The work is devoted to the study of the parameters of an installation for heating a coolant using liquid forcing through throttle openings. A scheme of a full-size experimental stand has been developed and the principles of operation are described in detail. For visual observation of the state of the liquid at different angular speeds of rotation of the rotor, a transparent drum model is made. The influence of the shape of the rotor skirt and the depth of its immersion in the liquid on the filling capacity of the rotor cavity at an angular velocity from 42 to 314 rad/s has been determined. The optimal parameters of the depth of immersion of the drum skirt with a diameter of 0.5 m in the liquid, at low rotor speeds of 16, 24, 32 rad/s, were obtained. The angle of inclination is calculated and it is experimentally proved that for a conical shape it is 5 degrees. It was found that at angular velocities of the rotor more than 100 rad/s, the shape and depth of immersion of the skirt in the liquid do not affect the filling of the rotor, since the feed is higher than its flow through the throttle openings. It is shown that the use of rotational forces to heat the liquid allows using an electric motor with less power, since it is spent only on unwinding the rotor with the liquid. The calculated dependence of the liquid pressure on the side walls of the rotor, the liquid heating temperature on the angular velocity of rotation of the rotor and on two values of the area of the throttle openings, at $31.4 \cdot 10^{-6}$ m^2 and $64.34 \cdot 10^{-6}$ m^2, is obtained. When the total area of the throttle openings is doubled, the temperature of the liquid heating at the same angular velocities increases from 35.6 °C to 82.5 °C. The above installation parameters allow you to get hot water when using small shell-and-tube heat exchangers

***Keywords:** installation, inertial forces, throttling, pressure, temperature, rotor, liquid heating, pump, drum*

UDC 533.2
DOI: 10.15587/1729-4061.2022.264227

DEVELOPMENT AND CREATION OF A HYDRODYNAMIC LIQUID HEATING UNIT

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Received date 23.06.2022
Accepted date 29.08.2022
Published date 31.10.2022

***How to Cite:** 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. doi: https://doi.org/10.15587/1729-4061.2022.264227*

1. Introduction

The depletion of traditional energy sources of oil, gas, coal and their extraction in the world and in Kazakhstan at present, during the energy crisis, are carried out exponentially. Therefore, the search for ways to use electrical energy in installations that make it possible to increase its efficiency is an urgent task for every state in the world. In this regard, this direction has become a priority in the Republic of Kazakhstan, as it allows reducing the energy intensity of the republic's economy. For an accelerated solution to this problem, it is necessary to search for and develop green energy sources as soon as possible – wind, sunlight, water flows, geothermal heat, as well as the internal energy of liquid media, etc.

In the countries of Western Europe, the CIS and China, autonomous heat supply systems have been actively developing in recent years, where heat energy is generated from solar collectors, heat pumps using earth energy, vortex heat generators, etc. These units are used by private residential buildings, remote from centralized heat supply, isolated enterprises and organizations with low consumed heat and energy [1].

In modern realities, along with developing technologies of autonomous heat supply, the search for ways and means of economical consumption of energy resources is one of the priorities of all industries. Therefore, research aimed at creating a heating system for various liquids with the most effective thermophysical parameters is relevant.

2. Literature review and problem statement

Vortex heat generators or heaters using a hydrodynamic method of heating liquids have certain advantages and disadvantages compared to electric heating units that consume a sufficient amount of electrical energy. By using heat generators, it is possible to heat any liquid [2]. The high efficiency of these units in the absence of water treatment, electrochemical protection against corrosion, allows saving on the manufacture of an expensive heat exchanger [3]. However, to pump the coolant, these installations use a pumping unit that consumes electrical energy. To date, from a scientific point of view, the reduction of energy consumption of vortex heat generators has not been proven and the processes of converting electrical energy into heat energy with intermediate conversion into mechanical energy have not been investigated [4].

One of the most important achievements of science and technology is the creation and use of the field of centrifugal forces, which has proved to be very effective in mechanical engineering (rotary systems), space technology (stabilization of spacecraft by rotation), liquid gyroscopes and many others.

There are a number of works devoted to these issues in space technology. The calculations of the most complex centrifuges in chemical technology have led to engineering methods. At the same time, not all problems with the dynamics of liquid rotation systems received sufficient development and coverage. In recent years, studies have been conducted on the dynamics of rotating bodies with cavities containing liquid. The problems of stabilizing and controlling the movement of a rotor with a fluid-containing cavity are important both from a theoretical point of view and due to a number of technical applications. It is described in [5] that on modern supersonic aircraft, due to the aerodynamic heating of the skin, the environment surrounding the hydraulic system has a temperature that is much higher than that allowed for the liquids used. Therefore, when creating hydraulic systems (HS) of supersonic aircraft, it is impossible to use the convective heat exchange cycle to maintain a given liquid temperature. The stationary and non-stationary modes of operation of the hydraulic system, their calculation, determination of the temperature of the working liquid, methods for maintaining its preset temperature are considered, and experimental and computational work is carried out. The calculated data of the temperature regimes of the hydraulic system and its cooling systems show an increase in the temperature of the working liquid during its throttling. In this case, the heating of the liquid during overflows is considered taking into account all factors affecting the thermodynamic state of the throttled liquid, where a stationary flow passes without performing external work at a constant speed and steady pressures before and after the throttle. However, the author, when calculating, does not take into account the volumetric-temperature expansion of the liquid, that is, the density and heat capacity of the working liquid in front of the throttle. Therefore, the data of the calculated work differ sharply from the experimental data.

The technological role of water in energy technologies and in hydraulic systems is more briefly described in patents for inventions [6], where a liquid in the form of water can be used not only as an efficient energy carrier, but also as an affordable and cheap energy resource. However, so far it has not received wide use and application, although there have been various attempts and proposals for its implementation.

As shown in [7], the use of the electrohydraulic effect has an effective impact on the destruction of organic matter and increases the yield of light and medium fractions from oil bottom sediments. Therefore, the possibility of this electrohydraulic effect can also be used for the treatment of liquids with the subsequent removal of dissolved oxygen from the water composition, as well as carbon dioxide. The treated water can also be used in liquid heating systems of a full-size experimental stand.

In the work [8], the design of a grain dryer based on thermosiphons, including a heat generator, has been developed. In this device, liquid fuel is used to generate heat, where flue gases should form. The air in the heater rises from the ambient temperature to 60 °C. The disadvantage of this heat generator is that it is environmentally harmful and fire-hazardous.

Traditional types of heat energy production [9], in addition to meeting the needs of humanity, cause enormous harm to the environment. To solve environmental problems related to energy production, scientists around the world strive to adapt heat, chemical, mechanical, and light energy to regional local conditions. Currently created alternative energy sources are expensive and their service life is limited.

As you know, the throttle in the hydraulic drive is an adjustable (or unregulated) local resistance, by changing the area of the through hole during operation, you can get the required amount of liquid (or liquid flow), which takes into account the flow rate through the throttle, the area of the flow area of the hole, the pressure drop in throttle and free fall acceleration.

As the authors of the papers point out, devices operating on the principle of a heat generator can be effectively used for water disinfection (destruction of all types of bacteria) and water preparation for various domestic and technological needs that do not require chemical reagents (chlorine, copper sulfate).

The units can be perfectly used to provide drinking and hot water to hospitals, children's facilities, hotels, various-purpose swimming pools, private houses, bathhouses, etc., and have advantages over existing systems: durability, 3–4 times lower energy consumption, and at the same time disinfection, filtration, softening and heating of water to a temperature of +95 °C and there is no need to use high voltages and expensive metals (for the case of water disinfection by ionization).

In the work [10], the analysis of the calculation of the throughput of hollow perforated rotating shells is carried out. The essence of the hydrodynamic paradox arising during their rotation is considered. In accordance with this hypothesis, when a liquid enters the outflow hole in the presence of a large fluid velocity gradient on the inner surface of the shell, the fluid flow, directed almost perpendicular to the hole axis, interacts with the walls of this hole. After hitting the walls of the hole, the liquid flow will be divided into two streams: one part will flow out in the form of a jet through the hole in the shell, and the other part will be reflected inward and mixed with the liquid in the shell. As a result of mixing with the reflected liquid, a layer of liquid is formed in the near-wall region of the shell, which has a significant rotation speed. The thickness of such a layer will be the greater, the greater the depth of penetration of the reflected liquid jet into the shell and the greater the distance between adjacent holes.

However, this paper only presents computational works, and there are no experimental data and comparative materials.

In the following paper [11], methods for heating the working fluid of a hydraulic drive when working at low temperatures are considered. The design of a warm-up throttle with automatic control of the conditional passage remotely depending on the temperature of the working fluid in the hydraulic system tank is proposed, and a method for calculating the main parameters of the proposed throttle is presented in order to simplify its implementation.

However, it is very difficult to estimate the diameter of the throttle valves where the fluid passes. Nevertheless, good temperature dependences can be obtained.

The paper [12] presents the results of a theoretical study of a new type of liquid heater – hydrodynamic. The heater consists of a rotor with blades and a stator with counter blades. The rotor rotates at high speed. Water is supplied along the axis of the rotor through the channel, then, under the action of centrifugal forces, it moves into the working cavity, where it is heated. Water is drained through the outlet. Heating of water in the working cavity occurs due to friction and intense turbulence during its movement. This work is also proposed in the form of settlement work. The proposed shape and diameter of the throttle valves do not allow increasing the required temperature. This requires an increase in the applied pressure. The maximum heating temperature of existing heaters is 56 °C.

Thus, at present, hydrodynamic heaters have not yet found wide application. We believe this is due to the lack of knowledge of this type of equipment and insufficient information coverage.

The presented data allow us to consider the technological role of water in energy technologies in a new way – it is now not only an efficient energy carrier, but also a fairly affordable and very cheap energy resource, whose reserves on the planet are many times greater than the reserves of organic, nuclear and thermonuclear fuel.

In this connection, the search for constructive solutions aimed at improving the methods of obtaining heat and its economical consumption is promising.

3. The aim and objectives of the study

The aim of the study is the development and creation of a heat generator.

To achieve this aim, the following objectives are solved:

– to calculate and determine the parameters of the liquid pressure (from 0.1 to 3.0 MPa) at various values of the angular velocity (from 42–314 rad/s) of the electric motor of the heat generator;

– to obtain dependences of liquid heating on the diameter of the throttle openings of the heat generating plant.

4. Materials and methods

The object of research is the production of thermal energy in the created rotary-type devices, by converting electrical energy.

The main hypothesis of the study is that when the liquid moves inside the drum, there is braking at the entrance to the throttle opening in a cylindrical rotor with a nozzle diameter of 2.0 mm, and the outlet temperature of the liquid at the outlet increases.

As we assume, the assembled experimental setup is based on the principle of obtaining heat by pushing various liquids through choke holes of a certain diameter. This principle, as the simplest and most effective way of warming up the working liquid (water, antifreeze, transformer oil, etc.) to the working temperature, is used in hydraulic drives of self-propelled machines, aviation hydraulic systems, as well as in heating systems of the housing and communal sector, etc.

We have limited the experimental heat generating unit for generating thermal energy to 0.523 m in body diameter, 0.3 m in height and 0.5 m in drum diameter.

It was found that the liquid raised along the conical skirt along the bottom of the drum rushes to the side walls, where part of it is ejected through the throttle openings, and part forms an annular space, and the air is locked and compressed in the cavity of the drum, which prevents the creation of a large annular space and, accordingly, a pressure drop in the throttle openings.

In the laboratory of Hydrodynamics and Heat Transfer of the Physics and Technical Faculty of the Karaganda University named after Ye. A. Buketov (Republic of Kazakhstan), a full-size experimental installation (Fig. 1) and the heating system stand (Fig. 2) were made.

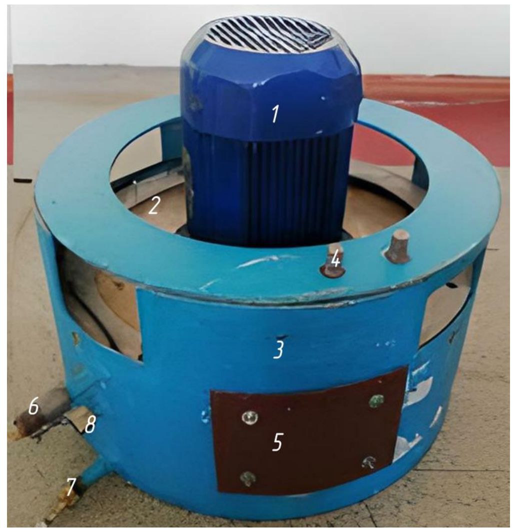

Fig. 1. Full-size experimental setup:
1 – an electric motor with a rotor; 2 – a suspension plate for mounting an electric motor; 3 – the main body of the installation; 4 – studs for mounting a suspension plate; 5 – an observation window; 6 – a hot water outlet fitting; 7 – a water supply fitting; 8 – terminals for connecting an electronic digital thermometer

In the heating system (Fig. 2), an electric motor installed in the housing of the experimental installation rotates the rotor. The rotor is mounted above the liquid surface and is made in the form of a hollow cylindrical drum with a conical skirt. Part of the conical skirt is constantly in the water, and throttles with calibrated holes are installed on the side wall of the drum. The «VESPER» frequency converter provides a change in the number of rotations of the rotor in the range of 0...3,000 rot/min. The control of the difference in liquid levels in the cavities of the EI is carried out by level meters. To fix and limit the maximum value of the liquid temperature in the radiator, a temperature relay is provided. Warmed water from the cavity *B* flows by gravity through the pressure line through the valve, radiator and drain line into the cavity *A*. The throttle is installed in the drain line to regulate the liquid level in the cavity *A*. To maintain the height difference *h* with significant liquid flow rates, a pump is installed on the pressure line, which operates with the valve closed.

The principle of operation of the full-size experimental setup is as follows. The heating system is filled with water and the liquid level should not exceed the liquid level in the cavity «B» of the full-size experimental setup.

The electric motor 1 is switched on and the rotor 5 is rotated (Fig. 3). Due to its liquidity and centrifugal forces, the liquid rises along the conical skirt of the rotor and fills the drum (Fig. 4).

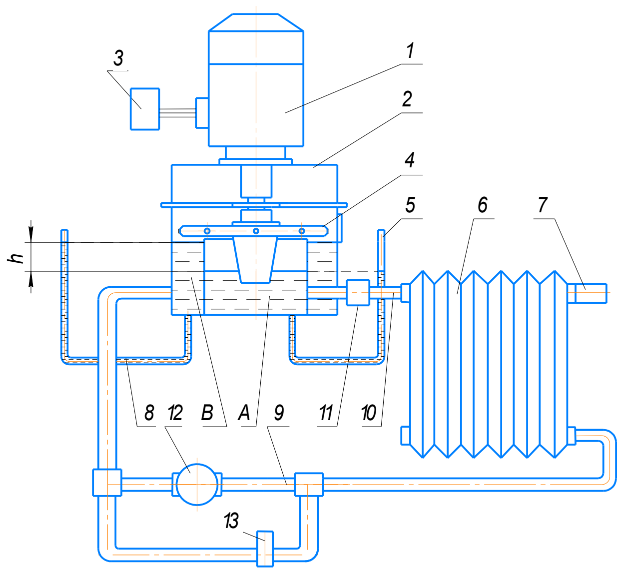

Fig. 2. General view of the heating system with a full-size experimental installation: 1 – electric motor; 2 – corpus; 3 – VESPER frequency converter; 4 – rotor; 5, 8 – level meters; 6 – radiator; 7 – temperature relay; 9 – drain line; 10 – pressure line; 11 – throttle; 12 – pump; 13 – gate valve

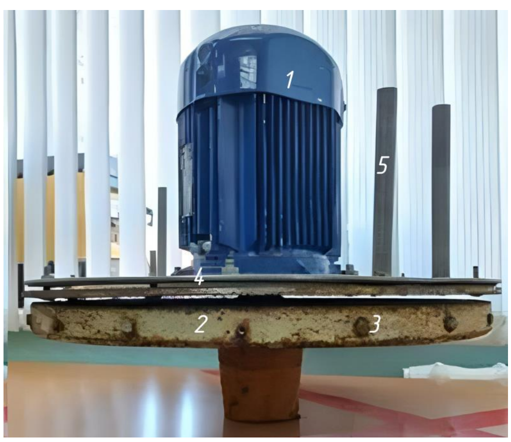

Fig. 3. General view of the rotor with an electric motor: 1 – electric motor; 2 – rotor with a conical skirt; 3 – throttles; 4 – suspension plate for mounting the electric motor; 5 – studs for mounting the suspension plate

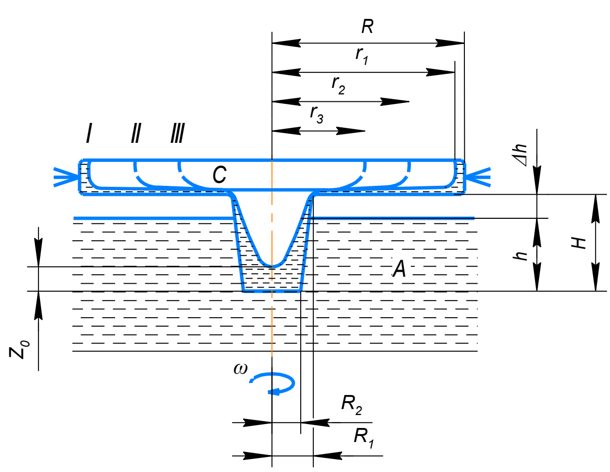

Fig. 4. The state of the liquid at different angular speeds of the rotor

To confirm the results of analytical studies, a full-size experimental stand was made.

Technical data of the stand:

– the volume of liquid in the installation 0.02 m^3;
– the volume of the rotor cavity 0.0014 m^3;
– depth of immersion of the rotor skirt in water 0.07 m;
– angular rotation speeds of the rotor 142, 176, 208, 248 rad/s;
– the total area of the throttle holes:
a) for the first experiment $\delta=31.4\cdot10^{-6}$ m^2;
b) for the second experiment $\delta=64.34\cdot10^{-6}$ m^2;
– initial temperature of the liquid 20 °C.

For laboratory studies, the depth of immersion of the rotor skirt in water of 0.07 m was taken from the condition of fluid flow from cavity *B* to cavity *A* of the experimental setup.

Based on the average values of multiple measurements, graphs of the dependence of the liquid heating temperature on the angular velocity and the total area of the throttle holes are constructed. The range of temperature measurement points does not exceed 6 %.

5. Results of hydrodynamic heating of the liquid

5. 1. Determination of fluid pressure and the influence of the angular velocity of the rotor on the depth of immersion of the drum

The developed experimental installation is based on the principle of obtaining heat by pressing the liquid (water, antifreeze, antifreeze, transformer oil, etc.) through throttle holes. This principle, as the simplest and most effective way of warming up the working liquid to the working temperature, is used in hydraulic drives of self-propelled machines, aviation hydraulic systems, as well as in heating systems of the housing and communal sector, etc.

The temperature increase during throttling can be determined by equating the energy given to the liquid flowing out of the throttle holes to the energy spent on heating it:

$$V\Delta p = V\gamma c m\Delta t, \qquad (1)$$

where V – the volume of liquid, flowing through the throttle holes, m^3; Δp – differential pressure in throttle holes, N/m^2; γ – volumetric weight of the liquid, kg/m^3; c – specific heat capacity of the liquid, J/(kg·grad); m – mechanical equivalent of heat, kg·m/J; $\Delta t = t - t_0$ – liquid temperature increment; t, t_0 – the desired and initial temperatures, °C.

By converting formula (1) we get:

$$\Delta t = \Delta p/\gamma\cdot c\cdot m. \qquad (2)$$

Taking the values for the liquid $\gamma=1000.0$ kg/m^3, $c=4209.104$ J/(kg·grad), $m=1.0$ kg·m/J, expression (2) can be reduced to the form:

$$\Delta t = 2.37\cdot10^{-7}\Delta p. \qquad (3)$$

It follows from expression (3) that when a liquid is throttled under pressure from 10 MPa to zero, its temperature rises by 2.37÷6 °C in one pass through the throttle [5]. In this connection, in all existing systems, hydraulic pumps are used to create pressure in front of the throttle holes. However, in an installation for heat generation, pressure is created by the forces of a rotating mass of liquid in the rotor, which makes it possible to abandon hydraulic pumps.

From the theory of equilibrium of a liquid in a vessel uniformly rotating relative to the vertical axis, it is known that at a constant angular velocity ω, the surfaces of equal pressure are a paraboloid whose axis coincides with the axis of rotation of the vessel [11].

Formulas (4), (5) are used to calculate the height and volume of the paraboloid:

$$H = \frac{\omega^2 \cdot R_1^2}{2g}, \qquad (4)$$

$$V = \frac{1}{3}\pi H\left(R_1^2 + R_2^2 \cdot R_1 \cdot R_2\right). \qquad (5)$$

According to expression (4), the height of the paraboloid H is a quadratic function of the angular velocity of the rotor and the radius of the conical skirt. In this case, the vertex of the paraboloid, depending on the angular velocity, can move up or down, and will fall even below the end of the conical skirt (Fig. 4).

Separate results in this direction are published in [12], where an inertial heater using the principle of liquid throttling is used. The increase in the temperature of the working fluid is affected not only by the angular speed of rotation of the rotor, but also by the cross-sectional area of the throttles and the thermophysical parameters of tap water, antifreeze and spindle oil (density, specific gravity and viscosity). To measure the viscosity, a vibration viscometer of the SV-A series was used.

The paper [13] presents preliminary data on the study of fluid outflow from throttle holes with a diameter of 1.5, 2.0 and 3.0 mm, located at a distance of 0.235 m from the center of rotation, at a preliminary static pressure of 0.01 MPa.

Throttles for fluid outflow are developed on the basis of injectors used in coal-water fuel, shown in [14]. Chokes have a cylindrical shape for spraying liquid without impurities.

The preliminary static fluid pressure affects the fluid flow through the throttle openings only at low angular velocities of the rotor, and with their increase, its value in the total flow decreases sharply. In this paper, the results are obtained for the range of angular velocities from 0 to 147 rad/s. However, as experimental work shows, with an increase in the angular velocity, an increase in the coefficient of fluid flow is also observed.

In connection with the above, we have developed and tested a full-size hydrodynamic stand for liquid heating.

It can be seen from Fig. 4 that the conical shape of the skirt at the same angular velocities of the rotor provides better liquid supply and contributes to the creation of pressure at the side cylindrical wall of the drum. The higher the pressure, the higher the flow of liquid through the throttle openings. The water flowing out of the throttle openings, hitting the side wall of the corpus, falls down under its weight and enters the cavity B. Since the liquid level in the cavity B is always greater than in the cavity A, due to the difference in levels, it will constantly circulate through the heating system.

The value of the liquid pressure P, developed at the radius R of the rotor drum, is calculated by the expression:

$$p = \frac{\gamma\omega^2\left(R^2 - r_i^2\right)}{2g}, \qquad (6)$$

where γ – volumetric weight of the liquid, N/m^3; R – the outer radius of the liquid ring in the rotor, m; r_i – the inner radius of the liquid ring in the rotor drum, m; g – acceleration of free fall, m/s^2; ω – angular rotation speed of the rotor, rad/s.

Based on the calculation, the dependences of the angular velocity ω of the rotor rotation on the depth of immersion of the skirt h (Fig. 5) into a liquid, provided that the liquid from the cavity A rises to the upper edge of the skirt, but does not overflow into the cavity C, are obtained (Fig. 4). The calculated curve 1 corresponds to the cylindrical shape of the skirt, and curve 2 corresponds to the conical shape with an angle of inclination of 5 degrees.

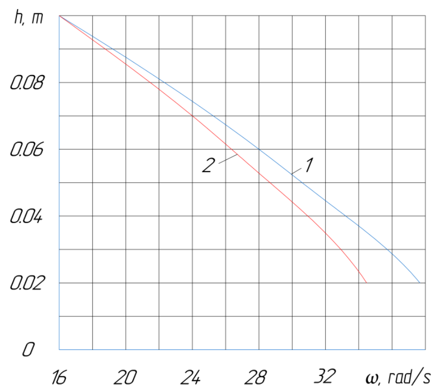

Fig. 5. Dependence of the angular velocity of the rotor on the depth of immersion of the skirt in the liquid: 1 – cylindrical shape of the skirt, 2 – conical shape shape of the skirt

It can be seen from expression (6) that the value of the liquid pressure at the throttle holes (Fig. 4) affects the diameter of the drum and the angular velocity of the rotor. Since the diameter of the drum on the full-size experimental installation remains constant, equal to 0.5 m, then, in relation to the stand, the calculated pressure values were determined for the angular velocities of the rotor 42, 76, 105, 136, 142, 176, 208, 215, 248, 314 rad/s (Fig. 6).

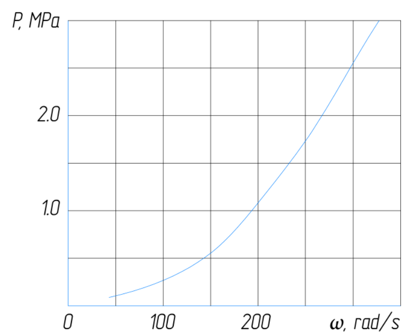

Fig. 6. The calculated dependence of the liquid pressure on the side wall of the drum on the angular velocity of the rotor

From Fig. 6 it follows that the greater the angular velocity of the rotor, the higher the liquid pressure in front of the throttle holes. Substituting the pressure parameters in expression 3, it is possible to obtain calculated indicators of temperature change.

5. 2. Measurement of liquid temperature at different diameters of throttle openings

Fig. 7 presents graphs of the dependence of the liquid temperature on the work time of the experimental installation, with the total area of the throttle holes.

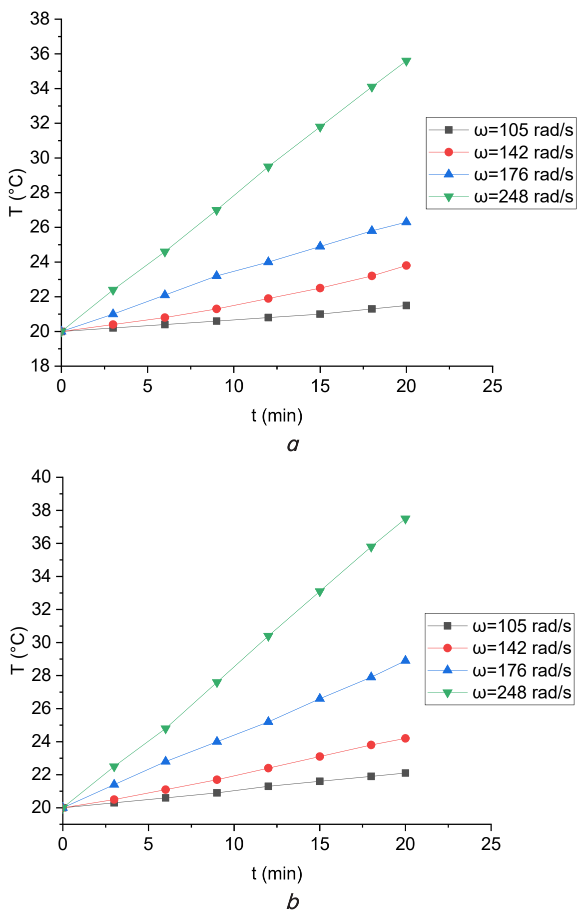

Fig. 7. Changes in the temperature of the liquid when an air cavity occurs for different diameters of throttle openings: *a* – $\delta=31.4\cdot10^{-6}$ m^2; *b* – $\delta=64.34\cdot10^{-6}$ m

From Fig. 7, *a* it can be seen that the temperature of the liquid depends on the angular velocity of rotation of the rotor, with multiple temperature measurements, the average temperature increase per minute for the first curve was 0.075 °C, for the second 0.19 °C, for the third 0.315 °C, for the fourth 0.78 °C.

Doubling the area of the throttle holes (Fig. 7, *b*) gave an every minute average temperature increase for the first curve of 0.105 °C, for the second 0.21 °C, for the third 0.445 °C, for the fourth 0.875 °C.

It follows from this that the increase in the temperature of the liquid is affected by both the angular velocity of rotation of the rotor and the area of the throttle holes. However, in order to ensure optimal work of the experimental installation, it is necessary that the volume of liquid lifted by the conical skirt exceeds its flow through the throttle holes.

Otherwise, the liquid pressure at the throttle holes will be low, respectively, and the temperature of the working liquid.

The results of the experiment showed that the water raised 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 (Fig. 4, I). The trapped air in the rotor, according to formula (6), reduces the pressure of the liquid at the throttle holes and the increase in its temperature.

To determine the reason for the small increase in the temperature of the liquid, a transparent mock-up was made, where a tinted liquid was used.

At the initial stage of the experiments, the difference between the results and the calculated indicators was revealed, which was the reason for the development and manufacture of a transparent layout for visual viewing of liquid movement. In the course of our experiments using the mock-up, it was found that the liquid lifted along the conical skirt along the bottom of the drum rushes to the side walls, where part of it is ejected through the throttle holes, and part forms an annular space. At the same time, air is locked and compressed in the drum cavity, which prevents the creation of a large annular space and, accordingly, the pressure drop in the throttle holes.

The results of experimental studies of the every minute increase in temperature before and after the elimination of air blocking in a full-size test bench (total area of the throttle openings $\delta=31.4\cdot10^{-6}$ m^2) are shown in Table 1.

Table 1

Every minute increase in water temperature

Angular speed of the rotor, ω (rad/s)	Every minute average increase in water temperature, T (°C)	
	Before airing is eliminated	After removing air
105	0.075	0.45
142	0.19	0.765
176	0.315	1.85
248	0.78	3.125

It can be seen from the table that the temperature after the elimination of air blocking from the drum cavity for various angular velocities of the rotor increased several times, which is associated with an increase in the annular space of the liquid, respectively, the pressure at the throttle holes.

The use of a transparent mock-up also made it possible to determine a change in the pressure distribution near the drum walls. In the initial stage, at low angular velocities of the rotor, when the liquid in small volumes rises into the cavity of the drum, the surface of the liquid near the walls has a generally accepted form of liquid, as in open vessels. However, as the experimental and visual results show, the subsequent increase in the angular velocity of the rotor rotation sharply changes the shape of the liquid surface profile, which differs from the liquid profile in open vessels. In this case, the profile of the liquid present forms an arcuate shape.

For subsequent experiments on a full-size stand, this drawback was eliminated, which made it possible to increase the warm-up temperature of the liquid (Fig. 8).

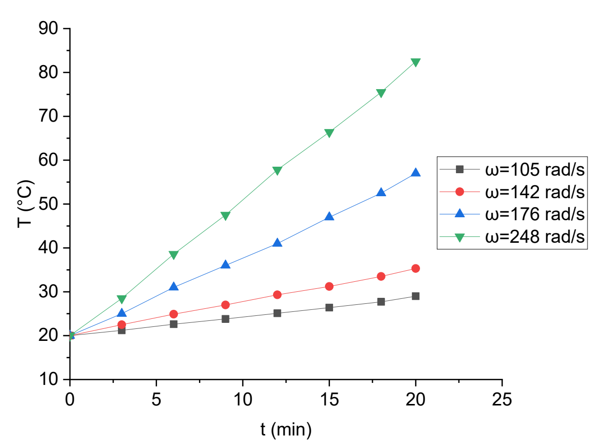

Fig. 8. Change in the temperature of the liquid in the absence of air in the drum cavity of the rotor

From Fig. 7 it can be seen that with an increase in the angular velocity of rotation of the rotor, the temperature of the liquid increases, while the average temperature increase per minute for the first curve was 0.45 °C, for the second 0.765 °C, for the third 1.85 °C and for the fourth 3.125 °C. Therefore, a comparison of the dependencies of Fig. 7, *a*, Fig. 8 shows, with the same input data, that the absence of drying of the rotor cavity allows increasing the temperature of the liquid more than four times, which indicates the formation of a ring of liquid in the cavity of the rotor *C* (Fig. 4, II, III).

Fig. 9 shows the effect of the air cavity in the rotor at different angular speeds of rotation on the heating of the liquid during its throttling.

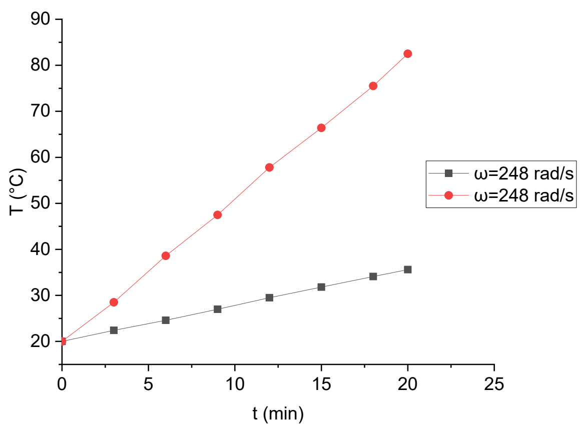

Fig. 9. The effect of the air cavity in the rotor on the heating of the liquid during its throttling

As the comparative data show, the absence of an air cavity makes it possible to increase the temperature of the liquid by more than four times (Fig. 9), which indicates the complete formation of a liquid ring in the cavity of the rotor C (Fig. 4, II, III).

6. Discussion of the results obtained during the creation and manufacture of a liquid heating unit

As the results show, the use of the forces of the rotating mass of the liquid for its heating allows using an electric motor of lower power, which saves the consumed electrical energy. In this case, the power of the electric motor is spent only on unwinding (rotation) of the total mass of the rotor, while the volume of liquid in the rotor remains constant, since after filling the rotor cavity, the flow through the throttle holes and its rise along the conical skirt of the rotor rotation are stabilized. This process allows you to get the temperature of the liquid necessary for heating a detached building.

Currently, all over the world much attention is paid to the savings of electrical energy. Therefore, the development and creation of a heat generator that uses electrical energy to rotate the rotor with the subsequent generation of thermal energy for separate buildings and workshops are very attractive. With a small consumption of electrical energy, it is possible to obtain warm water for domestic use and with the optimal operating mode of the installation and hot water for the heating system. Previously used water heating systems used cylindrical drums, which did not allow raising the temperature of the liquid above 35.6 °C. In our proposed method, the temperature of the liquid can reach 82.5 °C, i.e. it is possible to increase the temperature of the liquid almost twice.

Additional financial investments are required to create and implement this industrial installation.

The disadvantage of this study is that the experimental work was carried out only within the framework of the doctoral student's dissertation research. It is also necessary to take into account that the liquids used should not contain impurities of oxygen and other gases, and the system should be closed, since this raises the problem of liquid deaeration. And also for the application of this installation, it is necessary to create a second circuit with a good heat exchanger that could heat the liquid for domestic use.

This unit can be used for heating oil products in winter and during transportation. The only difficulty is the selection of the necessary chokes to obtain the necessary pressures during the rotation of the rotor.

As can be seen (Fig. 4), the calculated conical shape of the skirt, in comparison with the cylindrical shape, at the same angular speeds of rotation of the rotor provides uniform fluid supply and increases the pressure on the side cylindrical wall of the drum. At the same time, the higher the pressure, the greater the flow of liquid through the throttle openings. When the drum skirt is immersed during rotation, the liquid from the cavity A rises to the upper edge of the skirt, but does not overflow into the cavity C (Fig. 4). The data obtained from Fig. 5 are calculated for the cylindrical shape of the skirt (1 curve), and 2 corresponds to the conical shape, with an angle of inclination of 5 degrees.

The calculated data obtained by (6) show that the amount of fluid pressure in the throttle openings (Fig. 4) affects the diameter of the drum and the angular velocity of the rotor. The diameter of the drum on a full-size experimental installation is 0.5 m, therefore, the calculated pressure values for the angular velocities of the rotor 42, 76, 105, 136, 142, 176, 208, 215, 248, 314 rad/s were determined (Fig. 6). Next, substituting the obtained pressure data, we calculate the temperature differences according to formula (3).

As can be seen from Fig. 6, the heating temperature of the liquid depends both on the angular speed of rotation of the rotor and on the total area of the throttle openings. After 20 minutes of operation of the unit at the outlet, the temperature of the liquid rises from room temperature to 35.6 °C, when the drum rotor rotates at an angular velocity of 248 rad/s. At the same time, the total area of the throttle holes is $31.4 \cdot 10^{-6}$ m^2.

And with a total area exceeding twice ($64.34 \cdot 10^{-6}$ m^2) at the same values of angular velocity, the temperature increased to 37.5 °C. Repeated experimental results have shown that the water raised by the conical rotor skirt rushes along the bottom of the drum to the throttle openings, which is why an air cavity forms in its upper part (Fig. 4, I) and which does not allow increasing the fluid pressure in the throttle openings and outlet temperatures. To find out the reason for the decrease in fluid pressure, we made a transparent mock-up, where a tinted liquid was used.

It was also found that at angular velocities of the rotor more than 100 rad/s, the shape and depth of immersion of the skirt into the liquid do not affect the filling capacity of the rotor, since the feed is higher than its flow through the throttle openings.

After finding out the reasons, this drawback was eliminated, which made it possible to increase the temperature of the liquid at the same standard parameters from 20 °C to 82.5 °C.

Thus, when the liquid rotates, centrifugal forces act on each of its particles located at a distance from the axis of rotation, contributing to the creation of pressure on the side surfaces of the drum and pushing it through the throttle openings at high speed.

The device proposed by us differs from most heaters in that it can significantly simplify the design and increase the efficiency of the heating process, and the main principle of its operation is the direct conversion of mechanical energy into thermal energy. The heat generating installation can be used for individual heating and hot water supply of premises or small buildings for various purposes. However, additional financial investments are required to create this installation and implement it. It is also necessary to take into account that the liquids used should not contain impurities of oxygen and other gases and the system should be closed, since this raises the problem of liquid deaeration.

7. Conclusions

1. The optimal parameters of the depth of immersion of the drum skirt with a diameter of 0.5 m in the liquid are determined, based on the angular rotation speed of the rotor 16, 24, 32 rad/s. The calculated data of the liquid pressure on the side wall of the drum when the electric motor rotates with an angular velocity from 42 to 314 rad/s are obtained. Our device uses a conical drum, where the angle of inclination was 5 degrees. All existing devices use various rotors, including active and passive ones. They do not allow increasing the temperature of the liquid at the outlet.

2. Temperature dependences on the rotation of the rotor (105, 142, 176, 248 rad/s) were obtained for two values of the areas of the throttle holes. The original scientific result was obtained when the drum rotor rotates at an angular velocity of 248 rad/s for 20 minutes, with a total area of the throttle holes equal to $31.4 \cdot 10^{-6}$ m^2, the temperature of the liquid at the outlet of the device increases from 20 to 35.6 °C, and at $64.34 \cdot 10^{-6}$ m^2, from 20 to 82.5 °C. As you know, the existing devices are 3 times larger in size and the power consumption of the electric motor is 7 times greater.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Acknowledgments

This research is funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant no. AP14870433).

References

1. Bloess, A., Schill, W.-P., Zerrahn, A. (2018). Power-to-heat for renewable energy integration: A review of technologies, modeling approaches, and flexibility potentials. Applied Energy, 212, 1611–1626. doi: https://doi.org/10.1016/j.apenergy.2017.12.073
2. Osipenko, S. B. O koeffitsiente poleznogo deystviya. Available at: http://www.afuelsystems.com/arhdoc/400%25.pdf
3. Shastoon, V., Kovalenko, V., Ilchenko, O. (2010). Technology which keeps energy and provides a heat with the use of hydrodynamic heat generators. News of the Dnipropetrovsk State Agrarian and Economic University, 1, 88–91. Available at: http://ojs.dsau.dp.ua/index.php/vestnik/article/view/358
4. Breido, J. V., Kalinin, A. A., Lissitsyn, D. V. (2018). Algorithms of Energy Efficient Control of Electric Technological Complex for Autonomous Heat Supply. EAI Endorsed Transactions on Energy Web, 5 (19), 155040. doi: https://doi.org/10.4108/eai.10-7-2018.155040
5. Shumilov, I. S. (2016). Temperatura rabochey zhidkosti aviatsionnykh gidrosistem. Mashiny i Ustanovki: proektirovanie, razrabotka i ekspluatatsiya. Elektron. zhurn., 2, 51–75. Available at: https://www.researchgate.net/publication/301945902_Fluid_Temperature_of_Aero_Hydraulic_Systems/fulltext/573a6fcc08aea45ee83f8e17/Fluid-Temperature-of-Aero-Hydraulic-Systems.pdf
6. Griggs, J. L. (1991). Pat. No. 5188090 USA. Apparatus for heating fluids. No. US 07/682,003; declareted: 08.08.1991, published: 23.02.1993. Available at: https://patents.google.com/patent/US5188090A/en
7. Tleuov, A. (2009). Netraditsionnye istochniki energii. Astana, 248.
8. Baranov, E. I., Yakushko, S. I. (2012). Obosnovanie i raschet gidrodinamicheskogo paradoksa, voznikayuschego pri istechenii zhidkosti iz otverstiy perforirovannoy vraschayuscheysya obolochki. Visnyk Sumskoho derzhavnoho universytetu. Seriya Tekhnichni nauky, 4, 7–13.
9. Mokhammad, A. A., Khorosh, I. A., Titov, M. A., Kulikova, N. P. (2015). The calculation of the throttle device heating working fluid of hydraulic drive having a temperature dependence. Vestnik KrasGAU, 12, 38–44. Available at: https://elibrary.ru/item.asp?id=25054268
10. Pasyuk, A. S. (2018). Gidrodinamicheskiy nagrevatel' zhidkosti v pischevoy promyshlennosti. Vestnik nauki i obrazovaniya, 1 (2 (38)), 30–33. Available at: https://elibrary.ru/item.asp?id=32430829
11. Aghakashi, V., Saidi, M. H. (2018). Turbulent decaying swirling flow in a pipe. Heat Transfer Research, 49 (16), 1559–1585. doi: https://doi.org/10.1615/heattransres.2018021519
12. Oshanov, Y., Ovcharov, M., Nussupbekov, B., Stoev, M. (2020). Influence of the main properties of the liquid on the temperature indicators of the inertial heat generator. Bulgarian Chemical Communications, 52, 188–191. Available at: http://www.bcc.bas.bg/BCC_Volumes/Volume_52_Special_A_2020/BCC-52-A.pdf
13. Oshanov, Y. Z., Ovcharov, M. S., Nusupbekov, B. R. (2022). Influence of inertial forces on the flow rate velocity of fluid outflow through the throttle bores of the rotor. Heat Transfer Research, 53 (14), 1–8. doi: https://doi.org/10.1615/heattransres.2022038753
14. Nussupbekov, B., Khassenov, A., Nussupbekov, U., Akhmadiyev, B., Karabekova, D., Kutum, B., Tanasheva, N. (2022). Development of technology for obtaining coal-water fuel. Eastern-European Journal of Enterprise Technologies, 3 (8 (117)), 39–46. doi: https://doi.org/10.15587/1729-4061.2022.259734