DOI 10.31489/2023PH4/82-90

UDC 662.99

B.R. Nussupbekov[1], M.S. Ovcharov[1], E.Z. Oshanov[1], U.B. Yesbergenov[2*], M.S. Duisenbayeva[1], A.A. Tishbekov[1], M.K. Amanzholova[1]

[1]*Karaganda Buketov University, Kazakhstan;*
[2]*"BILGE-ORAZ" LLP, Kazakhstan*
[*]*Corresponding authors e-mail*: *m_o_l_d_i_r_89@mail.ru*

Determination of the effects of the diameters of the throttle holes on the fluid flow of an inertial hydrodynamic installation

In the article, in order to solve environmental problems associated with heating buildings and structures, the methods of converting electrical energy into thermal energy and the processes occurring at the same time are considered. Well-known thermal installations, such as vortex, cavitation, cavitation-vortex, rotary, do not fully meet the requirements of consumers. In these conditions, the search for effective solutions is an urgent task. Such solutions include a method of obtaining thermal energy by creating pressure at the throttle openings by inertia forces of a rotating mass of liquid. To determine the flow of liquid through the throttle holes, an experimental stand was made. With the help of the stand, we determined the flow rate of liquid through throttle holes with a diameter of 1.5, 2, 3 mm. During the experiment, it was found that the larger the diameter of the throttle opening, the higher the fluid flow. However, it is impossible to excessively increase the diameter of the throttle opening, as this will complicate the creation of pressure at the throttle openings. It is found that with an increase in the angular velocity of the rotor, the fluid pressure at the throttle openings increases, and the proportion of fluid flow from the preliminary static pressure in the total flow decreases. It is certain that the preliminary static pressure in the supply line has a significant effect on the flow rate only at low rotor speeds (ω up to = 76 rad / s), and with increasing angular velocity, its influence decreases and the coefficient k tends to 1.

Keywords: vortex effect, cavitation, swirling flow, kinetic energy, choke hole, liquid.

Introduction

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

Vortex liquid heaters are a type of heat exchange devices that use the Zh. Ranka effect to heat or cool liquids. The wound. The vortex effect, or the Wound effect, manifests itself in a swirling flow of a viscous compressible fluid and is realized in a very simple device called a vortex tube [2]. When a liquid passes through a vortex tube, vortices and turbulent flows are created. This contributes to more intensive mixing of the liquid and more efficient heat exchange between the heated liquid and the environment [3].

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. Vortex 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.

Devices using vortex technology to generate heat are known. When exposed to water by an external force field of a mechanical type, for example, created by an electric pump, it is possible to obtain thermal energy due to:

1) dissipation of the energy of vortex motion due to the irreversible process of dissipation of part of the mechanical energy of motion due to viscous friction and the transfer of this energy into heat;

2) reversible phase transitions of water from the free state to an ordered, close to the liquid crystal state, in which the specific heat capacity of water in this phase is two times less than in the free state. Since during mechanical treatment of water in a reactor of a fixed volume, accompanied by cavitation, part of the water passes into a liquid crystal state, this exothermic phase transition is accompanied by the release of excess heat [4].

In the article [5], the methods of heating the hydraulic drive working fluid when operating at low temperatures are considered. The method of increasing the durability of a hydraulic drive operating at low temperatures is preheating the working fluid by throttling. The authors of the work proposed a design of a heating throttle with automatic regulation of the conditional passage remotely depending on the temperature of the working fluid in the hydraulic system tank and presented a method for calculating the main parameters of the proposed throttle. However, the authors of the works do not show the results of the calculation.

The paper [6] presents the results of a hydrodynamic liquid heater. The difference between this installation and other heaters is that it allows you to significantly simplify the design and increase the efficiency of the heating process. The main principle of its operation is the direct conversion of mechanical energy into thermal energy. As a result, the efficiency of the heater is 80%. However, the author of the works did not show the experimental data of the proposed installation.

It is shown in [7] that on modern supersonic aircraft, due to aerodynamic heating of the skin, the environment surrounding the hydraulic system has a temperature that is much higher than the permissible for the liquids used. Therefore, when creating hydraulic systems of such aircraft, it is impossible to use a convective heat exchange cycle to maintain a given liquid temperature. In this regard, the authors of the works considered stationary and non-stationary modes of operation of the hydraulic system, their calculation, determination of the temperature of the working fluid, methods of maintaining its set temperature. The obtained data allows us to estimate the surface temperature.

The article [8] presents the results of laboratory studies of hydrodynamic liquid heaters. The calculated data is shown. However, the proposed shape and diameter of the throttle valves do not allow to increase the required temperature. This requires an increase in the applied pressure. The maximum heating temperature of existing heaters is 56 °C.

The vortex technologies used for the autonomous heating system are based on the Rank−Hilsch effect. In most works, the mechanism of separation of the swirling flow into a cooled core and hot peripheral layers, as well as the thermogasodynamic parameters of devices implementing the vortex effect, are investigated. The presence of screw-shaped vortex structures in swirling flows and the significant influence of the precession of the vortex core on the energy separation process have been experimentally established. According to the hypothesis of vortex interaction, the energy separation process is the result of the interaction of two vortices moving along the axis towards each other, where the peripheral one rotates according to the law of a potential vortex, and the axial one according to the law of a quasi-solid body.

It is important to note that energy separation in the vortex interaction hypothesis is a complex and multifaceted phenomenon that requires detailed study and analysis using numerical models, experiments and theoretical approaches.

A physical phenomenon like cavitation occurs when the pressure in a certain area of a liquid decreases to a level at which the liquid begins to evaporate, forming bubbles. Then, when the pressure around the bubbles rises again, the kinetic energy of the colliding particles at the moment of closing of the bubbles causes local hydraulic micro-shocks, accompanied by high pressure and temperature drops in the centers of the bubbles (according to calculations, temperatures can reach values of 1000-1500 °. With and above and the local pressure can reach 150-200 MPa.

The work [9] is devoted to the study of the parameters of the installation for heating the coolant using liquid injection through throttle openings. A scheme of a full-size experimental stand has been developed and the principles of its 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. However, the transparent model is subject to deformations with strong rotation, and it is also difficult to evaluate the data.

In the case when the closing of bubbles occurs near the walls of the hydraulic system, continuous micro-impacts can cause mechanical erosion and local damage to surfaces. Due to high temperatures and the presence of oxygen in the air, active oxidation of surfaces occurs. Oxidative processes are further aggravated by the fact that dissolved air in a liquid contains almost one and a half times more oxygen than atmospheric air.

Experimental

To determine the flow of liquid through the throttle holes, an experimental stand was made [10].

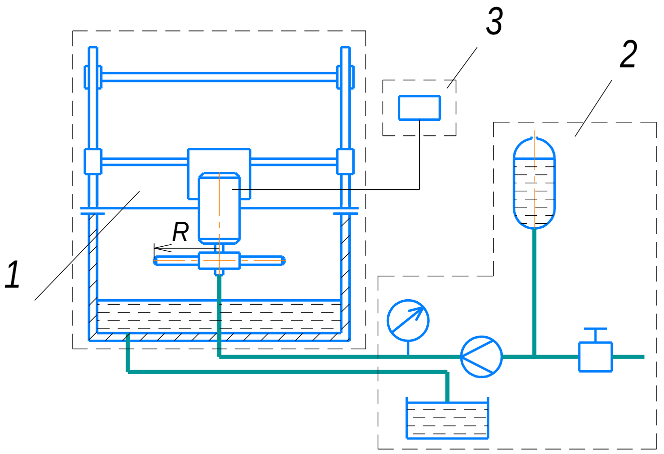

Figure 1. Scheme of the experimental stand 1-main unit, 2-hydraulic unit, 3-power supply unit

The stand allows for the study of liquid forcing through throttle holes with a diameter of 1.5, 2, 3 mm, located at a distance of 0.235 m from the center of rotation of the rotor, with a static height of the liquid column equal to 1.0 m (9796.462 Pa).

The opening of the valve 13 ensures the beginning of water flow through the supply line 9 to the throttle openings, as soon as the column of liquid in the accumulator 12 reaches a predetermined level, readings are taken from the flow meter 11. The liquid flow rate (Q_n) is fixed for the angular velocities of the rotor varying in the range 0...314 rad/s.

When the electric motor 4 is switched on, the mass of liquid inside the rotor is rotated. Inertial forces arise in the rotating mass of the liquid, which create pressure in the radial direction in front of the throttle openings.

It is known that when the rotor rotates, the liquid in the drum cavity tends to the periphery, thereby forming a ring of liquid, the cross section of which directly affects the pressure at the throttle openings. Since the distance from the center of rotation to the throttle holes (R) remains constant, equal to 0.235 m, the pressure value is affected only by the change in angular velocity.

Results and Discussion

The flow of liquid through the throttle holes depends on several factors, such as the diameter of the hole, the pressure of the liquid in front of the hole, the viscosity of the liquid, the length and shape of the channel in front of the hole, etc.

For an ideal frictionless fluid, the flow rate of the fluid through the throttle orifice can be calculated using the Torriceli-Chazele equation. However, in practice, due to friction and other losses, the fluid flow rate may be less than that calculated using the Torriceli-Chazele equation. Therefore, for a more accurate calculation of fluid flow through the throttle opening, it is necessary to take into account factors related to specific operating conditions and the design of the system.

The theoretical flow of liquid through the throttle openings is calculated by the expression

$$Q_m = S\sqrt{\frac{2Pg}{\gamma}}, \tag{1}$$

where S - the area of the throttle opening.

With a constant radius of the rotor drum, having previously assumed the internal cross-section diameters of the liquid ring equal to 0.4, 0.3, and 0.2 m, it is possible to determine the calculated values of the liquid pressure at the throttle openings [10].

According to the expression (1), we determine the theoretical flow rate of the liquid for the diameters of the throttle orifice 1.5, 2, 3 mm, using the calculated pressures. The results of the theoretical flow rate are included in Tables 1-3.

Table 1

Theoretical fluid flow through a 1.5 mm diameter choke hole, at different positions of the fluid ring

Angular velocity of the rotor, ω (rad/s)	Theoretical fluid flow rate (Q_{m1}) through the throttle opening, at different radii of the inner ring of fluid in the rotor drum (m^3/s)			
	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	6,968E-05	9,29E-05	0,000106	0,000116
76	0,00012609	0,000168	0,000193	0,00021
136	0,00022563	0,000301	0,000345	0,000376
215	0,00035669	0,000476	0,000545	0,000594
314	0,00052094	0,000695	0,000796	0,000868

Table 2

Theoretical fluid flow through a 2 mm diameter choke hole, at different positions of the fluid ring

Angular velocity of the rotor, ω (rad/s)	Theoretical fluid flow rate (Q_{m2}) through the throttle opening, at different radii of the inner ring of fluid in the rotor drum (m^3/s)			
	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	0,00012387	0,000165	0,000189	0,000206
76	0,00022415	0,000299	0,000342	0,000374
136	0,00040111	0,000535	0,000613	0,000669
215	0,0006341	0,000845	0,000969	0,001057
314	0,00092609	0,001235	0,001415	0,001543

Table 3

Theoretical fluid flow through a 3 mm diameter choke hole, at different positions of the fluid ring

Angular velocity of the rotor, ω (rad/s)	Theoretical fluid flow rate (Q_{m3}) through the throttle opening, at different radii of the inner ring of fluid in the rotor drum (m^3/s)			
	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	0,00027871	0,000372	0,000426	0,000465
76	0,00050433	0,000672	0,00077	0,000841
136	0,00090249	0,001203	0,001379	0,001504
215	0,00142673	0,001902	0,002179	0,002378
314	0,0020837	0,002778	0,003183	0,003473

According to Tables 1-3, the larger the diameter of the throttle opening, the higher the theoretical fluid flow. However, it is impossible to indefinitely increase the diameter of the throttle hole, as this will complicate the creation of pressure at the throttle holes.

Considering that the stand [2] provides a preliminary static fluid P_n pressure inside the rotor, expression (2) will take the form

$$Q_{\Sigma m} = S\sqrt{\frac{2(P+P_n)g}{\gamma}}, \tag{2}$$

where P_n - preliminary static pressure of the liquid in the supply line.

According to expression (2), we determine the theoretical flow rate of the liquid for the diameters of the throttle opening 1.5, 2, 3 mm, taking into account the preliminary static pressure of the liquid P_n in the system. The results of the total theoretical consumption are shown in Figures 2-4.

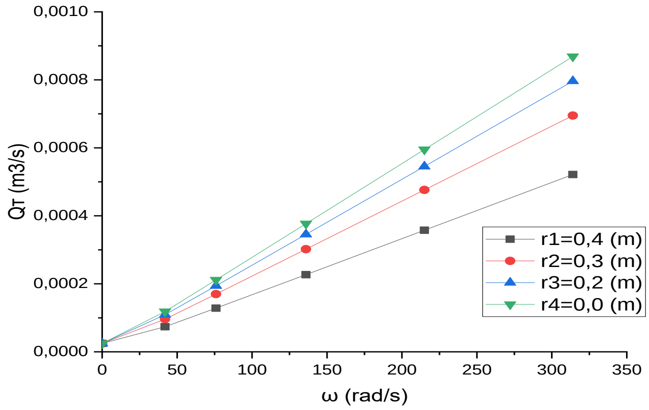

Figure 2. Total theoretical fluid flow through a 1.5 mm diameter choke hole, at different positions of the fluid ring

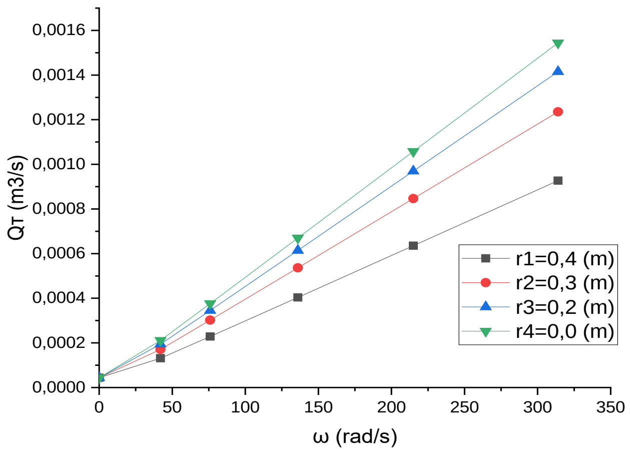

Figure 3. Total theoretical fluid flow through a 2.0 mm diameter choke hole, at different positions of the fluid ring

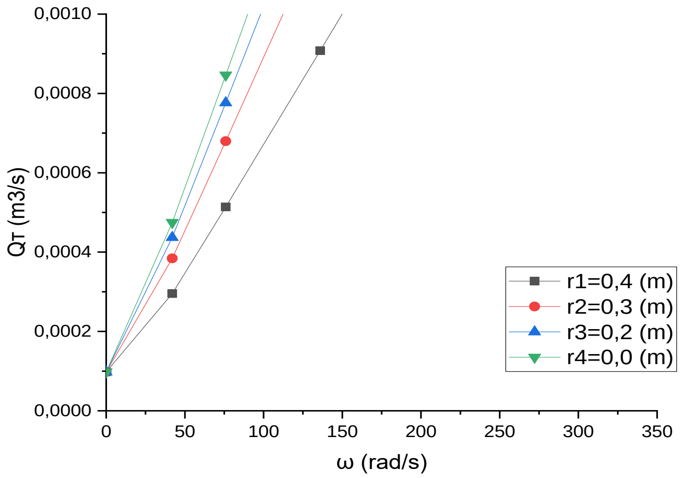

Figure 4. The total theoretical flow of liquid through the throttle hole with a diameter of 3.0 mm, at different positions of the liquid ring

According to formula (1), with an increase in the angular velocity of the rotor, the fluid pressure at the walls of the throttle opening increases, then the proportion of fluid flow from the preliminary static pressure in the total flow decreases. The relationship between expressions (1) and (2) can be represented as

$$Q_m = k \cdot Q_{\Sigma m}, \tag{3}$$

where: k - the coefficient of distribution of fluid flow from static pressure for different angular velocities of the rotor.

From expression (3), the coefficient can be defined as the ratio of the theoretical flow rate to the total theoretical flow rate, and since the flow rates depend on the angular velocity and cross section of the fluid ring in the rotor drum, these dependence graphs are shown in Figure 5.

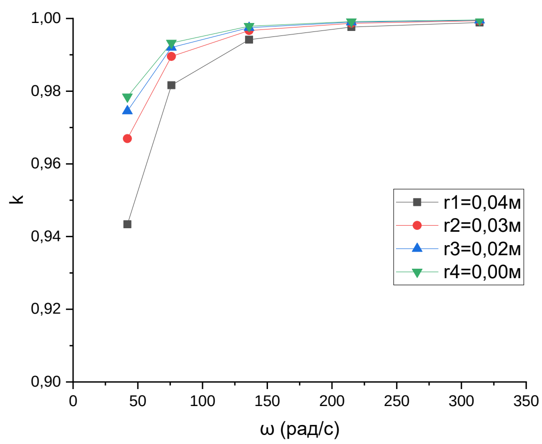

Figure 5. Dependence of the liquid flow distribution coefficient on the static pressure in the total flow rate for different angular velocities of the rotor

Figure 5 shows that the preliminary static pressure in the supply line has a significant effect on the flow rate only at low rotor speeds (up to ω= 76 rad / s), and with increasing angular velocity, its influence decreases and the coefficient k tends to 1. This is due to the fact that with an increase in the angular velocity of the rotor, the fluid pressure at the throttle openings is several times higher than the static pressure in the supply line.

It should also be noted that the value of the coefficient of distribution of fluid flow from static pressure k depends on the angular velocity of the rotor and the inner radius of the fluid ring in the drum, but does not depend on the diameter of the throttle opening.

It follows from the above that the experimental values obtained at the stand are applicable to a thermal installation at certain positions of the liquid ring in the rotor drum.

Since during experimental studies [2] the flow meter 11 shows the total main flow rate of the liquid, the inertial flow rate is determined by the expression

$$Q_i = k \cdot Q. \tag{4}$$

It follows from expression (4) that the inertial flow rate and the flow through the throttle openings of the thermal installation are identical.

Knowing that the inertial radial velocity can be represented as

$$\upsilon_i = \frac{k \cdot Q}{S} = \frac{Q_i}{S}, \tag{5}$$

where S – the area of the throttle opening.

However, in most practical situations, the effect of coriolis forces on the flow of liquid through the throttle openings of a rotating vessel is insignificant and can be ignored. This is due to the fact that the influence of coriolis forces on the flow of liquid depends on many factors, such as the speed of rotation of the vessel, the diameter of the holes and other parameters, which in most cases are not critical for the flow of liquid.

Conclusions

To determine the effect of the diameters of the throttle holes on the fluid flow of the inertial hydrodynamic installation, an experimental stand was made. The results of the experiment showed that the larger the diameter of the throttle opening, the higher the fluid flow.

Using the calculated pressures, the theoretical flow rate of the liquid for the diameters of the throttle opening 1.5, 2, 3 mm was determined, as well as the effect of the preliminary static pressure on the total theoretical flow rate. The calculated data showed that with an increase in the angular velocity of the rotor, the fluid pressure at the walls of the throttle opening increases, and the proportion of fluid flow from the preliminary static pressure in the total flow decreases. The obtained dependence showed that the preliminary static pressure in the supply line has a significant effect on the flow rate only at low rotor speeds (up to ω = 76 rad / s), and with increasing angular velocity, its influence decreases and the coefficient k tends to 1 regardless of the diameter of the throttle holes. This is due to the fact that with an increase in the angular velocity of the rotor, the fluid pressure at the throttle openings is several times higher than the static pressure in the supply line.

Acknowledgements

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

References

1 Калинин А.А. Параметрическая оптимизация электротехнологического комплекса для автономного теплоснабжения / А.А. Калинин. — Караганда, 2018. — 150 с. — [Электронный ресурс]. — Режим доступа: https://www.kstu.kz/wp-content/uploads/dis/Калинин%20А%20А%20Диссертация.pdf

2 Меркулов А.П. Вихревой эффект и его применение в технике / А.П. Меркулов. — М.: Машиностроение, 1969. — 185 с.

3 Гуцол А.Ф. Эффект Ранка / А.Ф. Гуцол // УФН. — 1997. — Т. 167. — Вып. 6. — С. 665–687.

4 Калинин А.А. Архитектура автоматизированной системы научных исследований энергетических характеристик ГДН с трубным ротором / А.А. Калинин // Научные тр. Междунар. симпоз. «Информационные и системные технологии в индустрии, образовании и науке» (21–22 сентября 2006 г.). — Караганда: Изд-во Караганд. гос. техн. ун-та, 2006. — С.110–112.

5 Мохаммад А.А. Расчет дроссельного устройства разогрева рабочей жидкости гидропривода с автоматическим управлением в зависимости от температуры / А.А. Мохаммад, И.А. Хорош, М.А.Титов, Н.П. Куликова // Вестн. КрасГАУ, 2015. — № 12. — С. 38–44. — [Электронный ресурс]. — Режим доступа: https://elibrary.ru/item.asp?id=25054268)6.

6 Пасюк А.С. Гидродинамический нагреватель жидкости в пищевой промышленности / А.С. Пасюк // Вестн. науки и образования. — 2018. — Т. 1, № 2 (38). — С. 30–33. — [Электронный ресурс]. — Режим доступа: https://elibrary.ru/item.asp?id=32430829)

7 Шумилов И.С. Температура рабочей жидкости авиационных гидросистем / И.С. Шумилов // Машины и установки: проектирование, разработка и эксплуатация. — 2016. — № 2. — С. 51–75. — [Электронный ресурс]. — Режим доступа: https://www.researchgate.net/publication/301945902_Fluid_Temperature_of_Aero_Hydraulic_Systems/fulltext/573a6fcc08aea45ee83f8e17/Fluid-Temperature-of-Aero-Hydraulic-Systems.pdf

8 Oshanov Y. Influence of the main properties of the liquid on the temperature indicators of the inertial heat generator [Electronic resource] / Y. Oshanov, M. Ovcharov, B. Nussupbekov, M. Stoev // Bulgarian Chemical Communications. — 2020. — Vol. 52. — P. 188–191. Access mode: http://www.bcc.bas.bg/BCC_Volumes/Volume_52_Special_A_2020/BCC-52-A.pdf.

9 Nussupbekov B. Development and creation of a hydrodynamic liquid heating unit / B. Nussupbekov, Y. Oshanov, M. Ovcharov, E. Mussenova, D. Ospanova, M. Bolatbekova // Eastern-European Journal of Enterprise Technologies. — 2022. — N 5/8 (119). — P. 62–69. doi: https://doi.org/10.15587/1729-4061.2022.264227

10 Oshanov E.Z. Influence of inertial forces on the flow rate velocity of fluid outflow through the throttle bores of the rotor / E.Z. Oshanov, M.S. Ovcharov, B.R. Nusupbekov // Heat Transfer Research. — 2022. — N 53(14). — P. 1–8. https://www.scopus.com/record/display.uri?eid=2-s2.0-85134825340&origin=resultslist&sort=plf-f

Б.Р. Нусупбеков, М.С. Овчаров, Е.З. Ошанов, У.Б. Есбергенов, М.С. Дуйсенбаева, А.А. Тишбеков, М.Қ. Аманжолова

Дроссель саңылау диаметрлерінің инерциялық гидродинамикалық қондырғының сұйықтық ағынына әсерін анықтау

Мақалада ғимараттар мен құрылыстарды жылытуға байланысты электр энергиясын жылу энергиясына айналдырудың экологиялық мәселелерін шешуге бағытталған әдістер мен процестер қарастырылған. Құйынды, кавитациялық, кавитациялық-құйынды, айналмалы сияқты белгілі жылу қондырғылары тұтынушылардың талаптарын толық қанағаттандырмайды. Осы жағдайларда тиімді шешімдерді іздеу өзекті міндет болып табылады. Мұндай шешімдерге сұйықтықтың айналмалы массасының инерция күштерімен дроссельдік тесіктерге қысым жасау арқылы жылу энергиясын алу әдісі жатады. Дроссель саңылаулары арқылы сұйықтық ағынын анықтау үшін эксперименттік стенд жасалды. Стендтің көмегімен біз диаметрі 1.5, 2, 3 мм дроссель саңылаулары арқылы сұйықтық ағынын анықтадық. Тәжірибе барысында дроссель саңылауының диаметрі неғұрлым үлкен болса, сұйықтық ағыны соғұрлым жоғары болатындығы белгілі болды. Дегенмен, дроссель саңылауының диаметрін шамадан тыс ұлғайтуға болмайды, себебі бұл дроссель саңылауларында қысым жасауды қиындатады. Ротордың бұрыштық жылдамдығының жоғарылауымен дроссель саңылауларындағы сұйықтық қысымы артып, жалпы ағынның алдын-ала статикалық қысымынан сұйықтық ағынының үлесі төмендейтіні анықталды. Жеткізу желісіндегі алдын-ала статикалық қысым ротордың үлкен айналымымен ғана емес (ω =76 рад/с дейін) ағынға айтарлықтай әсер ететіні сөзсіз, ал бұрыштық жылдамдықтың өсуімен оның әсері азаяды және коэффициент k 1-ге ұмтылады.

Кілт сөздер: құйынды әсер, кавитация, бұралған ағын, кинетикалық энергия, дроссель саңылауы, сұйықтық.

Б.Р. Нусупбеков, М.С. Овчаров, Е.З. Ошанов, У.Б. Есбергенов, М.С. Дуйсенбаева, А.А. Тишбеков, М.К. Аманжолова

Определение влияния диаметров дроссельных отверстий на поток жидкости инерционной гидродинамической установки

В статье для решения экологических проблем, связанных с обогревом зданий и сооружений, рассмотрены способы преобразования электрической энергии в тепловую и процессы, происходящие при этом. Известные тепловые установки, такие как вихревые, кавитационные, кавитационно-вихревые, ротационные не в полной мере удовлетворяют требованиям потребителей. В данных условиях поиск эффективных решений является актуальной задачей. К таким решениям можно отнести способ получения тепловой энергии путем создания давления у дроссельных отверстий силами инерции вращающейся массы жидкости. Для определения расхода жидкости через дроссельные отверстия был изготовлен экспериментальный стенд. С помощью стенда нами был определен расход жидкости через дроссельные отверстия диаметром 1,5; 2; 3 мм. В ходе эксперимента было выявлено, что чем больше диаметр дроссельного отверстия, тем выше расход жидкости. Однако нельзя чрезмерно увеличивать диаметр дроссельного отверстия, так как это осложнит создание давления у дроссельных отверстий. Установлено, что с повышением угловой скорости ротора растет давление жидкости у дроссельных отверстий, а доля расхода жидкости от предварительного статического давления в общем расходе снижается. Определено, что предварительное статическое давление в подводящей магистрали оказывает существенное влияние на расход только при небольших оборотах ротора (до ω = 76 рад/с), а с ростом угловой скорости ее влияние уменьшается и коэффициент k стремится к 1.

Ключевые слова: вихревой эффект, кавитация, закрученный поток, кинетическая энергия, дроссельное отверстие, жидкость.

References

1 Kalinin, A.A. (2018). Parametricheskaia optimizatsiia elektrotekhnologicheskogo kompleksa dlia avtonomnogo teplosnabzheniia [Parametric optimization of electrotechnological complex for autonomous heat supply]. Karaganda. Retrieved from https://www.kstu.kz/wp-content/uploads/dis/Калинин%20А%20А%20Диссертация.pdf [in Russian].

2 Merkulov, A.P. (1969). Vikhrevoi effekt i ego primenenie v tekhnike [Vortex effect and its application in technology]. Moscow: Mashinostroenie [in Russian].

3 Gutsol, A.F. (1997). Effekt Ranka [Runque effect] / A.F. Gutsol. *UFN*, 167, 6, 665–687 [in Russian].

4 Kalinin, A.A. (2006). Arkhitektura avtomatizirovannoi sistemy nauchnykh issledovanii energeticheskikh kharakteristik GDN s trubnym rotorom [Architecture of an automated system for scientific research of the energy characteristics of a gas pump with a pipe rotor]. *Nauchnye trudy Mezhdunarodnogo simpoziuma «Informatsionnye i sistemnye tekhnologii v industrii, obrazovanii i nauke» (21–22 sentiabria 2006 g.) — Scientific proceedings of the International Symposium "Information and System Technologies in Industry, Education and Science" (September 21-22, 2006)*. Karaganda: Izdatelstvo Karagandinskogo gosudarstvennogo tekhnicheskogo universiteta, 110–112 [in Russian].

5 Mokhammad, A.A., Khorosh, I.A., Titov, M.A., & Kulikova, N.P. (2015). Raschet drosselnogo ustroistva razogreva rabochei zhidkosti gidroprivoda s avtomaticheskim upravleniem v zavisimosti ot temperatury [The calculation of the throttle device heating working fluid of hydraulic drive having a temperature dependence]. *Vestnik Krasnoiarskogo gosudarstvennogo agrarnogo universiteta — Bulletin of Krasnoyarsk State Agrarian University*, 12, 38–44. Retrieved from https://elibrary.ru/item.asp?id=25054268)6 [in Russian].

6 Pasyuk, A.S. (2018). Gidrodinamicheskii nagrevatel zhidkosti v pishchevoi promyshlennosti [Hydrodynamic liquid heater in the food industry]. *Vestnik nauki i obrazovaniia — Bulletin of Science and Education, 1* (2 (38)), 30–33. Retrieved from https://elibrary.ru/item.asp?id=32430829) [in Russian].

7 Shumilov, I.S. (2016). Temperatura rabochei zhidkosti aviatsionnykh gidrosistem [Temperature of the working fluid of aircraft hydraulic systems]. *Mashiny i ustanovki: proektirovanie, razrabotka i ekspluatatsiia — Machines and plants: design, development and operation*, 2, 51–75. Retrieved from https://www.researchgate.net/publication/301945902_Fluid_Temperature_of_Aero_Hydraulic_Systems/fulltext/573a6fcc08aea45ee83f8e17/Fluid-Temperature-of-Aero-Hydraulic-Systems.pdf [in Russian].

8 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. Retrieved from http://www.bcc.bas.bg/BCC_Volumes/Volume_52_Special_A_2020/BCC-52-A.pdf.

9 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

10 Oshanov, E.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. https://www.scopus.com/record/display.uri?eid=2-s2.0-85134825340&origin=resultslist&sort=plf-f