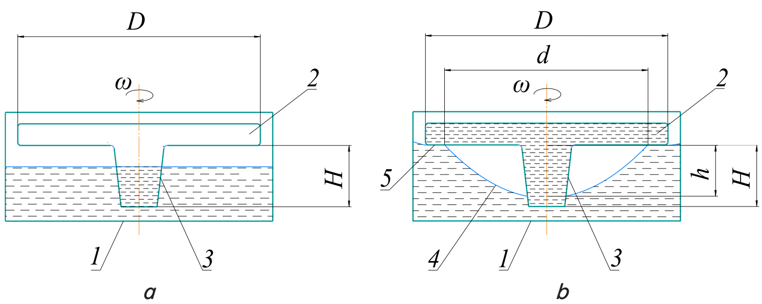


Fig. 4. Condition of the moving parts of the heat generator: *a* – static state; *b* – dynamic state

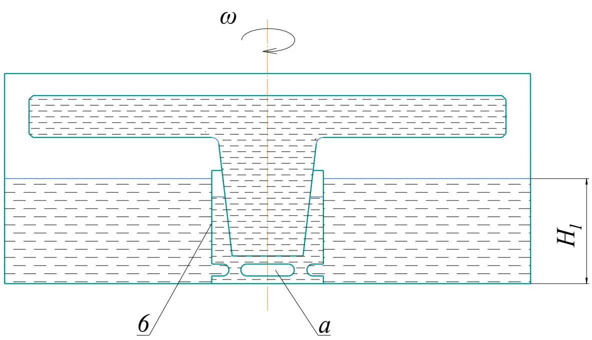


Fig. 5. Diagram of the installation of a special guiding cylinder in a hydrodynamic installation

The liquid flow guide cylinder simultaneously acts as a liquid calmer, and cuts off its bulk from the rotating skirt.

It should also be noted that compliance with the location levels of heating devices and the hydrodynamic installation allows for the supply of coolant in the system by gravity. This is due to the fact that the rotor of the hydrodynamic installation functions as a pump. However, an additional low-power circulation pump is provided in the heating system, which can be turned off during normal circulation of the coolant.

## 5. Results of work on the study of fluid parameters in an inertial hydrodynamic installation

### 5. 1. The results of changing the position of the vertex of the paraboloid of the free surface and the volume of liquid in the vessel

Using the above expressions, the maximum angular velocity of rotation is determined at which liquid will not spill out of the vessels. At the same time, the calculated dependences of the angular velocity of rotation of the vessels on the liquid level in them show that the lower the liquid level, the higher the required value of the angular velocity.

However, dependency graphs were previously defined and constructed. At the same time, the ordinate of the vertex of the paraboloid of the free surface at a given angular velocity depends not only on the angular velocity, but also on the volume of liquid in the vessel. The following Fig.6 shows the dependence of the positions of the ordinate of the vertex of the paraboloid of the free surface on the height of the liquid level in the drum.

It can be seen from expression (3) that surfaces of equal pressure represent a parabolic shape. It should be noted that different paraboloids of equal pressure correspond to different values of the constant.

It can be seen from expression (3) that surfaces of equal pressure represent a family of congruent paraboloids. Different values of the constant *C* correspond to different paraboloids of equal pressure. The free surface is also a surface of equal pressure, where at all points the pressure is equal to the external pressure $p_0$. Since the volume of the liquid is equal to the volume of the paraboloid, the ordinate of the vertex of the paraboloid $z_0$ can be calculated. Taking $z_0=2h_1-h$, and presenting formula (6) in the following form $\omega=\sqrt{((h-z_0)\cdot 2g)/r^2}$, it is possible to determine the angular velocity at which the liquid will not spill out of the rotor skirt. The dependencies in Fig. 6–8 are based on theoretical studies.

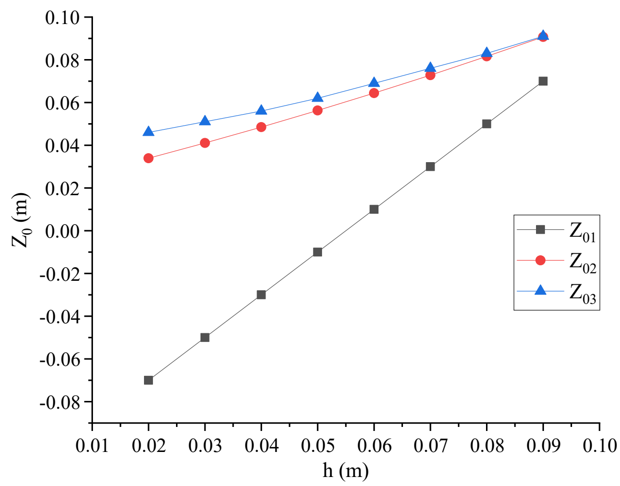


Fig. 6. Dependence of the positions of the vertex ordinate of the paraboloid of the free surface on the height of the liquid level from the condition of its non-spilling: $Z_{01}$ – at a taper angle of 0°; $Z_{02}$ – at a taper angle of 5°; $Z_{03}$ – at a taper angle of 10°

The graph shows that at the height of the liquid level of 0.020 m, the ordinate of the vertex of the paraboloid is 0.070 m, and at the level of 0.060 m, this parameter is 0.010 m. Thus, it can be stated that the change in the ordinate of the vertex of the paraboloid depends on the liquid level in the drum.

Later, during laboratory work, the results are obtained and the dependence (Fig. 7) of the volume of liquid in the vessel on the height of the liquid level are plotted. Dependencies in Fig. 7 are based on theoretical research.

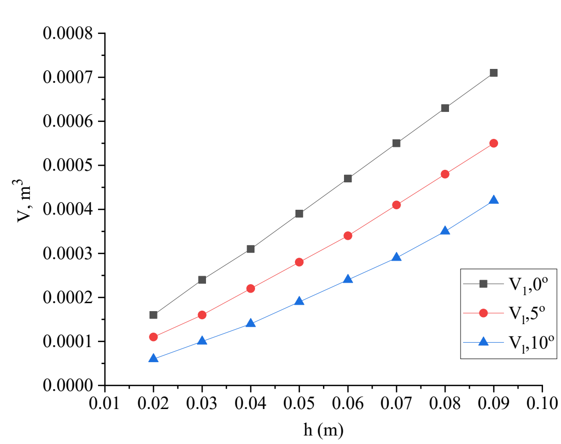


Fig. 7. Dependence of the volume of liquid in the vessel on the height of the liquid level from the condition of its no-spilling

As can be seen from the graph, data taper angle of 5°, at a liquid level height of 0.02 m, the volume of the liquid is $11.0\cdot10^{-5}$ m$^3$. And when the liquid level increased to 0.09 m, the volume of liquid is $55.0\cdot10^{-5}$ m$^3$.

At a taper angle of 10°, respectively, there is also an increase in the volume of the liquid. The increase in liquid volume is observed in the range from $6.0\cdot10^{-5}$ m$^3$ to $42.0\cdot10^{-5}$ m$^3$.

**5. 2. Results of liquid temperature measurements from the rotor rotation velocity**

The results of the experiment showed that the water lifted by the conical skirt of the rotor rushes along the bottom of the drum to the throttle holes, which is why an air cavity is formed in its upper part. The trapped air in the rotor, according to (6), reduces the pressure of the liquid at the throttle openings and the increase in its temperature [17].

The rotation velocity of the liquid is significantly lower than the rotation velocity of the rotor. Dynamic surface contact occurs. The contact belt is determined by the angular velocity of the liquid, and the higher it is, the larger the contact surface. This has a negative effect not only on the operation of the engine, but also on the hydrodynamic installation as a whole.

Since the radius of the drum of the heat generating unit remains constant, 0.5 m, then having previously assumed radii equal to 0.4, 0.3 and 0.2 m for various positions, respectively, and at $r_i$=0, for angular velocities of the rotor 42, 76, 136, 215, 314 rad/s, let's calculate the pressure values according to a known method [19]. The calculated values correspond to the density of water at a temperature of 20 °C. Table 1 shows the calculated pressure in the throttle openings of the rotor drum at different positions of the liquid ring.

Table 1

Design pressure at the throttle holes in the rotor drum, for different positions of the liquid ring

| Angular velocity of the rotor, ω (rad/s) | Pressure ($p$) at the throttle openings, for different radii of the inner ring of the liquid in the rotor drum (MPa) | | | |
|---|---|---|---|---|
| | $r_1$=0.4 (m) | $r_2$=0.3 (m) | $r_3$=0.2 (m) | $r_4$=0.0 (m) |
| 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 42 | 0.020 | 0.035 | 0.046 | 0.055 |
| 76 | 0.065 | 0.116 | 0.152 | 0.181 |
| 136 | 0.208 | 0.370 | 0.486 | 0.578 |
| 215 | 0.520 | 0.925 | 1.213 | 1.445 |
| 314 | 1.109 | 1.972 | 2.588 | 3.081 |

Table 1 shows that as the angular velocity of the rotor increases, both the cross section of the liquid ring and the pressure at the throttle openings increase. However, at the angular velocity of the rotor, the liquid pressure at the throttle openings will also be zero, since without rotation, the liquid will not flow into the drum.

Substituting the calculated pressure values into the expression (7) (Table 1), it is possible to determine the theoretical increase in water temperature in one pass through the throttle openings, provided that the pressure drops to zero.

It follows from Fig. 8 that the smaller the inner radius of the liquid ring, the higher the temperature of the pressed liquid through the throttle openings. However, in reality, the heating of water due to heat transfer is somewhat lower, but nevertheless, to obtain a set temperature in the heating system, repeated pumping of liquid through the throttle openings is sufficient. Therefore, the turnover of the liquid associated with its flow through the throttle openings is important in a thermal installation. Dependencies in Fig. 8 are based on theoretical research. The description of the method for obtaining the dependence in Fig. 8 is given and constructed according to the indicators obtained by formula (7) and Table 1.

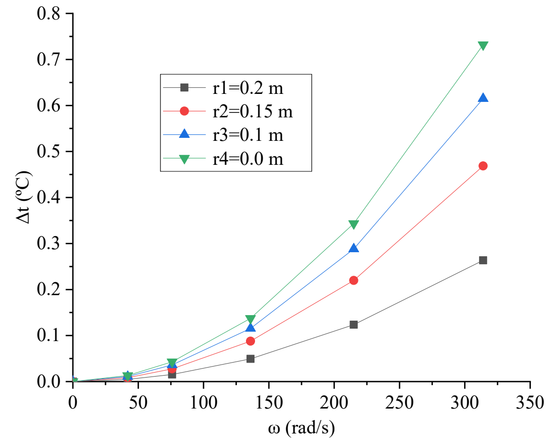


Fig. 8. Dependence of the increase in water temperature in one passage through the throttle openings on the design pressure

After laboratory work, it was possible to eliminate air locking in the rotor drum, which allowed a 4-fold increase in temperature every minute, and in the future, it is possible to use only the conical shape of the skirt, for better filling of the rotor cavity.

At the same time, the small gap between the skirt and the cylinder does not allow the formation of dynamic surface contact of the liquid with the lower surface of the rotor. The liquid flow guide cylinder simultaneously acts as a liquid calmer, and cuts off its bulk from the rotating skirt. At the same time, the small gap between the skirt and the cylinder does not allow the formation of dynamic surface contact of the liquid with the lower surface of the rotor.

## 6. Discussion of the results of a study related to the shape of the rotor of a hydrodynamic heater

The heating of the liquid when passing through the throttle openings of a certain diameter of 1.5 mm, 2 mm and 3 mm occurs due to the Joule-Thomson effect. This effect occurs when a gas or liquid expands or contracts as it passes through the throttle opening. This fact can be observed in Fig. 8, which shows an increase in temperature. Experimental studies have shown that when liquid passes through the throttle opening, the pressure decreases. This leads to a decrease in intermolecular forces and an increase in the average velocity of the molecules. The higher velocity of the molecules leads to a large number of collisions between the molecules, which leads to an increase in their internal energy and, consequently, to an increase in the temperature of the liquid.

To ensure effective heating of the liquid, the optimal shape of the skirt was determined. To do this, it was determined to what maximum angular velocity the vessel can be spun so that the liquid does not spill out of it. According to the results of the study, it was found that the higher the taper, the higher the filling capacity. The effect of the angular velocity on the change in the level of immersion of the skirt in the liquid is smoothed using a special guide cylinder (Fig. 5) in a hydrodynamic installation.

With the help of a transparent layout, the movement of the liquid was observed and the reason for the insufficient increase in the temperature of the coolant was determined. During rotation, tinted water, lifted by the conical skirt of the rotor, rushed along the bottom of the drum to the throttle openings, as a result of which an air cavity was formed in its upper part, as shown in Fig. 2. To eliminate this disadvantage, as shown in Fig. 2, a special guiding cylinder for liquid flow was provided.

To eliminate air locking in the upper part of the drum of the heat generating unit, a pipe with holes in the center was passed along its entire length. When the rotor rotates around the periphery of the tube, the pressure decreases due to the high velocity, which makes it easy to remove air from the center of the drum cavity. The spray gun effect used is a phenomenon that occurs when a liquid or gas passes through a narrow opening at high velocity. With such a flow near the hole, the velocity of the liquid (or gas) reaches significant values, and the pressure decreases. The spray effect creates a vacuum in the system, which has a beneficial effect on increasing the cross-section of the liquid supply ring into the drum. The ring of liquid in the rotating drum of the rotor is formed as a result of the action of centrifugal force on the liquid, which is directed radially from the center of rotation to the periphery. The formed ring of liquid along the inner surface of the drum (Table 1) is maintained at a constant angular velocity of rotation of the rotor, which has a positive effect on the energy consumption of an external source and temperature control of the installation. As shown in Fig. 6, the removal of trapped air increases the inflow and volume of liquid into the drum cavity, which leads to an increase in the ordinate level of the vertex of the paraboloid of the free surface relative to the calculated one.

After a preliminary test, it is possible to obtain a dependence (Fig. 8), from which it can be seen that the smaller the inner radius of the liquid ring, the higher the temperature of the liquid supplied through the throttle openings. Therefore, if the liquid passes through the throttle opening at a high velocity, its temperature can increase significantly.

However, if the velocity of the liquid passing through the throttle opening is low, the Joule-Thomson effect can be neglected.

In addition, the work [20] shows how the efficiency of a hydrodynamic installation affects the turnover of the coolant, which was confirmed by a study of throttling through throttle openings with a total area of $31.4 \cdot 10^{-6}$ m$^2$ and $64.34 \cdot 10^{-6}$ m$^2$, where the indicators of the second case were 6 % higher.

A distinctive feature of this study in comparison with existing ones is that the pressure in front of the throttle openings is created by centrifugal forces arising in the rotating rotor of the liquid. The use of centrifugal forces makes it possible to use an electric motor with a capacity of up to 3 kW as an external rotor rotation activator. This is due to the fact that the rotor of the installation acts as a hydrodynamic pump, where the supply of liquid along the skirt and its flow through the throttle openings are balanced, and the power of the electric motor is spent only on maintaining rotation.

It should be noted that throttling in hydraulic systems is used to regulate the temperature of heat carriers within limits that depend on the specific conditions and requirements of the system. The specific temperature ranges depend on the characteristics of the equipment, the type of coolant and the operating conditions. In domestic heating systems, the temperature of the coolant usually varies from 60 °C to 80 °C.

The disadvantages of this study are that it is difficult to select an engine with the necessary parameters and the appropriate power to rotate the rotor. Also, the dependence of the magnitude of the centrifugal force on the angular velocity and distance from the center of rotation imposes its own limitations on the study. Increasing the distance affects the overall dimensions of the installation, and the angular velocity is limited by the capacity of the throttle openings. In the future, research is planned to improve the design of the installation, which will reduce its overall dimensions, while maintaining the pressure value at the throttle openings and determining the optimal angular velocity.

In the future, during the preparation of this experimental installation, the exact manufacture of the housing and the cylindrical rotor with appropriate parameters is required.

## 7. Conclusions

1. The study shows that at the same angular velocities, the height of the paraboloid in conical vessels is higher, since the supply of liquid into the cavity of the rotor drum contributes to the creation of pressure at its walls. It is known that the higher the pressure, the higher the flow of liquid through the throttle openings. In this case, the top of the paraboloid, depending on the angular velocity, can move up or down, and will drop even below the end of the conical skirt. The study shows that when the cylindrical skirt of the rotor is immersed in a liquid at 0.07 m, the branches of the paraboloid reach its upper edges at an angular velocity of 25 rad/s, whereas with a taper of 5° and 10° this occurs at angular velocities of 24.1 and 23.2 rad/s, respectively. This indicates that the conical shape of the skirt is preferable to the cylindrical one, since the creation of pressure in front of the rotor throttles is directly related to the supply of liquid.

2. During the study, the results of a study on the change in water temperature through throttle openings were obtained. Based on the study, it can be said that the smaller the inner radius of the liquid ring, the higher the temperature of the pressed liquid through the throttle openings. However, in reality, the heating of water due to heat transfer is somewhat lower, but nevertheless, to obtain a set temperature in the heating system, repeated pumping of liquid through the throttle openings is sufficient. Therefore, the turnover of the liquid associated with its flow through the throttle openings is important in a thermal installation. In the course of the study, theoretical results were obtained concerning the effect of changing the cross-section of the liquid ring on the temperature increase when it is forced through the throttle openings. For the inner radii of the liquid ring of 0.2 m, 0.15 m, 0.1 m and 0.0 m, the average temperature increase per pass through the throttle openings was 1.1 °C. Based on the conducted research, it can be concluded that a decrease in the inner radius of the liquid ring leads to an increase in the temperature of the pressed liquid through the throttle openings. However, in practice, water heating is slightly lower due to heat transfer. Nevertheless, to achieve the set temperature in the heating system, it is sufficient to repeatedly push the liquid through the throttle openings. Thus, the turnover of the liquid associated with its flow through the throttle openings plays an important role in the operation of the thermal installation.

## Conflict of interest

The authors declare that there is no conflict of interest regarding this research, including financial, personal, authorship or other nature that could affect the research and its results presented in this article.


## Financing

This research is funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant no. AP19678501).


## Data availability

Data will be provided upon reasonable request.

## Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

## References


1. Tergemes, K. T., Duisembaev, M. S. (2014). Vortex heat generator with an adjustable energy conversion coefficient for heating farmhouses. Research, results. Available at: https://articlekz.com/article/12654
2. Guo, G., Lu, K., Xu, S., Yuan, J., Bai, T., Yang, K., He, Z. (2023). Effects of in-nozzle liquid fuel vortex cavitation on characteristics of flow and spray: Numerical research. International Communications in Heat and Mass Transfer, 148, 107040. https://doi.org/10.1016/j.icheatmasstransfer.2023.107040
3. Usychenko, V. G. (2012). The Ranque effect as a self-organization phenomenon. Technical Physics, 57 (3), 379–385. https://doi.org/10.1134/s1063784212030164
4. Aghakashi, V., Saidi, M. H. (2018). Turbulent decaying swirling flow in a pipe. Heat Transfer Research, 49 (16), 1559–1585. https://doi.org/10.1615/heattransres.2018021519
5. Yurchenko, V. V., Isaev, V. L., Kuchin, V. N., Kalinin, A. A., Zeynullin, A. A. (2014). Pat. No. 31003 KZ. Mechanical heat generator. declareted: 13.10.2014; published: 15.03.2016. Available at: https://kzpatents.com/4-31003-teplogenerator-mehanicheskijj.html
6. Kalinin, A. A., Kuchin, V. N., Breydo, I. V., Isaev, V. L., Yurchenko, V. V. (2016). Pat. No. 31624 KZ. Cavitation vortex heat generator. declareted: 04.12.2014; published: 30.09.2016. Available at: https://kzpatents.com/4-31624-teplogenerator-kavitacionno-vihrevojj.html
7. Mujtaba, M., Cuntang, W., Yasin, F. M., Xie, F. (2018). Throttle Valve as a Heating Element in Wind Hydraulic Thermal System. Journal of Advance Research in Mechanical & Civil Engineering (ISSN: 2208-2379), 5 (2), 01–11. https://doi.org/10.53555/nnmce.v5i2.304
8. Ved, V., Nikolsky, V., Oliynyk, O., Lipeev, A. (2017). Examining a cavitation heat generator and the control method over the efficiency of its operation. Eastern-European Journal of Enterprise Technologies, 4 (8 (88)), 22–28. https://doi.org/10.15587/1729-4061.2017.108580
9. Casiano, M. J., Hulka, J. R., Yang, V. (2010). Liquid-Propellant Rocket Engine Throttling: A Comprehensive Review. Journal of Propulsion and Power, 26 (5), 897–923. https://doi.org/10.2514/1.49791
10. Kapranova, A. B., Lebedev, A. E., Melzer, A. M., Neklyudov, S. V. (2019). About Formation of Elements of a Cyber-Physical System for Efficient Throttling of Fluid in an Axial Valve. Cyber-Physical Systems: Advances in Design & Modelling, 109–119. https://doi.org/10.1007/978-3-030-32579-4_9
11. Kapranova, A. B., Lebedev, A. E., Meltser, A. M., Neklyudov, S. V. (2018). On the influence of the throughput of the axial valve on the parameters of the stochastic model of cavitation. RHJ Journal of the Chemical Society named after D.I. Mendeleev, 62 (4), 51–53.
12. Kireev, V., Nizamova, A., Urmancheev, S. (2019). The hydraulic resistance of thermoviscous liquid flow in a plane channel with a variable cross-section. Journal of Physics: Conference Series, 1158, 032014. https://doi.org/10.1088/1742-6596/1158/3/032014
13. Qian, J., Liu, C., Qiu, C., Li, W., Chen, D. (2024). Liquid hydrogen cavitation analysis inside an oblique globe valve. Flow Measurement and Instrumentation, 97, 102599. https://doi.org/10.1016/j.flowmeasinst.2024.102599
14. Hwang, S., Kim, H., Choi, H., Kim, T., Kim, H. (2024). Design evaluation of an immersion heater using a fluid with low Prandtl number based on computation fluid dynamics analysis. Journal of Mechanical Science and Technology, 38 (4), 2151–2159. https://doi.org/10.1007/s12206-024-0343-2
15. Ghahramani, E., Ström, H., Bensow, R. E. (2021). Numerical simulation and analysis of multi-scale cavitating flows. Journal of Fluid Mechanics, 922. https://doi.org/10.1017/jfm.2021.424
16. Oshanov, E., Abdirova, N., Tusuphanova, A. (2023). Determination of the maximum angular speed rotation of inertial heating hydrodynamic installation rotor. Abstracts of I International Scientific and Practical Conference. Varna, 222–226.
17. Nussupbekov, B., Oshanov, Y., Ovcharov, M., Mussenova, E., Ospanova, D., Bolatbekova, M. (2022). Development and creation of a hydrodynamic liquid heating unit. Eastern-European Journal of Enterprise Technologies, 5 (8 (119)), 62–69. https://doi.org/10.15587/1729-4061.2022.264227
18. Hoppe, F., Breuer, M. (2020). A deterministic breakup model for Euler–Lagrange simulations of turbulent microbubble-laden flows. International Journal of Multiphase Flow, 123, 103119. https://doi.org/10.1016/j.ijmultiphaseflow.2019.103119
19. Nussupbekov, B. R., Ovcharov, M. S., Oshanov, E. Z., Yesbergenov, U. B., Duisenbayeva, M. S., Tishbekov, A. A., Amanzholova, M. K. (2023). Determination of the effects of the diameters of the throttle holes on the fluid flow of an inertial hydrodynamic installation. Bulletin of the Karaganda University «Physics Series», 112 (4), 82–90. https://doi.org/10.31489/2023ph4/82-90
20. Nussupbekov, B., Oshanov, Y., Ovcharov, M., Kutum, B., Duisenbayeva, M., Kongyrbayeva, A. (2023). Identifying regularities of fluid throttling of an inertial hydrodynamic installation. Eastern-European Journal of Enterprise Technologies, 6 (7 (126)), 26–32. https://doi.org/10.15587/1729-4061.2023.292522