UDC 532
DOI: 10.15587/1729-4061.2023.292522

IDENTIFYING REGULARITIES OF FLUID THROTTLING OF AN INERTIAL HYDRODYNAMIC INSTALLATION

Bekbolat Nussupbekov
Professor, Candidate of Technical Sciences*
Yerlan Oshanov
Senior Lecturer, Master of Transport**
Michael Ovcharov
Full Professor, Candidate of Technical Sciences**
Bayan Kutum
Master of Physical Sciences
Alternative Energy Research Center***
Moldir Duisenbayeva
Corresponding author
Doctoral Student*
E-mail: m_o_l_d_i_r_89@mail.ru
Aitkul Kongyrbayeva
Doctoral Student*
*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 article presents the results of experimental research conducted on a specially designed setup for pressurizing various types of fluids through throttle orifices. To determine the optimal operating mode of the thermal system, throttle nozzles of different diameters, specifically 1.5 mm, 2 mm, and 3 mm, were utilized.

One of the primary advantages of vortex heaters is their high heat exchange efficiency. This is attributed to the vortical motions and turbulence generated within the device, which promote more vigorous fluid mixing, thus enhancing heat transfer efficiency.

However, vortex heaters do have certain drawbacks. Vortical components may experience wear and require regular maintenance and replacement.

Subsequently, during the course of experimental work, an alternative inertia-based hydrodynamic system for heating heat carriers was developed and installed in a laboratory experimental facility. The research focus was on technical water. The results indicated that the static pre-pressure generated by the supply of water from the water main into the system decreases as the rotor's angular velocity increases. Experimental investigations demonstrated that rotor rotation leads to a redistribution of flow characteristics in throttle orifices for both static and dynamic inertial fluid discharge. Given that any static column of liquid results in level flow through throttle orifices, their flow static parameters were established.

Furthermore, the research revealed that with the increase in rotor angular velocity, the fluid pressure at the throttle orifices rises, while the share of fluid discharge from the initial static pressure decreases in the overall fluid flow

Keywords: process water, pressure, angular velocity, throttle nozzles, fluid flow, hydrodynamic heater

Received date 23.09.2023
Accepted date 30.11.2023
Published date 21.12.2023

***How to Cite:** 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. doi: https://doi.org/10.15587/1729-4061.2023.292522*

1. Introduction

This article examines the optimal technical parameters of an inertial hydrodynamic installation for liquid heating. The study of liquid heating systems with effective thermophysical characteristics is relevant in the field of economical energy consumption. Thus, when the liquid is throttled, its temperature increases. This principle can be used to heat various liquids in various systems, such as heating systems, industrial processes or laboratory studies.

To date, studies are being conducted on heating systems for liquids, more often water, when pumping liquids from a higher pressure to a lower one without performing work. The so-called throttle liquid heating or hydrodynamic liquid heater. This method does not require the use of any type of fuel and additional devices such as a pump, which has found application in heat pumps, refrigeration units, cooling systems, etc. In this regard, the study of ways to obtain heat and improve design problems is relevant.

Traditional types of thermal energy production, in addition to meeting the needs of humanity, cause enormous harm to the environment. To solve environmental problems related to energy production, renewable energy is widely sought to adapt to local conditions. Along with the use of alternative energy sources for space heating, thermal installations based on previously known provisions of heat engineering and hydraulics are being developed. In this regard, it can be noted that the possibility of ensuring continuous rotational movement of the elements of mechanisms, with small friction losses, allows to use this advantage in almost all industries (car transmission, hydraulic motors, pumps, etc.).

Therefore, the search for new efficient devices using the principle of throttling the liquid to heat it is an urgent technological task today. Since reserves of natural hydrocarbon resources are decreasing all over the world. Therefore, the task of every scientist, researcher, innovator is to search for alternative energy sources.

2. Literature review and problem statement

The paper [1] presents air conditioning in refrigeration and in systems, also liquid throttling is used to control the flow of working fluid (refrigerant) and control its pressure. The paper provides an in-depth analysis of the effect of mixed refrigerants on the thermodynamic characteristics of the refrigeration cycle with a throttling system. The use of the obtained liquids in production or in everyday life is not shown.

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. In this paper does not show the application of this method or mathematical modeling.

The paper [3] presents experimental results of the practical possibility of using the throttling effect in hydraulic systems for the implementation of commercial industrial domestic heating systems. The work is relevant in countries where heating systems operate using oil burners, the development of environmentally friendly systems for heat generation is especially relevant. The study with other liquids is not shown, there are no comparative analyses.

Many studies are devoted directly to the physical phenomena occurring during throttling. Work [4] is devoted to the experimental analysis of the flow through the throttle valve, which was affected by cavitation, namely air bubbles formed in the liquid. Where the amount of dissolved gas in the liquid is directly proportional to the partial pressure of the gas in the liquid, which is determined by Henry's law. Thus, the solubility of a gas in liquids depends on temperature and pressure. There are no descriptions of the sizes of throttle valves in the work, and comparative analyses with other studies are not given.

In [5], the evaluation of hydraulic systems in terms of the energy and dynamic properties of the components, which relate to important criteria for their operation, is investigated. This paper describes the advantages and disadvantages of the systems. But the dynamic properties of the studied energy-saving measurement system are not considered.

In the article [6], the methods of heating the hydraulic drive working fluid when operating at low temperatures are considered. These chokes are usually used and located along pressure lines as the simplest and most effective way to heat the working fluid to operating temperature and in hydraulic drives of self-propelled machines for the northern regions. But the mathematical data is not shown.

The interaction [7] of fine particles with an expanding gas flow under fluidization conditions is considered. The objects of study are finely dispersed materials, their single particles, gas flow in a fluidized layer. The study used the laws of dynamics and hydrodynamics, the classical laws of mechanics, as well as mathematical methods for the analytical solution of equations. During the study, an analytical equation was obtained to find the height of the particle ascent depending on the gas flow rate for given geometric parameters of the gas flow. The obtained formulas can be used in the process of studying the process of convective drying of finely dispersed materials for various design parameters of the dryer. In practice, as a rule, there are various empirical formulas that describe such interactions of particles for specific parameters, which make it difficult to generalize them. In this work, the correctness of the assumed conditions necessary for the analytical solution of the differential equation of particle motion is proved. The application of these proven formulas is not fully shown.

In this paper [8], experimental studies were carried out to establish characteristic shrinkage zones during drilling of polymer composite materials, as well as their values. The methods used are the analysis of the quality indicators of PCM (polymeric composite materials) holes and the method of expert assessments. The calculation of the required cutting forces and the roughness height when drilling holes in PCM is proposed, taking into account chip settling under the action of a wedge. These results and calculation methods can be easily transferred in the manufacture of throttles for a heat generating plant. The article does not consider the disadvantages of the material used for milling cutters.

In this article [9], nonstationary mixed convection heat transfer in a square housing with differential heating is investigated. It was found that fast rotation and high frequency combined with a low coefficient of thermal conductivity are most effective for increasing the overall heat transfer rate. However, in this case, the drive power supplied to generate thermal energy is determined by the maximum fluid pressure and pump flow rate.

In the course of the study [10–12], the authors obtained an analytical equation for determining the velocity of a particle during its rise and fall in a gas jet. In this paper, the correctness of the accepted conditions necessary for the analytical solution of the differential equation of particle motion is proved. As a result, formulas were obtained to determine the velocity of a particle in a gas jet and the height of its rise depending on the gas flow. However, there is no information in the article about the use of these formulas for various liquids, although a fluidized bed is considered.

Currently, hydrodynamic heaters have not yet become widespread. Let's believe that this is due to insufficient knowledge about this type of equipment and insufficient amount of information. The presented data allow to take a fresh look at the technological role of hydrodynamic heaters, now it is not only an effective way to heat a liquid, but also a fairly inexpensive and very expensive energy source. The use of inertial forces of a rotating mass of liquid for its heating allows the use of an electric motor of lower power, which saves the consumed electrical energy. In this sense, the search for constructive solutions for improving methods of heat generation and its economical consumption is promising.

3. The aim and objectives of the study

The aim of this study is to design and test a throttle valve with a diameter from 1.5 mm to 3.0 mm for an inertial hydrodynamic system. This will allow to get a good temperature and pressure dependence.

To achieve this aim, the following objectives were set:

– to determine the preliminary pressure at the throttle outlet at different angular speeds of rotation of the rotor;

– to get the results of measuring static and total pressure in throttle holes with a diameter of 1.5 mm;

– to determine the effects on the flow rate of changing the direction of the jet exit from the throttle holes of the rotor with a diameter of 2.0 mm.

4. Materials and Methods

The object of the study is a hydrodynamic thermal installation, where electrical energy is converted into thermal energy due to changes in velocity and pressure in the flow.

The main hypothesis of the study is that the static pre-pressure created by the supply of liquid from the water supply system decreases with an increase in the angular velocity of rotation of the rotor. When the liquid from the water pipe enters the rotating rotor of the system, it is subjected to the action of centrifugal force, which acts on each of its particles and contributes to the creation of pressure in front of the throttle openings. As it is assumed, the assembled laboratory installation using the centrifugal forces of a rotating mass of liquid and a method of controlled heating of the liquid is an attractive and promising direction for obtaining thermal energy. The technological solution is achieved by the fact that the static preliminary pressure created by supplying liquid from the water supply system decreases with an increase in the angular velocity of the rotor.

When the liquid from the water supply enters the rotating rotor of the system, it is subjected to the action of centrifugal force, which acts on each of its particles and is directed from the center of rotation toward the walls with throttle openings. The higher the angular velocity of the rotor's rotation, the stronger the centrifugal force, and the more liquid is forced out of the throttle openings.

A full-scale experimental setup [13] was used to establish fluid flow rates at various pressures and total areas of throttle orifices and to assess their influence on the heat transfer medium's temperature.

To determine the optimal operating mode of the thermal system, various diameter nozzles were used as throttle orifices. Nozzles are employed in hydraulic systems when a specific flow pattern of the exiting liquid is required. Nozzles have a consistent flow coefficient, making them widely used, and the thermal installation is no exception.

In the thermal installation, cylindrical nozzles that extend outward from the vessel are employed (Fig. 1), as the flow rate of liquid when the nozzle length exceeds the orifice diameter by three times is approximately 30 % higher than that of flow through an orifice in a thin wall (Fig. 2) [14].

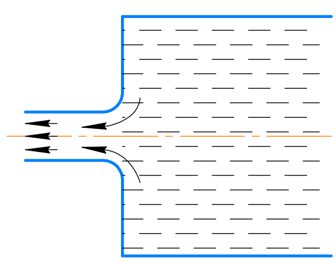

Fig. 1. Liquid flow through throttle orifices: the outflow of liquid from the cylindrical nozzle

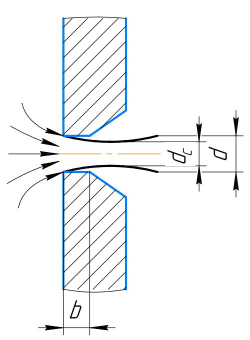

Fig. 2. Liquid flow through throttle orifices: the outflow of liquid through the opening of a thin wall

It is well-known that the pressure drop Δp and fluid flow rate Q through an orifice in a thin wall are related by the equation:

$$Q = \mu \cdot S\sqrt{\frac{2\Delta pg}{\gamma}}, \tag{1}$$

where S – the cross-sectional area of the orifice, μ – the discharge coefficient.

The discharge coefficient is equal to the product of the cross-sectional area of the orifice and the square root of the pressure drop $\mu=\varphi\varepsilon$, where φ – coefficient of velocity, ε – coefficient of the compression of the jet as it exits the orifice.

The coefficient of velocity φ is equal to the ratio. $\varphi = \frac{V}{V_m}$, where $V_m = \sqrt{2gH}$ the coefficient of velocity is equal to the ratio of the actual velocity of fluid discharge to the theoretical velocity of an ideal fluid under the same pressure head H, V – the coefficient of velocity represents the actual velocity of real fluid, taking into account the deceleration of the fluid layers at the orifice's edge.

The coefficient of compression ε is determined by the ratio $\varepsilon = \frac{S_c}{S}$, where S – compression coefficient, $S_c = \pi d_c^2/4$ cross-sectional area of the jet at its compressed location.

The compression of the jet is caused by the fact that liquid particles move along curved paths towards the orifice from all directions, leading to the jet detaching from the wall at the inlet edge and compressing at a distance of approximately 0.5 d from it.

For approximate calculations, when low-viscosity liquids flow out of a round hole, the compression ratio of the jet is assumed to be equal to $\varepsilon=0.64$.

The discharge coefficient μ for specific types of orifices is determined after conducting experimental research using the following expression:

$$\mu = \frac{Q}{Q_m}, \tag{2}$$

where Q – the measured fluid flow rate through the orifice, Q_m – theoretical flow rate.

The theoretical flow rate of liquid through throttle orifices is calculated using the expression:

$$Q_m = S\sqrt{\frac{2Pg}{\gamma}}, \tag{3}$$

where S – throttle opening area.

5. Results of the study on the parameters of throttles in the inertial hydrodynamic installation

5. 1. Results determination of the preliminary pressure at the throttle outlet at different angular speeds of rotation of the rotor

The research has shown that the static initial pressure, created by supplying liquid from the water supply system into the installation, decreases as the angular velocity of the rotor increases. The results are presented in Fig. 3.

The results of measuring the flow rate of the installation with and without the additional tank through a throttle with a 3 mm orifice diameter at different initial water supply pressures are shown in Fig. 4–7.

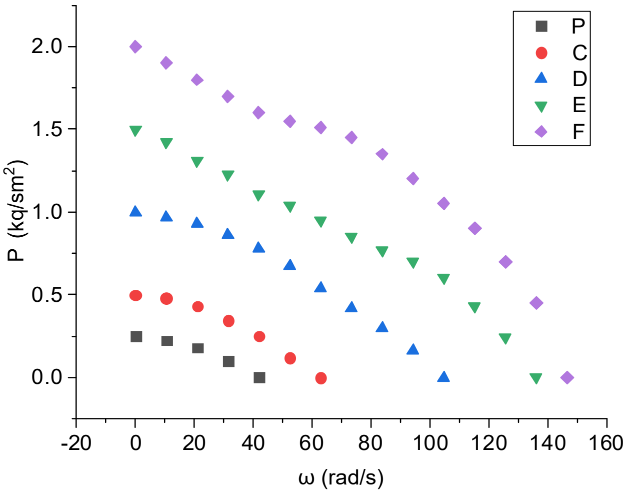

Fig. 3. Pressure drop curves with increasing rotor angular velocity

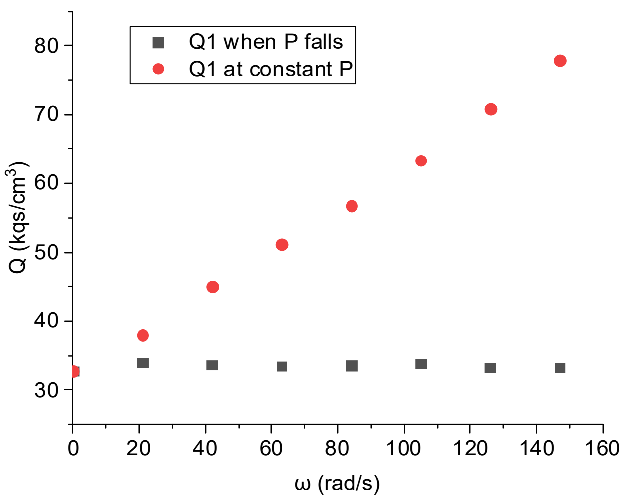

Fig. 4. Flow curves of the installation fluid with a pre-pressure of 0.25 kgf/cm^2 through throttle holes with a diameter of 3 mm

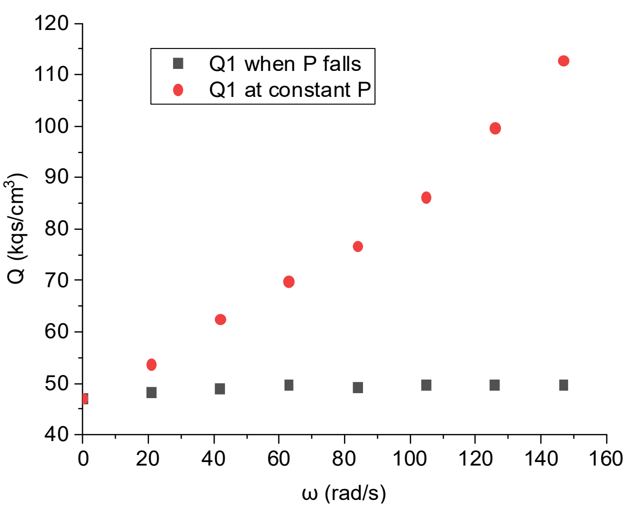

Fig. 5. Flow curves of the installation fluid with a pre-pressure of 0.5 kgf/cm^2 through throttle holes with a diameter of 3 mm

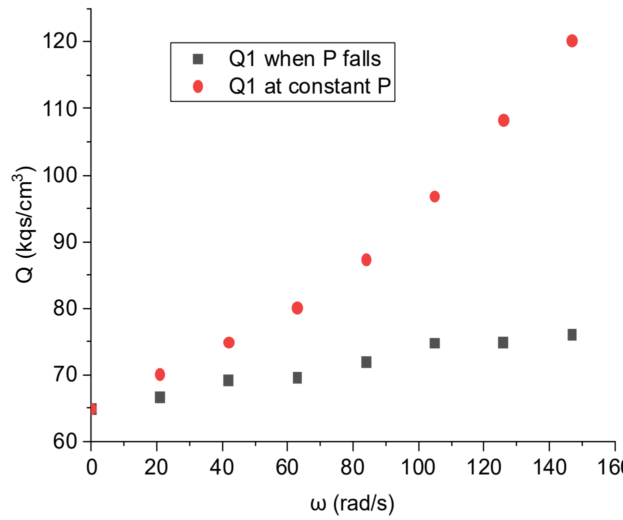

Fig. 6. Flow curves of the installation fluid with a pre-pressure of 1.0 kgf/cm^2 through throttle holes with a diameter of 3 mm

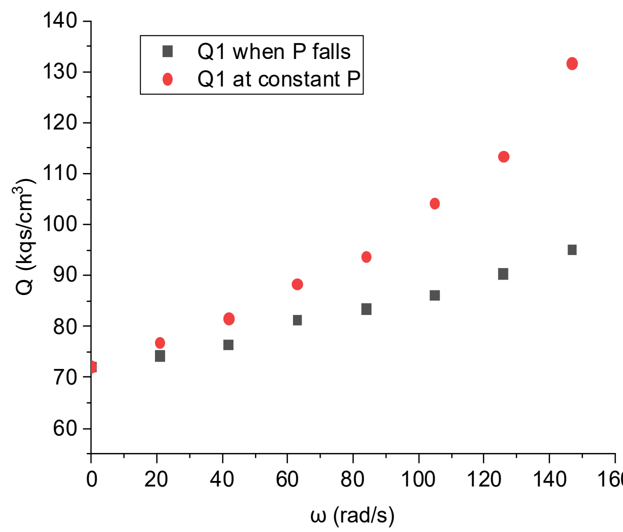

Fig. 7. Flow curves of the installation fluid with a preliminary pressure of 1.5 kgf/cm^2 through throttle holes with a diameter of 3 mm

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.

5. 2. Results of static and total pressure of throttle holes with a diameter of 1.5 mm **of the throttle at different angular speeds of rotation of the rotor**

In further experimental investigations, the case of creating the same total pressure at the throttle orifices was considered by adding static and inertial pressure. Table 1 provides data on the liquid flow rate through a throttle orifice with a diameter of 1.5 mm.

With an increase in the angular speed of the rotor, the liquid pressure at the throttle orifices increases, and the proportion of liquid flow from the initial static pressure decreases in the total liquid flow.

Table 1

Flow rate from static and total pressure at the throttle openings

d	R_{inertz}, kg/cm^2	ω, rad/s	R_{magist}, kg/cm^2	Q without rotor rotation, cm^3/s	Q with rotor rotation, cm^3/s
1.5	1.0	56.029	0.5	48.52	63.416
	0.75	48.522	0.75	67.294	82.214
	0.5	39.618	1.0	81.833	98.118

5. 3. Results determination of the effect on fluid flow of changing the direction of jet departure from the throttle holes of the rotor with a diameter of 2.0 mm

To establish the influence of the direction of the jet exit from the throttle orifices on the liquid flow rate, an experimental stand was used [15]. The results are provided in Table 2.

Table 2

The dependence of the fluid flow through the throttle holes with a diameter of 2 mm on the direction of the jet departure and the angular velocity of the rotor

Angular velocity of the rotor ω, rad/s	Direction of the throttle nozzle		
	Straight	Against the rotation	In the direction of rotation
	Flow rate Q_s, cm^3/s	Flow rate Q_a, cm^3/s	Flow rate Q_i, cm^3/s
0	31.875	30.253	30.248
48.52	43.066	42.918	43.649

To more accurately determine the influence of coriolis forces on the liquid flow through the throttle orifices of a rotating rotor, it is necessary to conduct specialized experiments that take into account all possible factors, including orifice geometry, vessel rotation speed, liquid viscosity, and other parameters.

6. Discussion of the results obtained for determining the optimal technical parameters of the inertia-based liquid heating system

The rotating rotor with throttle openings acts on the water supply pipeline like a pump with a higher flow rate than the water supply. This fact is consistent with Fig. 3, which illustrates that as the angular velocity of the rotor increases, the proportion of dynamic inertial liquid discharge begins to dominate over the initial static flow through the throttle openings.

From this, it follows that supplying liquid from the water supply cannot ensure the proper functioning of the installation. Therefore, for the normal operation of the installation, it is necessary to constantly increase the flow rate of water from the water supply, which complicates and distorts the research results. Hence, for subsequent measurements in the setup, an additional storage tank was provided, which can supply an additional volume of liquid when needed.

In Fig. 4, 5, it can be observed that initially, in the installation without an accumulator, the liquid flow rate increases gradually at angular speeds of 20–40 rad/s, respectively, and then pulsations occur. When the installation has an accumulator, it is possible to see a stable increase in the liquid flow rate. The curve changes proportionally to the increase in the angular speed of the rotor.

In Fig. 6, 7, pulsations in the flow rate curves can also be observed in the absence of an accumulator, although they are minor, but a stable increase is maintained over the entire range of rotor angular speeds. Pulsations begin at higher angular speeds of the rotor. The flow rate curves with the accumulator have a parabolic character, which is clearly visible in Fig. 7. This is due to the fact that, according to equation (6), the pressure at the throttle orifices is in a quadratic dependence on the angular speed of the rotor [15].

As can be seen from Table 2, when the throttle nozzle is oriented along the rotor pipe without rotating it, the fluid flow is higher. In this case, the fluid does not change direction inside the tube, which means that the local resistances are lower than when the flow direction changes.

At an angular velocity of the rotor of 48.52 radians per second, the liquid flow rate is lower when the throttle is positioned in the direction of rotation than when it is aligned in the opposite direction. This can be explained by the fact that during the rotor's rotation, Coriolis forces of inertia deflect the liquid within the throttle, resulting in a narrowing of the jet and reduced flow.

Experiments have shown that Coriolis forces depend on the direction of liquid movement within the rotating rotor. If the liquid moves along the rotor's rotational direction, it experiences fewer Coriolis forces than if it were moving against the rotor's rotation. Thus, for the thermal installation, schemes can be devised to reduce the impact of Coriolis forces on the liquid flow through the throttle nozzles.

In experimental investigations, the influence of Coriolis forces on the liquid flow through throttle orifices was considered by reducing the flow coefficient.

Experimental research has shown that when the rotor is in motion, there is a redistribution of flow characteristics for throttle openings concerning static and dynamic inertial liquid flow. Since any static column of liquid causes level flow through the throttle openings, their static flow characteristics were determined. With a stationary rotor, each throttle orifice has a constant flow rate, which corresponds to a diameter of 1.5 mm – $5.714*10^6$ m^3, a diameter of 2 mm – $10.02*10^6$ m^3, and a diameter of 3 mm – $21.28*10^6$ m^3 per unit time. This static flow rate contributes to the overall inertial liquid flow from the throttle opening.

Inertial liquid flow is influenced by both centrifugal force and tangential forces resulting from the interaction of the liquid with the drum walls. The speed of liquid flow depends on the radius, the number of throttle openings, and the angular velocity of the rotor's rotation. With an increase in the rotor's angular velocity, the centrifugal force grows, leading to an increase in the speed of liquid flow through the throttle openings. However, when the water supply's capacity is limited, and the system's flow rate is high, flow pulsation occurs due to the presence of air entering the water supply and connection points.

The study in [16] presents the percentage of static and inertial liquid flow for various angular velocities of the rotor in the form of a table. The work shows that the preliminary static flow in the supply main significantly affects the inertial flow at low rotor speeds (up to ω=21 rad/s). In this case, the inertial component does not exceed 74.4 %. However, as the angular velocity of the rotor increases, its influence decreases and approaches zero. This is because, with the increased angular velocity of the rotor, the liquid pressure at the throttle openings significantly exceeds the static pressure in the supply main. Therefore, at angular velocities greater than 84 rad/s, with a maximum error of 2.4 %, the flow rate can be considered negligible.

Until now, obtaining heat using hydrodynamic heaters using throttling was not perceived by scientists, they considered it insignificant. However, experience has shown that in order to control the location of a space probe or ships, it is necessary to apply a certain pressure to rotate the object. But at the same time, the temperature of the liquid always increased when passing through the throttle opening. In this regard, this process can be considered not only for spacecraft, but also for ground services.

7. Conclusions

1. The research showed that the static pre-pressure created by introducing water from the pipeline into the system decreases with an increase in the rotor's angular velocity. Curves of liquid flow rates were also demonstrated for setups with pipeline pre-pressures of 0.25 kgf/cm^2, 0.5 kgf/cm^2, 1.0 kgf/cm^2 and 1.5 kgf/cm^2 through throttle holes with a diameter of 3 mm. The results of the study revealed that for setups with pipeline pre-pressures of 0.25 kgf/cm^2 and 0.5 kgf/cm^2, there is an increase in liquid flow rates at angular velocities of 20–40 rad/s, and a stable growth of liquid flow rates beyond that. However, for setups with pipeline pre-pressures of 1.0 kgf/cm^2 and 1.5 kgf/cm^2, the vibration of the accumulating tank begins at higher rotor angular velocities of 150–160 rad/s.

2. During the research, static and cumulative pressure results were obtained for throttle holes with a diameter of 1.5 mm. Based on the study, it can be concluded that when the rotor is rotating, the liquid flow rate is 17 % higher than when the rotor is stationary. It was also found that with an increase in the rotor's angular velocity, the pressure of the liquid at the throttle holes increases, and the proportion of liquid flow from the static pre-pressure decreases in the cumulative liquid flow, down to 35 kg/cm^2.

3. Dependencies of liquid flow rates through throttle holes with a diameter of 2 mm on the jet's ejection direction and rotor's angular velocity were obtained. Coriolis forces depend on the direction of liquid movement inside the rotating rotor. At an angular velocity of 48.52 rad/s, the liquid flow rate is 1 % lower when the throttle is directed straight compared to when it is oriented in the direction of rotation.

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. Ruonan, W., Bin, L., Haodong, L. (2021). Experimental results and analysis of throttling refrigeration with ternary mixed refrigerant. E3S Web of Conferences, 236, 01008. doi: https://doi.org/10.1051/e3sconf/202123601008
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. doi: https://doi.org/10.1016/j.icheatmasstransfer.2023.107040
3. Alia, M. A. K. (2010). Hydraulic Domestic Heating by Throttling. Engineering, 02 (06), 461–465. doi: https://doi.org/10.4236/eng.2010.26060
4. Polášek, T., Hružík, L., Bureček, A., Ledvoň, M. (2022). Experimental Analysis of Flow Through Throttle Valve During Gaseous Cavitation. MATEC Web of Conferences, 369, 02008. doi: https://doi.org/10.1051/matecconf/202236902008
5. Vasina, M., Hruzik, L., Burecek, A. (2018). Energy and Dynamic Properties of Hydraulic Systems. Tehnicki Vjesnik - Technical Gazette, 25, 382–390. doi: https://doi.org/10.17559/tv-20131209081056
6. 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. Vestn. Kras GAU, 12, 38–44.
7. Shumilov, I. (2016). Fluid Temperature of Aero Hydraulic Systems. Machines and Plants: Design and Exploiting, 16 (02). doi: https://doi.org/10.7463/aplts.0216.0837432
8. Marinin, M. G., Mosalev, S. M., Naumov, V. I., Sysa, V. P. (2007). Pat. No. RU2357161C1. Throttle Type Heat Generator. declareted: 06.11.2007; published: 27.05.2009.
9. Saleh, H., Hashim, I. (2013). Unsteady heat transfer in an enclosure with a time-periodic rotating cylinder. Heat Transfer Research, 44 (2), 145–161. doi: https://doi.org/10.1615/heattransres.2012005450

10. Alpeissov, Y., Iskakov, R., Issenov, S., Ukenova, A. (2022). Obtaining a formula describing the interaction of fine particles with an expanding gas flow in a fluid layer. Eastern-European Journal of Enterprise Technologies, 2 (1 (116)), 87–97. doi: https://doi.org/10.15587/1729-4061.2022.255258
11. Maiorova, K., Vorobiov, I., Andrieiev, O., Lupkin, B., Sikulskiy, V. (2022). Forming the geometric accuracy and roughness of holes when drilling aircraft structures made from polymeric composite materials. Eastern-European Journal of Enterprise Technologies, 2 (1 (116)), 71–80. doi: https://doi.org/10.15587/1729-4061.2022.254555
12. 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
13. Oshanov, Y., Ovcharov, M., Nussupbekov, B., Stoev, M. (2020). The 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
14. Bashta, T. M. (1972). Engineering Hydraulics. Moscow: Mashinostroenie.
15. 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
16. 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