Теоретично обґрунтований механізм нагріву рідини в роторно-імпульсному апараті. Досліджено процес нагріву рідини із застосуванням роторно-імпульсного теплогенератора. Розроблений роторно-імпульсний апарат (кавітаційний теплогенератор) для децентралізованого обігріву будівель і споруд промислового призначення. Виконано аналіз показників ефективності роботи теплової системи з кавітаційним теплогенератором. Розроблено метод контролю інтенсивності процесу кавітації з використанням вібраційного компенсатора коливань

Ключові слова: кавітація, роторно-імпульсний апарат, кавітаційний теплогенератор, компенсація хвиль коливальної енергії, динамічний компенсатор вібрацій

Теоретически обоснован механизм нагрева жидкости в роторно-импульсном аппарате. Исследован процесс нагрева жидкости с применением роторно-импульсного теплогенератора. Разработан роторно-импульсный аппарат (кавитационный теплогенератор) для децентрализованного обогрева зданий и сооружений промышленного назначения. Выполнен анализ показателей эффективности работы тепловой системы с кавитационным теплогенератором. Разработан метод контроля интенсивности процесса кавитации с использованием вибрационного компенсатора колебаний

Ключевые слова: кавитация, роторно-импульсный аппарат, каитационный теплогенератор, компенсация волн колебательной энергии, динамический компенсатор вибраций

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EXAMINING A CAVITATION HEAT GENERATOR AND THE CONTROL METHOD OVER THE EFFICIENCY OF ITS OPERATION

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1. Introduction

Cavitation is a means for the local concentration of low density energy into high energy density connected with pulsations and the collapse of cavitation bubbles.

In the phase of rarefaction of the acoustic wave, or due to a local decrease in the pressure in the flow around the solid body, caverns (cavitation bubbles) are formed in the liquid, which are filled with saturated vapor of this liquid [1].

In the compression phase, under the influence of increased pressure and surface tension forces, the cavity collapses, and the vapor condenses at the interface. A gas dissolved in the liquid diffuses into the cavity through its surface, and then it undergoes strong adiabatic compression [2].

Hydrodynamic, electrodynamic, piezoelectric, magnetostrictive and mechanical cavitation generators are used for a cavitation attack to the fluid in the industry.

In hydrodynamic cavitators, such as rotary-impulse apparatus (RIA), hydrodynamic and acoustic effects are implemented in a liquid. The causes of the arising effects are the developed turbulence, pressure pulsation and liquid flow rate, the intensity of cavitation of shock waves and secondary nonlinear acoustic effects. When the rotor revolves, its chambers are periodically combined with the stator channels. The flow rate of the liquid in the stator channel is variable. When overpressure impulse expands in the stator channel, a short impulse of reduced pressure follows it. This is due to the fact that the inertial forces create a short impulse of reduced pressure and tensile stresses in the liquid, which causes cavitation.

Heat generators based on the cavitation equipment are a new generation of heat engines that convert mechanical and acoustic effects on liquid into heat. Heating of the heat-transfer agent is carried out when the kinetic energy of the liquid is transformed into heat energy due to the cavitation vortex effects [3].

The mechanism of obtaining heat energy due to the cavitation is based on secondary nonlinear effects in the liquid. Acoustic cavitation is an effective means for concentrating the energy of a sound wave of low density and a high energy density associated with pulsations and cavitation bubbles collapse. At the moment of collapse of the cavitation bubble, the pressure and temperature of gas increase sharply [4, 5].

At present, taking into account a sharp rise in prices for fuel and energy resources, development of energy-efficient heating equipment including decentralized heating equipment of buildings and facilities is a relevant scientific problem.

2. Literature review and problem statement

An analysis of the published data shows that the main works of researchers are aimed at studying the cavitation mechanism and structural calculation of cavitation apparatuses. In paper [6], the influence of the shape of the hydrodynamic channels on the course of the cavitation process was investigated. The substantiation of choice, calculation of the optimum cross-section of the hydroline was proposed. The authors of paper [7] present data on the results of development of a cavitation plant for water transport, there is no data on the possibility of using this equipment in heating systems.

In paper [8], author gave a description of the heating system of buildings with the use of RIA. The system is a recuperation plant, the heating is carried out by the circulation of the heat air. The use of such systems in Ukraine is extremely limited due to the need for additional capital investments for the re-equipment of heating systems.

There are no published data on the methods for estimation of the efficiency of cavitation apparatuses. The efficiency of liquid heating due to cavitation effects was estimated in paper [9]. The energy supplied for the formation of a cavitation bubble filled with steam is determined as:

$$E_0 = 4\pi r^2\sigma + \frac{4}{3}\pi r^3 (P_0 - P_p). \quad (1)$$

In the first approximation P_p was accepted.

The energy of compression of a cavitation bubble is determined by formula:

$$\mathrm{Ec} = 4\pi P(r_{\max}^3 + r_{\min}^3) \approx \frac{4}{3}\pi \mathrm{P} r_{\max}^3. \quad (2)$$

When a bubble with a radius of 1 mm is formed in water at a temperature of t=10 °C, saturated vapor pressure P_p=1.25·10^3, surface tension σ=7.28 10^{-4} N/m, the bubble formation energy is equal to E_o=1.995·10^{-5} E J. The energy of compression of a bubble by a liquid at atmospheric pressure P=10^5 Pa is equal to E_c=4.189 10^{-4} J. Thus, the energy of compression of a bubble is more than 20 times higher than the energy of its formation [9].

Table 1 shows values of the ratio of the energy of compression to the energy of formation of the cavitation bubble at different values of pressure in the liquid and vapor pressure in the cavitation bubble [10].

Table 1

Ratio of energy of compression to the energy of formation (E_c/E_o) of a cavitation bubble at different values of saturated vapor pressure in a cavitation bubble and pressure in a liquid

Ratio of energy of compression to the energy of formation	P=10^5, Pa					P_p=10^5, Pa				
	0.1	0.5	1	1.5	2	0.00238	0.0752	0.2031	0.483	0.715
						t=20 °C	t=40 °C	t=60 °C	t=80 °C	t=90 °C
E_c/E_o	2.1	10.5	20.9	31.5	41.9	20.99	6.65	2.46	1.04	0.69

The data (Table 1) indicate that the compression energy of the cavitation bubble increases linearly, depending on the pressure in the surrounding liquid. While water temperature increases and, correspondingly, saturated vapor pressure increases, the ratio of energy of the compression to the energy of the formation of cavitation bubbles decreases. As the pressure in the liquid increases, the value of the ratio of the compression energy to the energy of formation of the cavitation bubble increases.

To evaluate the efficiency of such a system, the heat productivity coefficient has been accepted [9]:

$$K = \frac{(E_c - E_0)\phi}{E_0} = \frac{\left[r(P - 2P_{\Pi}) - 3\sigma\right]\phi}{2rP_{\Pi} + 3\sigma}, \quad (3)$$

where r is the radius of a bubble, m.

The mass concentration of cavitation bubbles ϕ that form the cavitation cloud is determined as the ratio of volume of the cavitation cloud to the volume of the cavitation bubble at maximum expansion

$$\phi = \frac{3\upsilon_{\kappa}}{4\pi r_{\max}^3}, \quad (4)$$

where υ_{κ} is the volume of cavitation cloud, m^3.

Thus, if the hydraulic system in which the heat generator operates is open by pressure, the compression of bubble occurs under the pressure of the surrounding liquid. That is, there is an inflow of energy to the liquid from the environment [9].

The energy supplied to the liquid by the collapse of cavitation bubbles is directly proportional to their number. The degree of development of cavitation determines the index of cavitation, showing the ratio of the volume of the cavitation cloud to the total volume of liquid in the active working zone [4]. Under conditions of developed cavitation, the value of the cavitation index tends to unity.

A passing mechanism for the generation of heat in RIA is the heating of liquid due to friction in the gap between the rotor and the stator. The amount of heat generation depends on the amount of energy dissipated in the gap. When the rotor of RIA rotates, the liquid heats up due to the dissipation of energy. Determination of the temperature of heating of the liquid for a time interval Δτ can be based on the heat balance, assuming that there are no heat losses:

$$N\Delta\tau = M_g C \Delta\tau\Delta t. \quad (5)$$

A change in the temperature of the liquid due to friction in the gap $\Delta t = N/M_g$ sec, where M_g is the mass flow rate of liquid through the gap, and C is the specific heat capacity of water.

The amount of heat transferred to the liquid by friction in the gap is equal to the amount of energy dissipated in the gap when the rotor rotates. The energy costs for rotor rotation are determined by the methods recommended by authors of articles [10, 11]. With a small gap size, the liquid flow rate M_g through the gap is much less than the total flow rate M through RIA. Therefore, under real conditions, a part of the liquid passing through the gap is additionally heated and mixed with the main stream.

The energy required for the operation of RIA is made up of the energy used for the rotor rotation and the energy used for the injection of liquid into RIA. The loss of heat to the environment Q_1 is determined by the standard calculation methods.

Due to the fact that there are many approaches to the estimation of efficiency of heat operation of RIA, the actual task is to control the intensity of the cavitation process inside the apparatus.

According to [12], to control the cavitation process, it is necessary to measure the pressure in front of the working section of the cavitator, the rate in front of the working section, the thickness of the boundary layer on the side in front of the cavitator. The main indicator of the process in this case is the number of cavitation, which is determined by expression:

$$\sigma = \frac{P_0 - P_K}{(\rho v^2)/2} = \frac{2gH}{\frac{v^2}{2}}, \quad (6)$$

where P_0 is the pressure in the liquid; P_K is the pressure in the cavity; H is the depth; V is the rate; ρ is the density of water.

A method for the estimation of productivity of a cavitation chamber was proposed in paper [13]. As an indicator of the process, the pressure is used, which is calculated from the readings of a pressure gauge installed at the outlet of working chamber of the cavitation channel. In this case, it is necessary to take into account the hydraulic head loss in the entire hydraulic network.

The authors of paper [14] propose using an optical system to control the process of cavitation, which determines the degree of cavitation development by the average index of cavitation. An optical system consisting of a matrix of optocouplers emits light beams of the infrared range and takes rays reflected from the opposite side, from which it is possible to judge the shape and dimensions of the cavitation cavity. This controlling device can be used to determine the degree of development of cavitation in both hydrodynamic and ultrasonic cavitators. However, an essential disadvantage of the system is the impossibility of operation with dense, viscous liquids and aggressive media.

In paper [15], the possibility of estimation of the nature of the cavitating region by the value of the cavitation noise of a cavitator was considered. It was shown that the transition from the pre-cavitation flow of water to the cavitation one occurs at a temperature of ~50 °C.

Based on the above, during control over the cavitation process, most of the known methods come down to controlling indirect parameters of the process: pressure at the inlet and at the outlet of the cavitator, the rate of liquid and gas flows.

The main disadvantage of the described methods of control over the cavitation process is a fact that generally accepted measurements of pressure, rate, liquid level in the cavitating chamber cannot be carried out because of the erosive effect of cavitation on the measuring transducers [16, 17]. In addition, the measured magnitudes cannot characterize the cavitating field, which characterizes the process of cavitation.

Thus, the works and studies related to the development of heating systems using cavitation devices are a promising aspect for solving the task of modern energy-efficient technologies introduction in Ukraine.

3. The aim and objectives of the study

The objective of present work is to develop a rotary-impulse apparatus (cavitation heat generator) for the decentralized heating of buildings and facilities for residential and industrial purposes and to investigate the efficiency of its operation.

To achieve this objective, the following tasks were set:

– to design and fabricate an experimental-industrial rotor-impulse apparatus (RIA);

– to conduct bench tests of RIA and conduct an analysis of the performance indicators of its operation;

– to develop a method of control over turbulent pulsations of pressure and oscillations of the gas-liquid layer in a cavitator with experimental approbation of the method for the cavitation process efficiency.

4. Description of the circuit of a rotor-impulse apparatus

Fig. 1 shows a structural diagram of the developed rotor-impulse apparatus RIA (cavitation heat generator).

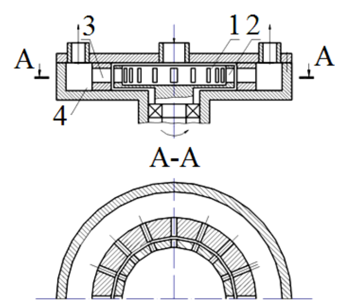

Fig. 1. Design of a cavitation chamber of the rotor type: 1 – rotor; 2 – rotor channels; 3 – stator channels; 4 – operation chamber

The operation principle of the device is as follows: the liquid is supplied under pressure through the inlet branch pipe into the cavity of rotor 1, passes through rotor channels 2, stator channels 3, operation chamber 4, leaves the device through the outlet branch pipe. The rotor channels are periodically combined with the stator channels during rotation. When the rotor channels are blocked by the stator side, the pressure in the rotor cavity increases, and when the rotor channel is combined with the stator channel, the pressure decreases, while a pressure impulse expands into the stator channel.

The flow rate of the liquid in the stator channel is variable. When a positive pressure impulse expands into the stator channel, a short impulse of reduced pressure appears after it, as the alignment of the rotor and stator channels is completed.

The volume of liquid entering the stator channel tends to exit the channel and the inertial forces create tensile stresses in the liquid, which causes cavitation.

Fig. 2 shows a thermal circuit for the decentralized heat supply with the developed built-in cavitation heat generator, assembled at OOO "Ukravia" (Pavlograd, Ukraine).

Feeding water from tank 4 is circulated to heat exchanger 3 by feeding pump 5 and is heated by the thermal energy of cavitation heat generator (cavitator) 2.

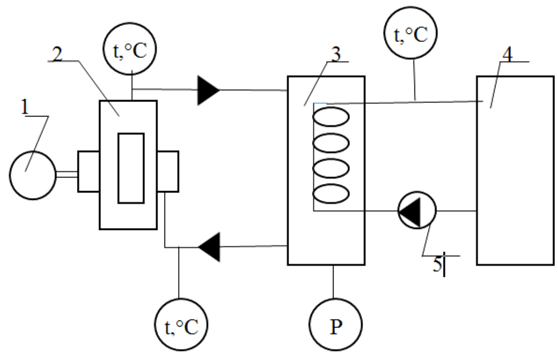

Fig. 2. Structural thermal circuit of the decentralized heat supply plant, where 1 – electric motor AIR-160S2, N=15 kW, n=2930 rpm; 2 – cavitation heat generator; 3 – heat exchanger of the surface type; 4 – a tank with feeding water, 400 liters; 5 – feeding pump YBC 25/6

5. Methods of thermal engineering tests of the decentralized heat supply plant

Experimental studies of the operation of the system using a cavitation heat generator were carried out in two stages. At the first stage of the study, the efficiency of heat operation of the developed heat generator was estimated. At the second stage – operation efficiency of the heat system with the installed cavitation heat generator.

At the first stage of the study, water was heated in a cavitation heat generator with disconnected heat exchanger and system.

The following parameters were recorded during the experiment:

– mass of heated water, m, kg;

– temperature of the liquid at the beginning of the heating in the cavitation heat generator, t_1,° C;

– temperature of the liquid at the end of heating, t_2, °C;

– water pressure before heating, P_1, bar;

– water pressure after heating, P_2, bar;

– the power used during heating process N_{exp}, kW·hour;

– heating time from t_1 to t_2, τ, min.

Experimental data processed in accordance with [18] are given in Table 2.

Table 2

Experimental data on thermal engineering tests of efficiency of the cavitation heat generator

t_1, °C	t_2, °C	P_1, MPa	P_2, MPa	m, kg	N_{exp}, kW·hour	τ, min
1	2	3	4	5	6	7
18	75	1.6	3.1	70	7.3	23

The efficiency of RIA as a heat generator was determined by the following parameters:

– amount of heat energy spent on liquid heating:

$$Q_B = M_B c_B (t_{fin} - t_{in}); \tag{7}$$

– amount of heat used on heating the equipment:

$$Q_O = M_O c_C (t_{fin} - t_{in}); \tag{8}$$

– coefficient of heat productivity:

$$K_Q = \frac{Q_В + Q_О + Q_П}{N \cdot 3600}; \tag{9}$$

– coefficient of efficiency:

$$\eta = \frac{Q_B}{N \cdot 3600}. \tag{10}$$

Coefficient of efficiency of the cavitation heat generator made up η=0.636.

The second stage of the research – evaluation of the efficiency of the heat system was carried out in the acting plant (Fig. 2).

During operation of the plant under working mode, the following parameters were controlled:

– temperature of the heat transfer agent at the inlet to the heat exchanger, t_1, °C;

– temperature of the liquid at the entrance to the cavitation chamber, t_2, °C;

– temperature of the water at the outlet of the cavitator, t_3, °C;

– temperature of the liquid at the outlet of the heat exchanger, t_4, °C;

– pressure in the cavitator, P, MPa;

– mass of the heated water, m, l;

– power used N_{exp}, kW·hour;

– flow rate of the heated medium, G, kg/sec;

– time heated to the set temperature, τ, min.

Temperatures $t_1 \div t_4$ were recorded by means of impulses arriving at the heat energy meter and duplicated by the pyrometer FLUS JR-863. Energy consumption during studies were determined using a stationary electric meter. An error in the readings of the control devices did not exceed 0.5 °C (this is explained by energy losses due to the dissipation during motion of heat-transfer agents). Results of the studies processed in accordance with [18] are given in Table 3.

Table 3

Experimental data on thermal engineering tests of efficiency of the heat system operation

t_1, °C	t_2, °C	t_3, °C	t_4, °C	P, MPa	$m_в$, l	N_{exp}, kW·hour	m, l	τ, min
1	2	3	4	5	6	7	8	9
18.5	18.5	58	59	0.125	400	25	400	93

Coefficient of efficiency of the system based on the results of data processing made up η=0.76. The obtained experimental data were compared with results of the energy efficiency of RIA operation, given in paper [19] (Table 4).

In columns 6 and 7, the numerator and denominator are indicators for different equipment productivity.

An analysis of indicators in Table 3 demonstrates effective operation of the developed cavitation heat generator and the heat system as a whole. The efficiency of the heat generator is by 18.3 % higher than the efficiency of RIA given in [19] and is 7.1 % higher than the efficiency of heat systems based on RIA described in [19].

Table 4

Indicators of energy efficiency of heat operation of the developed cavitation heat generator and heat system

Parameter name	Dimension	Designantion	Values of parameters			
			Developed device		Published data	
			Generator	Heat system	Single-stage RIA	Multi-stage RIA
Mass of heated water	kg	M	70	400	22/44	250/340
Temperature of water heating	°C	t	75	59	70/65	50/45
Time of heating	min	τ	23	93	35/30	25/150
Energy consumed	kW·h	N	7.3	25	5.3/4.9	33/30
Coefficient of efficiency		η	0.636	0.76	0.519/0.652	0.547/0.706

6. Control of efficiency of the cavitation process

As noted above, embryos of cavitation are the smallest particles of air that exist in the liquid in free state. Cavitation "cavities" (bubbles) are a source of spherical shock waves arising during pulsation and multiple compression and expansion of bubbles. During a "collapse" of the cavitation bubbles, the temperature and pressure increase locally, and radial cumulative streams are formed [20].

Thus, the cavitator can be considered as an auto-oscillatory link, characterized by significant pulsations of pressure and phase flow. The cavitation caverns act as a generator of oscillations in the connected oscillating system hydroline – bubble. In the self-oscillatory system under consideration, a constant source of energy is a device that provides a flow of liquid (pump) [21].

To control the cavitation process, it is proposed to use a method based on the absorption of waves of the oscillatory energy of the object that expand from the cavitator by using a vibration effect. In this case, the vibration sensor is installed between the cavitator transmitting the oscillations and the fixed support.

We shall consider a cavitator as a system that is actuated by the disturbing force of auto-oscillations of the liquid inside the cavitator:

$$P = P_0 \sin \omega t. \tag{11}$$

Differential equations of the oscillation of the system obtained with two degrees of freedom (an addition of the portable and relative motions) take the form:

$$m_1 z_1 + k_1 z_1 + k_2 (z_1 - z_2) = P_0 \sin \omega t;$$

$$m_2 z_2 + k_2 (z_2 - z_1) = 0, \tag{12}$$

where z_1 and z_2 are the absolute coordinates of the movements of the cavitator masses m_1 and of the support m_2, k_1 and k_2 are the rigidity of the elastic connection of the cavitator and of the support, respectively. In this case, the disturbing force acts on mass m_1, but it causes oscillations of additional mass m_2 only. After substituting the particular solutions into the system of equations (12), we obtain an expression for the determination of amplitude of these oscillations:

$$C_2 = -\frac{P_0}{m_2 \omega^2} = -\frac{P_0}{k_2}. \tag{13}$$

Thus, the addition of the oscillation compensator tuned to the frequency of the disturbing force to the cavitator forms a system with two degrees of freedom, inside which, at a frequency that coincides with the frequency of the disturbing force, an anti-resonance occurs.

The use of a dynamic compensator makes it possible to control the oscillations, which characterize the process of cavitation, and it will play the role of a passive vibration protection system of the cavitator. In this case, taking into account formula (13), the following dependence can be used for tuning:

$$C_2 = -\frac{P_0}{k_2} = -C_{OCH} \frac{k_1}{k_2} = -C_{OCH} \frac{m_1}{m_2}. \tag{14}$$

The calculation of a dynamic compensator without damping is associated with the need to satisfy a number of constraints. The choice of rigidity C_2 of the elastic element (or mass m_2) should also ensure its strength. In addition, it should be remembered that the attached mass m_2 should be at least 1–2 % of the mass of the protected object in the systems of passive vibration protection. For its "adjustment" to any value of the mass of compensator m_2, the following condition must be fulfilled:

$$\frac{\omega_1}{\omega_2} = \frac{m_1}{m_1 + m_2}. \tag{15}$$

When using a dynamic compensator, its efficiency is estimated by the ratio of amplitude of the oscillations of the design without compensator to the "residual" amplitude of the design's vibrations after the installation of compensator. The maximum efficiency of the compensator with attenuation is reached at $\omega_2 = \omega_0$. It is inversely proportional to the coefficient of relative damping ξ, which corresponds to the condition:

$$\frac{C_{OCH}}{C_1} = \frac{1}{2} \xi = m_2 \omega_2 / 2C. \tag{16}$$

For the approbation of the control method developed, a tuning-fork oscillator sensor [22] was placed in a flexible support of the cavitation heat generator. Vibrations were measured at several temperature values. Fig. 3 shows diagrams of change in the vibration level at different frequencies.

The total vibration at low frequencies at water temperature 50 °C is greater than at 60 °C (Fig. 3), and at high frequencies, on the contrary, at 50 °C, the total vibration is larger than at 60 °C. This indicates that there was a transition of vibration to the region of medium frequencies associated with the transition of the liquid to the active phase of cavitation over the given temperature range.

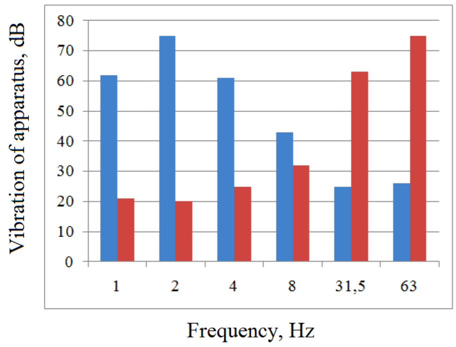

Fig. 3. Diagram of the vibration level changes at different frequencies: ■ — liquid's temperature 50 °C; ■ — liquid's temperature 60 °C

7. Discussion of results of examining a heat system with the cavitation heat generators

In the present work, we examined the designed and actually operating rotary-impulse apparatus (cavitation heat-generator) for decentralized heating of buildings and facilities for industrial purpose. A feature of the proposed design of the device is the structural solution of the cavitation chamber: the rotor channels are made in the form of a bucket-like profile of turbine blades. When the rotor revolves at high speed, according to the Bernoulli principle, pressure from the rotor valves drops sharply and temperature of the liquid rises, which increases the effect of cavitation. The gap between the rotor and the stator was determined experimentally by the total heat effect.

To increase energy efficiency of the heat system with cavitation heat generators, their sequential installation was proposed. The heated liquid must pass successively through a heat generator operating at high frequency, then through a heat generator operating at lower frequency. Frequencies should differ from each other by an order of magnitude and larger. Smaller cavitation embryos are excited in a generator with high frequency, they increase in size in the generator with low frequency. This leads to an increase in the impulses of cavitation pressure and increases the effect of cavitation.

Due to the use of a counter-flow heat exchanger in the system, the principle of continuity of the stream is observed when heated liquid enters the system. The total heat effect makes it possible to achieve the indicators given in Table 1, 2.

Energy efficiency of the system was estimated by the calculations performed on the basis of a comparison of data on the cost of heat for the centralized heating of industrial buildings and the heat energy obtained by the operation of the cavitation heat generator. The system proposed ensures the efficiency of application of more than 18 % in comparison with the system of centralized heating by natural gas. This is a confirmation of the fact that the use of the proposed design of a cavitation chamber and the subsequent connection of two cavitation heat generators is a successful design solution. The use of a night tariff can be promising for using the cavitation heat generators in heat systems.

A method for effective control of the cavitation process during operation of the heat generator was developed, based on the suppression of waves of the oscillatory energy of the object. The method is based on direct measurements of vibrations – a parameter, which characterizes the process of cavitation. Approbation of the method for efficiency control over the cavitation process in the thermal circuit for decentralized heat supply with the developed built-in cavitation heat generator was carried out under conditions of OOO "Ukravia" (Pavlograd, Ukraine). The vibration of the cavitation heat generator at different temperatures of the liquid at the outlet was measured. Results of the approbation make it possible to consider that the given control method could be used to evaluate efficiency of the cavitation process.

8. Conclusions

1. The design of a pilot-industrial sample of a rotary-impulse device for use in a decentralized heating system of buildings and facilities for residential and industrial purposes was proposed.

2. A bench test of the RIA developed was conducted in order to determine its characteristics. An analysis of efficiency indicators of the RIA design developed and the heat system was carried out in comparison with known data on similar plants. The system proposed provides for coefficient of efficiency at 0.76. It was established that effectiveness of the application of the design is larger than 18 % in comparison with the system of centralized heating of buildings and facilities for industrial use by natural gas. This confirms the fact that the design of the RIA proposed and the heat system based on it are energy efficient and could be used in decentralized heating systems of buildings and industrial facilities.

3. To implement effective control over the cavitation process during operation of the heat generator, a method was devised based on the measurement of oscillatory energy of the apparatus using a vibration compensation device. The method of control over efficiency of the cavitation process by the measurement of vibrations of the apparatus at various temperatures of the liquid at the outlet was tested in the operating system. Results of the approbation confirm the possibility of using the given control method to evaluate efficiency of the cavitation process in thermal systems.

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