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«NATIONAL RESEARCH OGAREV MORDOVIA STATE UNIVERSITY»

Institute of mechanics and power engineering

The department of heat power engineering systems

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MASTER'S THESIS

TEST OF THE MODEL OF THE HEAT EXCHANGER-BATTERY WITH FLUCTUATING COIL

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THE TASK FOR FINAL QUALIFYING WORK

(in the form of master's thesis)

Student: Verendyaykin German Grigorievich

1 Theme: Test of the model of the heat exchanger-battery with a fluctuating coil. № 7882 – C from 21.09.2018 year

2 The deadline for the submission of work to the protection of 13.06.2020

3 Initial data for final qualifying work state standards, SNiPs, patent database, RD, textbook.

4 The content of the final qualifying work

4.1 Review and analysis of literature sources on the research problem

4.2 Theoretical background

4.3 Description of the experimental installation and devices

4.4 Results of experimental studies

Head of works _______21.09.2018 A. P. Levtsev
signature, date initials, surname

The work has been accepted _______21.09.2018 G. G. Verendyaykin
signature, date initials, surname

ABSTRACT

Master's work contains 70 pages, 29 figures, 9 tables, 37 formulas, 46 references.

ENERGY EFFICIENCY, FLUCTUATING, COIL, WATERHAMMER, EXANGER-BATTERY, PULSAITUNG.

The project is aimed at solving the problems of increasing the efficiency of heat transfer of capacitive indirect heat exchangers and increasing their service life.

The essence of the development is to increase the intensity of heat transfer, reduce deposits due to the generated water hammer and use its energy to oscillate the cylindrical coil in the horizontal and vertical planes.

Capacitive heat exchangers are widely used in individual housing construction (cottages) and in apartment buildings equipped with individual heating points.

In the work, information was searched, theoretical studies and a constructive calculation of the necessary elements of the installation with a pulse feed.

As a result of this work, an installation was designed to transfer the kinetic energy of the fluid movement caused by a sharp interruption of the flow to the coil to increase heat transfer.

The degree of introduction into production is absent. Laboratory unit created.

CONTENT

INTRODUCTION

One of the strategic directions for the development of the Russian economy is the modernization of energy and increasing energy efficiency. The need to develop and activate energy saving processes in Russia is due to the presence of persistent negative trends in the growth of the energy intensity of the gross domestic product of Russia as the main indicator of the efficiency of energy resources use.

In recent years, the energy intensity of the domestic economy has increased, in addition, there are growing losses of energy resources in the production and transportation of electricity and heat. This leads to excessive tariffs, which leads to an increase in the share of energy costs in the structure of the cost of production of industrial enterprises.

In addition, the lack of a practical energy saving strategy and the complexity of energy-saving measures do not allow industrial enterprises to restrain the growth of cost and increase the competitiveness of their products.

The main reason for this situation is the lack of elaboration of methods for achieving the goals and objectives of innovative transformations in the development and implementation of energy-saving projects.

The main attention during the project implementation is paid to its technological component and the indicator of the final impact of this project on the specific energy intensity of the enterprise.

Currently, the problem of energy saving is considered mainly from the point of view of the technological aspect of the implementation of energy-saving projects. Scientific study of the organizational and economic component of energy saving implementation does not meet high requirements.

Energy saving as a factor of increasing the efficiency of an industrial enterprise can be due to the following circumstances:

- a factor of increasing the competitiveness of products in terms of reducing the cost of production, reducing the share of energy costs;

-energy saving can be considered as a factor of additional investment attraction, which contributes to the updating of technological equipment and improving the quality of manufactured products of industrial enterprises;

-energy saving is a factor that stabilizes the demand for energy resources in the direction of its reduction, which contributes to reducing the environmental burden in the areas where industrial enterprises operate.

Thus, energy saving and improving energy efficiency can have a positive impact on the country's economy as a whole - including improving the technological base of industrial enterprises with a subsequent increase in the quality of products, the market competitiveness of domestic enterprises in the world market, increasing the innovative potential of industrial enterprises and, ultimately, on the growth of the country's gross domestic product and improving the standard of living of society[7, 28].

All of the above confirms the relevance of the topic of the diploma project

The growth of individual residential buildings and multi-apartment buildings put into operation over the past 10 years has increased by 2.6 and 3 times, respectively. In terms of м² of input area for individual residential buildings, this increase was 20 million м², and for multi-apartment buildings 35 million м².

In the literature, one can also find an interpretation of these concepts for certain fields of activity. For example, for energy supply systems, the term energy efficiency is used for the stage of energy production, and the term energy saving is used for the stages of transport and sales (consumption) [32].

1 Review of information sources on the topic of scientific research

1.1 Importance of the study

Energy is an important material basis for the survival and development of man, as well as the driving force of various types of economic activity. Currently, energy, materials and information are called the three pillars of the prosperity and development of modern society. They became prerequisites for the development of human civilization. The importance of energy is self-evident. However, the fossil resources on which human society depends are nonrenewable. Energy consumption means a reduction in total reserves, and energy consumption will put a lot of pressure on the environment. Acid rain and the greenhouse effect are all indirect products of energy consumption. The energy problem has become the subject of great concern and the desire of all countries of the world to solve it. In recent years, countries have been actively seeking solutions to this problem. There are two main ways to prove your effectiveness: one is to vigorously develop renewable energy sources and find new alternative energy sources, including solar energy, nuclear energy, hydropower, wind energy, hydrogen energy, geothermal energy, tidal energy, biomass energy, etc. secondly, to develop energy-saving technologies, reduce energy consumption per unit of output and increase energy efficiency[31, 41, 42, 45]. The International Energy Agency (IEA) recently stated that for governments, improving energy efficiency is the best way to address climate change and energy security in the short term[17].

Heat exchangers are widely used when changing heat for different temperature environments. They are widely used in various sectors of the national economy, such as electric power, oil, chemical, construction, metallurgical and light industry. For example, in a thermal power plant, evaporators, superheaters, heaters, economizers, air heaters, condensers, high and low pressure heaters, and so on Are heat exchangers. It can be said that the performance of the heat exchanger Quality and low heat transfer coefficient are directly related to the efficient use of energy, and the development of high-efficiency heat exchangers with low resistance can make the use of low-quality energy that can not be used or restored without reuse, so that the heat exchanger "Integrated energy saving effect" has reached a new level. High-performance heat exchangers with low resistance are of great practical importance for saving energy and reducing energy consumption per unit of production. Using advanced technologies to increase heat transfer is an effective way to achieve this goal.

In 1929, E G Richardson [38]and other people applied hot wire anemometer to measure the velocity of the tube steady flow and pulsating flow, comparing with the average velocity gradient theoretical values and measured values in the cross-section of the tube found that the pulsating speed "annular effect". That is, the velocity of the fluid at the wall is higher than the tube center and the entire cross-section of the velocity distribution is more flat than steady flow velocity distribution. This also marks the beginning of pulsating heat transfer.

Pulsating flow heat transfer originated in the 1930s. When Richardson et al. used hot-wire anemometer to measure the steady and pulsating flow velocity in the tube, they found that the calculated value of the velocity gradient in the section of the tube was deviated from the theoretical value to some degree, so they found the velocity characteristic of pulsating flow: ring effect. This discovery became the origin of pulsating heat transfer research. Since then, scholars began to study pulsating heat transfer in depth. Allan and Frank studied the heat transfer characteristics of pulsating flow in the reciprocating pump and achieved a good enhancement effect.

Intensified heat transfer technology is an advanced technology for improving heat transfer performance developed in the 1960s and 1970s. Its main task is to increase the heat transfer rate to achieve the specified heat transfer with more economical equipment, or to use More efficient cooling methods to protect the safe operation of high-temperature components, or use higher thermal efficiency to achieve rational use of energy Professor Bergles, a well-known scholar of intensive heat transfer research in the United States, summarized the research objectives of enhanced heat transfer technology as: Encouragement and Accommodation of High Heat Fluxes. Since convective heat transfer is the most widely used in industrial practice, its research is also the most active.

In recent decades, the development of high-tech has directly promoted the continuous improvement of research on heat transfer enhancement. A new type of new, efficient and practical new technology for heat transfer enhancement has emerged, and this boom has continued to this day. The annual data on the number of enhanced heat transfer literatures in the United States by Professor Bergles, USA, intuitively reflects the rapid development of enhanced heat transfer research. Enhanced technology can be divided into passive and active technologies or passive and active technologies based on whether additional power is needed.

1.2 Flow pulsating heat transfer

The fluid pulsation process exists in a large amount in the heat exchanger. The pulsation frequency of the fluid ranges from 1 Hz to the ultrasonic frequency, and has a certain degree of influence on the heat transfer. Pan [34] numerical simulation study of the heat transfer effect of fluid pulsation on the spiral coil heat exchanger, the results show that the pulsation frequency and fluid velocity have the greatest impact on heat transfer. Leong [23] experimentally studied the effect of pulsating fluids on the heat transfer of channels containing porous media. The results show that applying pulsed flow to the channels of porous media will greatly increase the heat transfer effect and fit the correlation. Yapici [46] numerical method studies the effect of three pulse modes on the entropy production of fully developed segments. The relationship between inlet velocity and time is stepped, sinusoidal and zigzag. The results show that the step-type velocity has the highest entropy production and the highest temperature; increasing the fluid pulse velocity will have a bad effect on the useful work, and the heat transfer irreversibility will increase[7, 18, 37].

In 1989, The effect of pulsating flow on the heat transfer of sugar juice and its mechanism were studied by Deng Xiqun [30] Yang Zhuo and Li Xingren. They obtained pulsating flow is an effective heat transfer method. It was more suitable to strengthen viscous fluid. In turbulent region, the effect of pulsating flow on the heat transfer will be weakened with the increasing of Reynolds number; the intensity of turbulence increasing, the boundary layer thinning and cavitation are the main mechanism of pulsating heat transfer.

1.3 Surface vibration heat transfer

In 1990 was studied a new correlation method for the effect of vibration on forced-convection heat transfer by Takahashi, Kknji Endoh, Kazuo[43]. The forced convection heat transfer from a vibrating sphere, a cylinder and a square-section tube to water was experimentally investigated. The obtained heat transfer data with the vibration effect is well correlated in terms of the energy dissipation calculated from the fluid drag acting on the vibrating bodies. Through the use of the energy dissipation, the heat transfer from vibrating bodies to a fluid flow can be discussed analogously with the mass transfer. As a result of the study the following results were obtained.

In the heat transfer experiment, the following forms of vibration source are mainly used: 1) mechanical vibration or motor driven eccentric device, which is used in early experiments; 2) fluid flow induced by heat transfer elements, such as heat transfer Tube bundle in the device; 3) ultrasonic excitation heat transfer element generation. The following three aspects are summarized respectively, where A represents amplitude, f represents vibration frequency, D represents tube diameter, u represents incoming flow velocity, Re represents Reynolds number, h represents surface heat transfer coefficient, and definitions of other symbols are visible. Specific related literature.

Mechanical vibration is the most commonly used vibration source in heat transfer experiments. Under normal circumstances, the mechanical vibration device has a simple structure and can easily adjust parameters such as amplitude and frequency. This has an irreplaceable effect on the in-depth study of the influence of vibration parameters on heat transfer. Among them, Lemlish [20, 21], Deaver[5], , Hsieh [11], Dawood [4] and Scanlan [40], Saxena [39], Leung[24], Katinas[12, 13], Takahashi[44], Cheng[2] , Gau [9], Bronfenbrener [1], Fu [8], Lee [19], Cold Learning [22], Klacza [16], etc. for natural convection and The effects of vibration on heat transfer under forced conditions have been systematically studied.

1.4 Piezoelectric vibration heating technology

The heat transfer technology of piezoelectric sheets has been studied over the past ten years. A piezoelectric ceramic dielectric material is placed between two electrodes of the piezoelectric sheet. After applying alternating voltage, a vibration is generated, which is also called a buzzer, because vibration produces sound. Park [35] experimentally investigated and established convective heat transfer from vibrating ribs. The results show that the Nusselt number mainly depends on the speed of vibration and the speed caused by natural convective buoyancy. Frequencies of vibration speed are 0-20, 29-59 Hz, respectively. Petroski [36]optimized the effect of heat removal of piezoelectric sheet cooling electronics. When the piezoelectric ceramic sheet vibrates in a confined space or in the region of the proximal wall, the liquid in the surrounding space is disturbed, and hot or cold liquid is quickly transferred to the surrounding space, thereby enhancing heat transfer of the proximal wall of the liquid. Piezoelectric ceramics require little energy to achieve an increase in heat transfer coefficient.

1.5 Research status of vibration enhanced heat transfer technology

In 1995, Heat transfer and pressure drop correlations for the rectangular offset strip fin compact heat exchanger were studied by Manglik, Raj M. Bergles, Arthur E [29]. The development of thermal-hydraulic design tools for rectangular offset strip fin compact heat exchangers and the associated convection process are delineated. On the basis of current understanding of the physical phenomena and enhancement mechanisms, existing empirical f and j data for actual cores are reanalyzed. The asymptotic behavior of the data in the deep laminar and fully turbulent flow regimes is identified. The respective asymptotes for f and j are shown to be correlated by power law expressions in terms of Re and the dimensionless geometric parameters α, δ, and γ. Finally, rational design equations for f and j are presented in the form of single continuous expressions covering the laminar, transition, and turbulent flow regimes.

In 1997, Moschandreou et al. [33] analyzed the pulsating flow in the circular pipe full hot development zone of the constant wall temperature heat flux and concluded that the difference between the average Nusselt number (Nuo) and the corresponding Nusselt number (Nust) is increasing for the high frequency pulsating flow .

In 2003 Kim, D. H. Lee, Y. H. Chang, S. H.[14] are investigated effects of mechanical vibration on Critical Heat Flux in vertical annulus. This study presents the investigation of the vibration effect on CHF. The experiments condition was under atmospheric pressure at vertical heated annulus channel. The experiments for dynamic response of the heater section without vibration excitation were carried out at mass flux of 50 kg/m2/s and 400 kg/m2 /s. Vibration amplitude was increased at the ONB point during boiling process and the reason of the vibration increase is expected as the results of the flow regime change from subcooled region to bubbly region. CHF experiments with and without mechanical vibration were performed at mass flux of 115 kg/m2/s and 215 kg/m2 /s. Totally 162 data of CHF with vibration were gained and CHF was increased by mechanical vibration maximum 13.4 % at the mass flux of 115 kg/m2 /s and 16.4 % at the mass flux of 215 kg/m2 /s. The maximum CHF enhancement condition was at 30 Hz vibration frequency and 0.5 mm vibration amplitude. The dominant parameter of vibration which was effective on CHF enhancement was vibration amplitude and the reason of the CHF increase is expected as the increase of the liquid film thickness by increase of deposition of liquid droplet on the film.

After in 2007, Kim, D. H. Lee, Y. H. Chang, S. H. studied[15]. Vibration amplitude was one of the effective parameters on CHF enhancement. It seems to come from turbulence increasing and increment of deposition of droplet from the liquid film by vibration. Vibration is an effective method for heat transfer enhancement as well as CHF enhancement.

In 2008, Elsayed A.M. Elshafei et al. [6]investigated the heat transfer characteristic of pulsating turbulent air flow in a pipe which was heated at uniform heat flux. The experiments were performed over a ranges of $10^4<Re<4*10^4$ and $6.6 \leq f \leq 68$Hz. The experiments indicate that Nu is strongly affected by pulsation frequency and Reynolds number. Its local valve either increases or decreases over that of the steady flow. The higher valves of the local heat transfer coefficient occurred in the entrance of the test tube. It is observed also that the relative mean Nu either increases or decreases, depending on the frequency range. The percentage of maximum enhancement in η_m is about 9% at Re=37100, f=13.3; and the percentage of maximum reduction in η_m is about 12% at detected for Re=13350, f=42.5.

Currently, active research is being conducted, an example can be the research Davletshin, I. A. Gazizov, I. M. Paereliy, A. A.[3]. Heat transfer was estimated using the technique of simultaneous wall heating and wall temperature measurement by the same copper tracks. Distributions of heat transfer coefficient over the channel wall in steady and pulsating regimes of flow have been obtained. 30% augmentation of heat transfer compared with the steady flow values has been revealed in pulsating flow. The frequency range of (0-100) Hz and the relative amplitude of forced velocity pulsations of 0.3 have been studied.

In 2019, Hosseinian, A. Meghdadi Isfahani, A. H. [10] this study, the heat transfer enhancement due to the surface vibration for a double pipe heat exchanger, made of PVDF, is investigated. In order to create forced vibrations (3–9 m/s2, 100 Hz) on the outer surface of the heat exchanger electro-dynamic vibrators are used. Experiments were performed at inner Reynolds numbers ranging from 2533 to 9960. The effects of volume flow rate and temperature on heat transfer performance are evaluated. Results demonstrated that heat transfer coefficient increases by increasing vibration level and mass flow rate. The most increase in heat transfer coefficient is 97% which is obtained for the highest vibration level (9 m/s2) in the experiment range.

The thermal energy engineering research group of the university of Mordovia, Russia [17, 25–28] has applied pulsating sources such as diaphragm pump, impact valve and water hammer pump to the fields of heat supply and diesel engine waste heat recovery. Pulsating heat transfer has evolved from the early single-cycle diaphragm pump system to a more efficient double-cycle diaphragm pump system. Their research shows that: when the flow of the heated thermal medium is 0.5m3/h, the heat transfer coefficient under the pulsating condition increases by about 24%, and the pulsating frequency is within the range of 1-5hz.

Heat exchanger tube bundles may fail due to excessive vibration or noise. The main failure mechanisms are generated by the shell side fluid that passes around and between the tubes. This fluid may be a liquid, gas or multi-phase mixture. The most severe vibration mechanism is a fluid elastic instability, which may cause tube damage after only a few hours of operation. Clearly, such extreme causes of vibration must always be avoided. In contrast buffeting due to flow-turbulence causes very little vibration. However, after many years of service such remorseless low level vibration will produce tube wall thinning, due to fretting, which may be unacceptable in a high-integrity heat exchanger. Consequently, the issues of life cycle and integrity must frequently be included in heat exchanger specification. This paper reviews the various mechanisms that cause vibration and noise. Particular attention is given to methods for achieving good tube support arrangements that minimize vibration damage. References to the most recent sources of data are given and good working practice for the design and operation of standard and high-integrity heat exchangers is discussed.

1.6 Purpose and objectives of the study

The review and analysis of literature sources allowed us to formulate the goal and objectives for improving the efficiency of heat transfer of heat exchangers-accumulators.

The purpose of this study is to develop a model sample of a heat exchanger-accumulator with increased heat transfer intensification due to coil vibrations in two planes.

Research problem:

- to review the most well-known energy-efficient hot water heating systems for industrial and domestic needs using heat exchangers-accumulators and make an analysis of the efficiency;
- develop a mock-up of a supercharger heat exchanger with a capacity of 8 l / h;
- develop a diagram of a laboratory installation and conduct laboratory tests of a mock-up sample of a heat exchanger-accumulator with an oscillating coil;
- develop a mathematical model of a laboratory installation with a heat exchanger-accumulator with a vibrating coil in the form of an energy chain and conduct modeling of hydrodynamics and heat transfer processes;

- conduct hydraulic and thermal tests of a model sample of a battery heat exchanger with a vibrating coil for various pulse modes, obtain experimental results and evaluate their effectiveness.

2 Theoretical background

2.1 Mathematical transformation of the energy stage 1

The method of energy chains is successfully used to study the dynamics of adjacent systems with different physical nature. In contrast to transfer functions, energy chains operate with specific physical parameters (mass, active resistance, pliability).

As a disadvantage of energy chains, we can note the localization, but this does not matter significantly for our tasks.

The energy chain shown in figure 2.1 has three links:

1. Hydraulic link - count the loss of pressure by friction when fluid flows in a coil with active resistance r_1, taking into account the losses and the resistance valve r_2 and the inertial property of the liquid m_1.
2. Converter link - converts the pressure p to the force f, as well as the flow rate V to the linear velocity v.
3. Mechanical link - takes into account the friction losses in the supports of the heat exchanger using the resistance r_3, the mass of the oscillating parts m_2 and the elastic properties of the spring with the pliability l.

Let's compose the scheme of the energy chain:

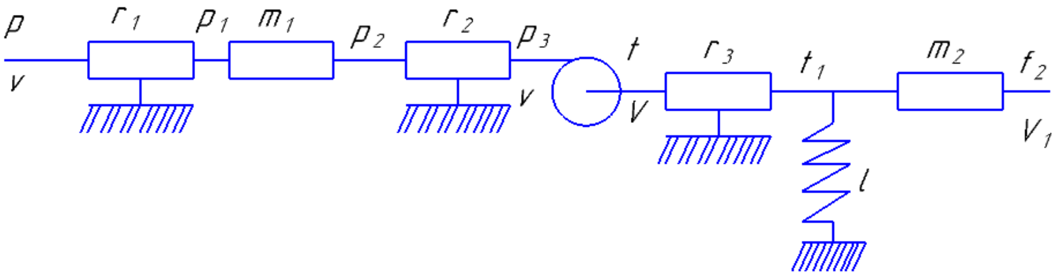

Figure 2.1 - Scheme of the energy circuit

We get three links in the energy chain 1. For each we make a system of equations.

For the first link:

$$\begin{cases} p = r_1 \cdot V^2 + m_1 \cdot \dot{V} + r_2 \cdot V^2 + P_3 \\ V = V \end{cases} . \tag{2.1}$$

For the second link:

$$\begin{cases} P_2 = f / S \\ V = v \cdot S \end{cases} . \tag{2.2}$$

For the third link:

$$\begin{cases} f = r_3 \cdot v + m_2 \cdot \dot{v}_1 + f_2 \\ V = l_2 \cdot \dot{f}_1 + v_1 \end{cases} . \tag{2.3}$$

Here S - piston area.

We can measure the speed of movement of the coil. So the black box will look like this:

Figure 2.2 - Scheme of the energy circuit way

The complex resistance of the circuit is written:

$$Z(S) = \frac{v_1(S)}{F_2(S)}. \tag{2.4}$$

Thus, we will transform the equations from right to left.

Imagine f_2 and V_1 as:

$$\begin{gathered} f_2 = f_{20} + \overline{f_2} \\ V_1 = V_{10} + \overline{V_1}\ . \end{gathered} \tag{2.5}$$

Equation on increment:

$$\dot{\overline{f_1}} = m_2 \dot{V_1} + f_2 \tag{2.6}$$

$$\dot{\overline{f_1}} = m_2 (V_{10} + \overline{V_1}) + f_{20} + \overline{f_2} \tag{2.7}$$

$$\dot{f_1} = m_2 \dot{\overline{V}}_1 + \dot{\overline{f_2}} \tag{2.8}$$

$$f = r_3 l m_2 \dot{\overline{v_1}} + r_3 l \dot{\overline{f_2}} + r_3 v_{10} + r_3 \overline{v_1} + m_2 \dot{\overline{v_1}} + f_{20} + \overline{f_2} \tag{2.9}$$

$$v = l\ (m_2 \dot{\overline{v_1}} + \dot{\overline{f_2}}) + v_{10} + \overline{v_1}\ . \tag{2.10}$$

Equation on P_3 :

$$P_3 = f / S = ((r_3 l m_2 + \dot{\overline{f_2}}) \cdot \dot{\overline{v_1}} + r_3 \overline{v_1} + r_3 v_{10} + r_3 l \dot{\overline{f_2}} + f_{20} + \overline{f_2}) / s \tag{2.11}$$

$$V = (l\ (m_2 \dot{\overline{v_1}} + \dot{\overline{f_2}}) + v_{10} + \overline{v_1}) / S . \tag{2.12}$$

Equation on V^2:

$$\begin{aligned} V^2 &\approx ([l\ m_2 \dot{\overline{v_1}} + \overline{v_1} + \dot{\overline{f}}) + v_{10}]^2) \cdot S \approx (v_{10}^2 + 2v_{10}(l\ m_2 \dot{\overline{v_1}} + \overline{v_1} + \dot{\overline{f}})) \cdot S \\ &= S^2 \cdot v_{10}^2 + 2 \cdot v_{10} \cdot S^2 \cdot l\ \cdot m_2 \cdot \dot{\overline{v_1}} + 2 \cdot S^2 \cdot v_{10} \cdot \overline{v_1} + 2 \cdot S^2 \cdot v_{10} \cdot \dot{\overline{f_2}} \end{aligned} \tag{2.13}$$

Equation on $\dot{\overline{V}}$:

$$\dot{\overline{V}} = S \cdot l\ \cdot m_2 \cdot \ddot{\overline{v_1}} + S \cdot \dot{\overline{v}}_1 + S \cdot l\ \cdot \ddot{\overline{f_2}} . \tag{2.14}$$

Equation on P:

$$\begin{aligned} P &= (S^2 \cdot r_1 \cdot v_{10}^2) + (r_1 \cdot 2 \cdot v_{10} \cdot S^2 \cdot l\ \cdot m_2 \cdot \dot{\overline{v_1}}) + (r_1 \cdot 2 \cdot S^2 \cdot v_{10} \cdot \overline{v_1}) + \\ &+ (r_1 \cdot S^2 \cdot v_{10} \cdot l \cdot \dot{\overline{f_2}}) + (S \cdot m_1 \cdot m_2 \cdot \ddot{v}_1) + (S \cdot m_1 \cdot \dot{\overline{v_1}}) + (S \cdot m_1 \cdot l \cdot \ddot{\overline{f_2}}) + \\ &+ (r_2 \cdot S^2 \cdot v_{10}^2) + (r_2 \cdot S^2 \cdot 2v_{10} \cdot l \cdot m_2 \cdot \dot{\overline{v_1}}) + (r_2 \cdot S^2 \cdot v_{10} \cdot \overline{v_1}) + \\ &+ (r_2 \cdot S^2 \cdot v_{10} \cdot l \cdot \dot{\overline{f}}_2) + \left(\frac{r_3 \cdot \dot{\overline{v_1}} \cdot l \cdot m_2}{S}\right) + \left(\frac{r_3 \cdot \overline{v_1}}{S}\right) + \left(\frac{r_3 \cdot v_{10}}{S}\right) + \left(\frac{r_3 \cdot l \cdot \dot{\overline{f_2}}}{S}\right) + \\ &+ \left(\frac{\overline{f_2}}{S}\right) + \left(\frac{f_{20}}{S}\right). \end{aligned} \tag{2.15}$$

We make mathematical transformations on the system

$$p=(S\cdot l\ \cdot m_2\cdot m_1\cdot \ddot{\overline{v}}_1)+\dot{\overline{v}}_1\cdot(S^2\cdot r_1\cdot 2\cdot v_{10}\cdot l\ \cdot m_2+S\cdot m_1+S^2\cdot r_2\cdot 2\cdot v_{10}\cdot l\cdot m_2+\frac{r_3\cdot l\cdot m_2}{S})+$$
$$+\overline{v}_1\cdot(S^2\ \cdot r_1\cdot v_{10}+S^2\cdot r_2\cdot v_{10}+\frac{r_3}{S})+\ddot{\overline{f}}_2\cdot S\cdot m_1\cdot l+$$
$$+\dot{\overline{f}}_2\cdot(S^2\cdot r_1\cdot v_{10}\cdot l+S^2\cdot r_2\cdot v_{10}\cdot l+\frac{r_3\cdot l}{S})+\frac{f_2}{S} \tag{2.16}$$

Here are the value of the coefficients:

$$a_1=S\cdot l\ \cdot m_2\cdot m\ . \tag{2.17}$$

$$a_3=S^2\ \cdot r_1\cdot v_{10}+S^2\cdot r_2\cdot v_{10}+\frac{r_3}{S} \tag{2.18}$$

$$b_1\ =S\cdot m_1\cdot l \tag{2.19}$$

$$b_2=S^2\cdot r_1\cdot v_{10}\cdot l+S^2\cdot r_2\cdot v_{10}\cdot l+\frac{r_3\cdot l}{S} \tag{2.20}$$

$$b_3=\frac{1}{S} \tag{2.21}$$

The last equation of the image:

$$(a_1\cdot p^2+a_2\cdot p+1)V(p)=-(b_1\cdot p^2+b_2\cdot p_2+1)\,f\,(p)\,. \tag{2.22}$$

Complex resistance circuit:

$$Z(p)=-\frac{a_1\cdot p^2+a_2\cdot p+1}{b_1\cdot p^2+b_2\cdot p+1}\,. \tag{2.23}$$

The frequency functions of the circuit:

$$
\begin{aligned}
Z(j\Omega) &= -\frac{-a_1\cdot\Omega^2 + a_2\cdot j\cdot\Omega + 1}{-b_1\cdot\Omega^2 + b_2\cdot j\cdot\Omega + 1} = \frac{1 - a_1\cdot\Omega^2 + a_2\cdot j\cdot\Omega}{b_1\cdot\Omega^2 - 1 - b_2\cdot j\cdot\Omega} = \\
&= \frac{(1 - a_1\cdot\Omega^2 + a_2\cdot j\cdot\Omega)\cdot((b_1\cdot\Omega^2 - 1) + b_2\cdot j\cdot\Omega)}{((b_1\cdot\Omega^2 - 1) - b_2\cdot j\cdot\Omega))\cdot((b_1\cdot\Omega^2 - 1) + b_2\cdot j\cdot\Omega)} = \\
&= \frac{b_1\cdot\Omega^2 - 1 + b_2\cdot j\cdot\Omega - a_1\cdot b_1\cdot\Omega^4 + a_1\cdot\Omega^2 - a_1\cdot b_2\cdot j\cdot\Omega^3 + a_2\cdot b_1\cdot j\cdot\Omega^3 - a_2 j\Omega - a_2 b_2\Omega^2}{(b_1\cdot\Omega^2 - 1)^2 + b_2{}^2\cdot\Omega^2} = \\
&= \frac{(b_1\cdot\Omega^2 - 1 - a_1\cdot b_1\cdot\Omega^4 + a_1\cdot\Omega^2 - a_2 b_2\Omega^2) + (b_2\cdot\Omega - a_1\cdot b_2\cdot\Omega^3 + a_2\cdot b_1\cdot\Omega^3 - a_2\Omega}{(b_1\cdot\Omega^2 - 1)^2 + b_2{}^2\cdot\Omega^2})\cdot j.
\end{aligned}
\tag{2.24}
$$

The real part of the frequency function:

$$
\mathrm{Re}(j\Omega) = \frac{b_1\cdot\Omega^2 - 1 - a_1\cdot b_1\cdot\Omega^4 + a_1\cdot\Omega^2 - a_2\cdot b_2\cdot\Omega^2}{(b_1\cdot\Omega^2 - 1)^2 + b_2{}^2\cdot\Omega^2}. \tag{2.25}
$$

The imaginary part of the frequency function:

$$
Z_M(j\Omega) = \frac{b_2\cdot\Omega - a_1\cdot b_2\cdot\Omega^3 - a_2\cdot\Omega}{(b_1\cdot\Omega^2 - 1)^2 + b_2{}^2\cdot\Omega^2}\cdot j. \tag{2.26}
$$

Amplitude frequency response of the circuit:

$$
A(\Omega) = \sqrt{\mathrm{Re}(j\Omega)^2 + Z_M(j\Omega)^2}. \tag{2.27}
$$

Phase frequency response of the circuit:

$$
\varphi(\Omega) = -\,arctg\,\frac{Z_M(j\Omega)}{\mathrm{Re}(j\Omega)}. \tag{2.28}
$$

2.2 Mathematical transformation of the energy stage 2

Consider this circuit link:

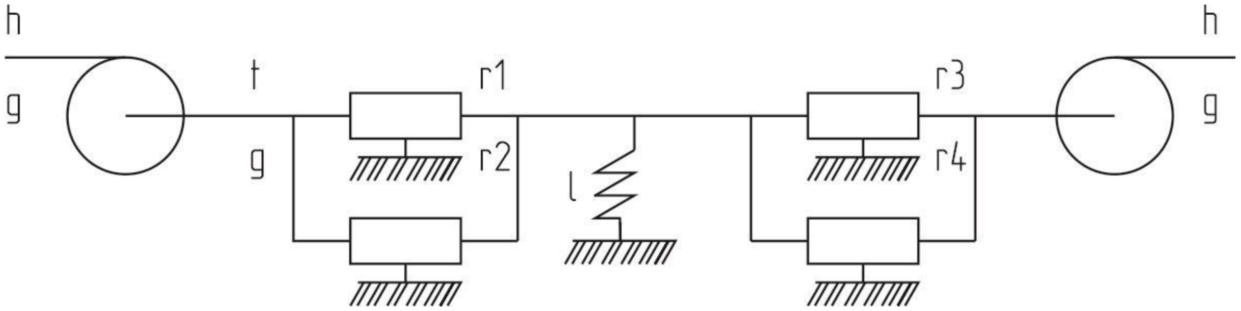

Figure 2.3 - Energy circuit of heat transfer

The circuit link equation:

$$\begin{cases} Z_1 = \dfrac{r_1 \cdot r_2}{r_1 + r_2} \\ Z_2 = \dfrac{r_3 \cdot r_4}{r_3 + r_4} \\ Z_3 = -\dfrac{1}{l \cdot p} \end{cases} \quad (2.30)$$

.

$$Z_{\Sigma} = Z_1 + Z_2 + Z_3 \quad (2.31)$$

.

2.3 Construction of frequency characteristics of the circuit when changing at least three parameters

After all the energy circuit were found integrated resistance, the amplitude – frequency characteristic, phase – frequency characteristics, will be sold with graphs that will clearly shows which parameter is affected to a greater or lesser extent on one or another dependency.

Several specific input parameters are accepted, with the help of which the simulation will take place Values may vary depending on our goals. All values will be listed in table 1.

Table 2.1 - Values for constructing frequency characteristics

M1=M2, kg	r1=r2=r3,N	V,l/sec	L1,mm/kg	P0, kPa	S mm^2
6,5	95,5	0,314	0,00011	300	0,001

Dependency graphs are plotted based on the input values. For the best perception of graphs values are taken only those that affect the dependence. The values obtained for the first stage of the energy circuit are shown in table 2.

.

Table 2.2 - Value amplitude frequency response for energy circuit 1:

Ω	A (Ω)	Ω	φ (Ω)
1	7.054341177	1	-0.089687295
2	7.125696105	2	-0.04498559
3	7.139036836	3	-0.030008009
4	7.143715554	4	-0.022510628
5	7.145882797	5	-0.018010206
6	7.147060507	6	-0.015009269
7	7.147770779	7	-0.012865477
8	7.148231834	8	-0.011257508
9	7.148547959	9	-0.010006799
10	7.148774095	10	-0.009006196

Further in these graphs are under construction:

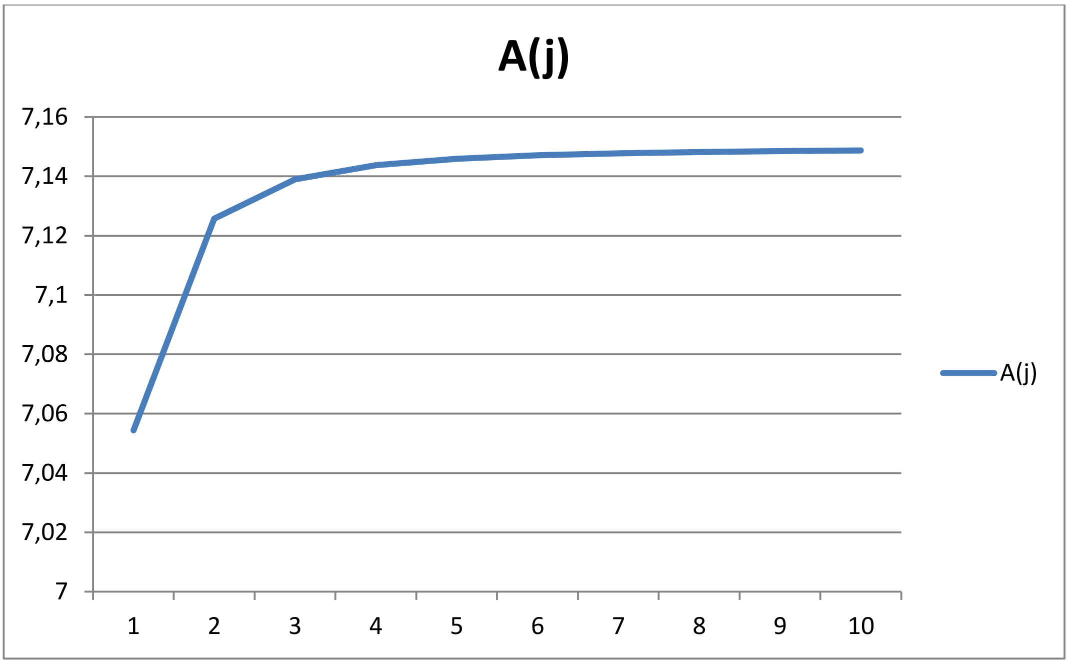

Figure 2.4 - Graphics A(j)

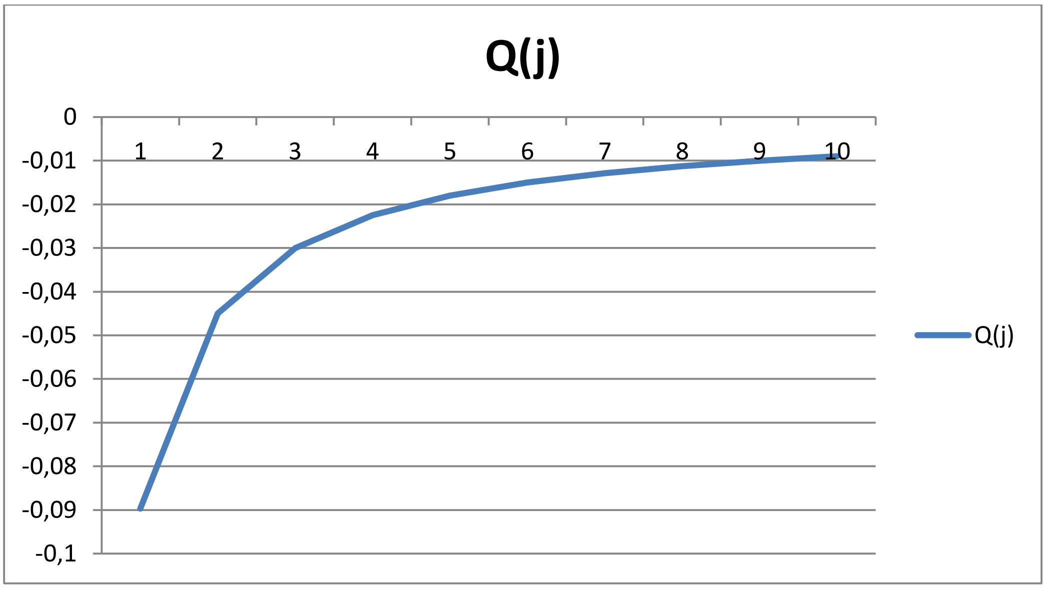

Figure 2.5 - Graphics Q(j)

3 Description of the experimental device

3.1 Prerequisites for creating a shock unit

When creating the layout of the impact device, it is generally considered that a few devices generate pulses according to the amount of motion.

The following picture shows the impact equipment:

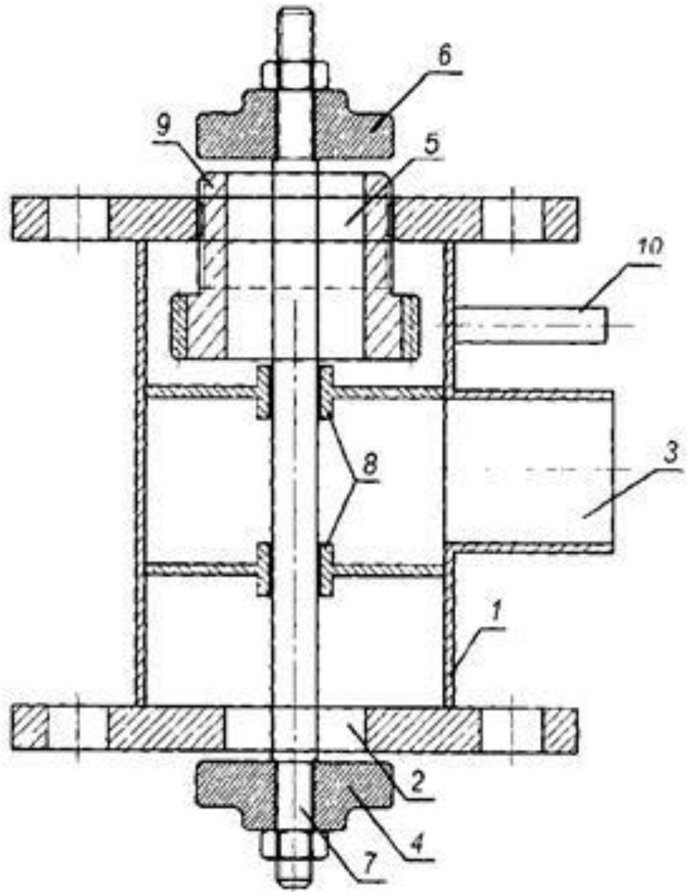

Figure 3.1 - Design of impact site

The shock absorbing assembly comprises a cylindrical body 1 with an inlet 2 and an outlet 3, impact valve 4 and a second damping valve 6 above the second inlet 5.

The inlet holes 2 and 5 are made coaxially along a centering rod 7 in a cylindrical housing 1 mounted on the sleeve 8, wherein the impact valves 4 and 6 are rigidly fixed at their ends.

A movable seat 9 is screwed into the second inlet 5, the worm gear 10 associated with the adjustment screw 11.

The impact member operates as follows: the liquid flow is simultaneously produced by one source in the two inlet openings 2 and 5. The distance between the impact valves 4 and 6 is greater than the distance between the inlets 2 and 5.

With one inlet fully open, the second is fully closed, ie one of the impact valves is "raised" and the second is in close proximity to the movable seat 9.

When the inlet is opened, water passing through it acts on the open damping valve, causing it to close and generate a hydraulic shock. And since the damper valves 4 and 6 are rigidly connected to each other by the centering rod 7, the movement of one of them causes the movement of the other, that is, the complete closing of one of them causes the other to be completely opened. For another impact valve, the process repeats in the same order.

Therefore, as shown in figure 3.1, this design can independently support the closing and opening of the damper valves 4 and 6. During the rotation, the strokes of the damping valves 4 and 6 are adjusted by the adjusting screw 11. Here, the torque is transmitted through the worm wheel 10 to the movable seat 9 screwed into the second inlet 5.

When the movable seat 9 is rotated, its translational movement is provided to increase or decrease the stroke of the impact valves 4 and 6.

A known design disadvantage of the impact member is its relatively low stability at low flow rates of the working medium and the violation of the alternating opening phase of the impact valve during operation of the device.

3.2 Impact unit with external drive

To improve technical and economic indicators, many options for optimizing modern heating and water supply systems are offered.

The use of locally generated pulses for the motion of the working body is one of these solutions.

In the water supply system, according to the principle of operation of the hydraulic RAM, the pulses of these working media are used to supply water to the consumer.

Periodic local water hammers are used in heating systems to improve heat exchange, achieve self-cleaning conditions for the coolant circulation surfaces of thermal equipment, and to mix and transfer coolant flows with different temperatures. For example, the heat network is included in the upper part of the heat loss system.

The tool for generating pulses of the working body movement value is a shock element (Aileron flow), which is installed in the heating and heating system in accordance with a specific solution, the solution of which is determined by the scope and purpose of the device.

Currently, there are a large number of technical solutions for flow aneurysms, which creates certain difficulties when choosing the actual use.

Currently, a utility model - the Shock component-has been developed. It belongs to the field of hydrodynamics, hydraulics and mechanical engineering and can be used in various fields where hydraulic shock and heating are used to create the impulse movement of liquids. This is due to the increased heat exchange of thermal power plants.

To generate a pulsating flow of the working fluid through a flow energy Converter, a shock node was installed in the experiment, as shown in the following figure:

Figure 3.2 - Impact site

The impact unit includes a hollow body and a cam rod, the hollow body having two holes for input and output for exhalation of the working medium. The impact valve is rigidly fixed in rigidity in the vertical direction and is mounted in the sleeve to reciprocate like a piston.

3.3 Operating principle of the impact

The impactor works as follows: the upper end of the component is connected to the outlet of the coil of the heat exchanger, and the lower end is connected to the hot water return tube. The inner Cam is connected to the electric motor via a metal rod on the right side, and the rotation of the Cam drives the reciprocating movement of the inner piston (valve), thereby causing a pulsation inside the pipe. The operating frequency of the ripple generator can be controlled by controlling the motor speed. The speed is controlled by a frequency Converter.

When using diagrams it is necessary to pay attention to:

- increase the stability of the damping device, since the opening and closing stages of the damping valve determine the position of the VALVE only when the shaft rotates and do not depend on the flow of the working medium;

- provides the ability to control the frequency of pulse generation of the working fluid movement regardless of the flow rate through the device;

- the task of obtaining a given added pressure value for hydraulic shock in the working environment at a wide range of flow rates

3.4 Installation of experimental equipment

The invention relates to the field of heat power engineering and can be used in the design of surface – type capacitive recuperative heat exchangers-mainly water-water heaters in heat supply and hot water supply systems.

It is known that in convective heat exchangers, channels for the passage of hot and cold working bodies are most often made in the form of smooth-walled pipes (RU 2150644, F28 D 7/00, publ. 10.06.2000).

The disadvantage of the known device is that during the flow of a contaminated liquid, suspended substances settle on the heat exchange surface, which worsens heat exchange.

There are known heat exchangers, in the channels of which complex surfaces – turbolizers-are placed to intensify heat exchange (SU 1383083, F28 F 1/40, F28 F 13/02, publ. 23.03.1988).

The disadvantage of the known device is the complexity of manufacturing.

Known heat exchangers that contain rubber pistons, polymer brushes, metal ruffs, specially rotating impellers or drills for cleaning heat transfer surfaces (RU 2130155, F28 D, 7/02, F28 G 7/00, publ. 10.05.1999).

The disadvantage of these devices is that during mechanical cleaning, partial damage to the heat transfer surfaces may occur, which accelerates corrosion, and in addition, cleaning requires stopping and disassembling the heat exchanger.

The closest technical solution is a heat exchanger containing a casing with inlet and outlet pipes, inside which a tubular system in the form of a coil with a heating circuit inlet pipe not rigidly connected to the casing, the coil is made in the form of a cone located in the center of the casing in hinged supports fixed rigidly to the casing, a shock unit connected to an electric drive. (RU 2 680 768, F28G 13/00, F28D 7/02, publ.26.02.2019).

The disadvantage of the known device is the restriction of the movement of the cone coil when it is subjected to hydraulic shock and, as a result, the heat transfer efficiency is not high enough.

The technical result is to increase the heat transfer coefficient in the heat exchanger between the heating and heated medium, reduce the metal content and simplify the design, self-cleaning the heat transfer surface.

The technical result is achieved due to the fact that the heat exchanger comprises a sealed casing with inlet and outlet pipe of the heating circuit, a tubular system, the heating circuit inlet, a cylindrical coil, the input and output of which is soldered pistons, installed the lower and upper chambers that perform the function of pivot bearings, a discharge nozzle with a shock site, and in the top chamber there is an additional spring.

The drawing shows a General view of the heat exchanger.

The heat exchanger comprises a housing 1 with inlet 2 and outlet pipe 3 for the heated circuit to the inlet 4 of the heating medium, connected to the upper chamber 5 within which piston 6 is connected with a cylindrical coil 7 in the casing

1, the lower end of the coil is connected to the piston 8 of the lower chamber 9 is connected with an outlet of the heating medium 10 associated with shock node 11 and the upper chamber 5 is additionally installed spring 12.

Combination of theoretical research and experimental methods; finite element numerical modeling simulation method; experimental verification method; comparative study method.

In the course of the study, all the work of the flow energy Converter was divided into 3 stages in order to more accurately understand the nature of the forces arising and more accurately determine the desired parameters on the obtained model

Initially, the heated liquid is filled directly into the heat exchanger housing 1 through the inlet pipe 2, and the heated liquid heated to a certain temperature will be drained through the outlet pipe 3. Then serves the tea to the environment by the input pipe 4, the upper chamber 5, the hollow piston upper chamber 6, a cylindrical coil 7, the piston lower chamber 8, the lower chamber 9, the outlet 10, the striking unit 11. Passing through the cylindrical coil 7, the heating liquid gives off heat to the heated liquid located in the casing 1. When the flow rate of the heating fluid reaches a certain value, the shock unit 11 is triggered and abruptly interrupts the flow, resulting in a hydraulic shock. A direct wave of hydraulic shock is accompanied by a transition of the kinetic energy of the flow into potential energy due to partial compression of the liquid. Further, the stored kinetic energy under the reverse wave of the hydrostrike passes into the kinetic energy of the flow, which is accompanied by its accelerated movement for some time in the opposite direction. The wave of accelerated backflow of the heating medium passing through the cylindrical coil acts on the walls of the cylindrical coil 7, causing a centrifugal force, tangential and axial components that will lift along the axis and twist the cylindrical coil 7 at a certain angle. Upon termination of the impact of the reverse wave of the water hammer, the cylindrical coil 7 is lowered to its original state under the action of the spring 12.

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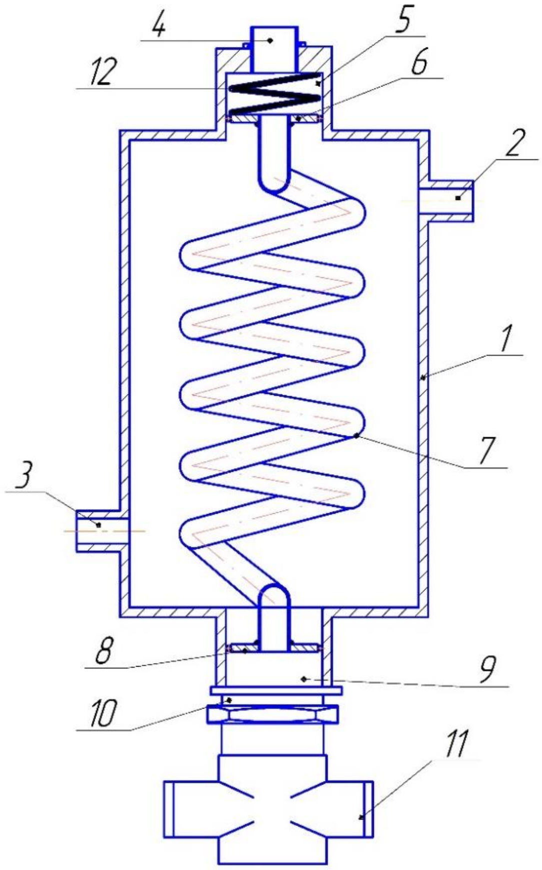


.

Figure 3.3 - The model of the heat exchanger-battery with fluctuating coil

The experimental device in this paper is mainly composed of heat exchanger body, copper coil, flange, rotary joint, pulsation generator, temperature sensor, flow meter, plastic pipe and various size gaskets.

The experimental setup includes: a capacitive regenerative heat exchanger surface, type 1, striking unit 2, electric 3, circulating pump 4 boiler 5 hot water flow meter vane type 6, transmitters temperature, contact-type 7, the General scheme of the experimental setup is presented in Fig. 3.3

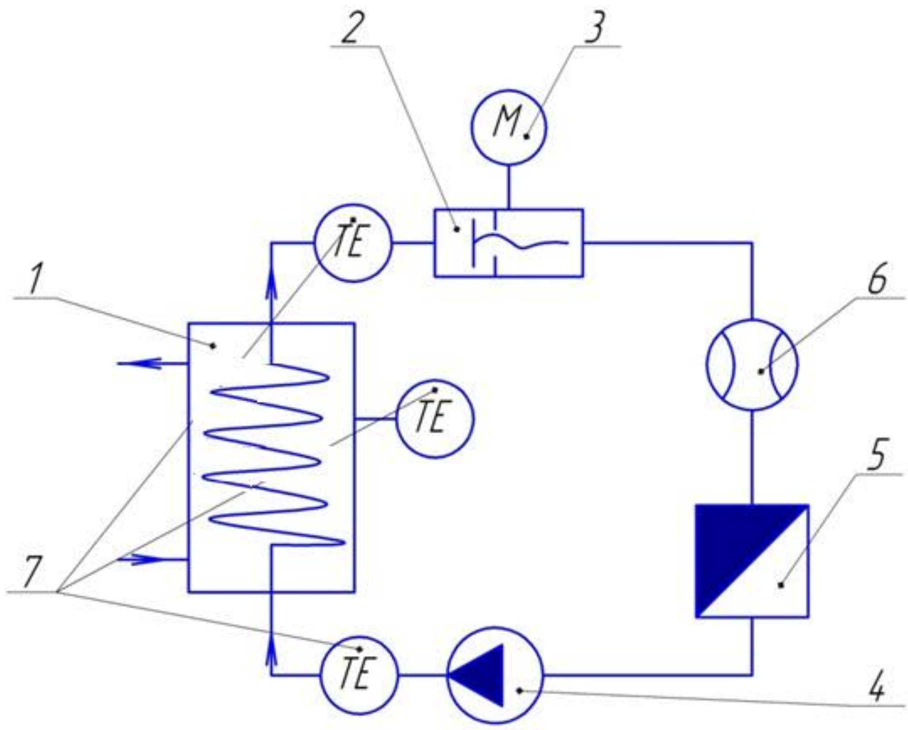


Figure 3.4 - Diagram of the experimental setup

The General view of the experimental installation is shown in Figure 3.4.

An important part of the system is the recuperative heat exchanger. The recuperative heat exchanger Fig. 12 includes a casing 1 with an inlet 2 and outlet 3 pipe at the heated circuit, inside of which is a tubular system in the form of a cone coil 4, mounted vertically in hinged supports 5, fixed to the casing 1. the Cone coil 4 performs an oscillatory movement in case of sharp interruptions of the flow before the outlet pipe 6, due to the impact valve. The heating medium is supplied to the upper hinge support by means of a supply pipe 7.

Figure 3.5 - Heat exchanger body and flange

-Heat exchanger body and flange. The heat exchanger body and flange are made of cast iron and painted to enhance insulation with air.

- Copper coil. The copper tube has strong anti-corrosion performance, is not easy to be oxidized, and is not easy to react with some liquid substances, and is easy to bend and shape.

The copper tube is light in weight, good in thermal conductivity, and high in low temperature strength. Often used in the manufacture of heat exchange equipment (such as condensers, etc.). It is also used in the assembly of cryogenic piping in oxygen plants. Copper pipes with small diameters are often used to transport pressurized fluids (such as lubrication systems, hydraulic systems, etc.) and pressure gauges used as meters.

Figure 3.6 - Copper coil

Copper pipes are the first choice for modern contractors to install tap water pipes, heating and cooling pipes in all residential commercial houses.

1. Since the copper pipe is easy to process and connect, it can save material and total cost when it is installed, and has good stability and reliability, which can save maintenance.

2. Copper is light. For twisted threaded tubes of the same inner diameter, the copper tube does not require the thickness of ferrous metal. When installed, copper pipes are less expensive to transport, easier to maintain, and take up less space.

3. Copper can change shape. Because the copper tube can be bent and deformed, it can often be made into elbows and joints, and smooth bending allows the copper tube to bend at any angle.

4. Copper is easy to connect.

5. Copper is safe. No leakage, no combustion, no toxic gases, corrosion resistance.

A piston is a cylindrical part that makes a reciprocating movement inside the cylinder and serves to turn a change in the pressure of a gas, steam or liquid into mechanical work, or Vice versa — a reciprocating movement into a change in pressure.

The piston performs a number of important functions:

- provides transfer of mechanical forces to the connecting rod;
- responsible for sealing the combustion chamber

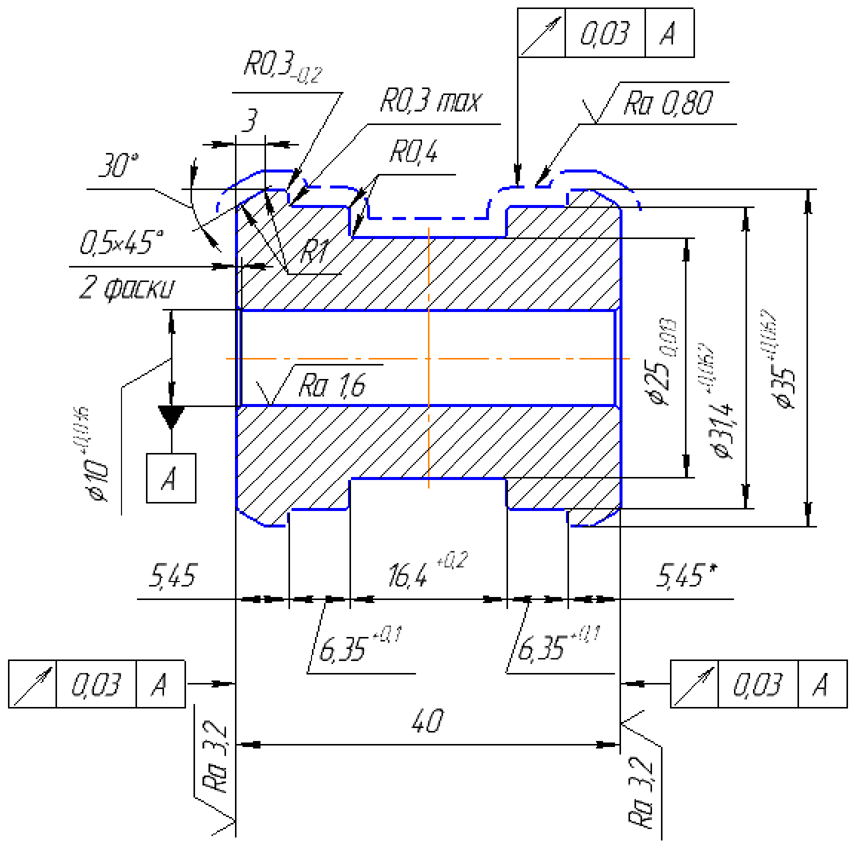


Figure 3.7 - Scheme of the piston

Figure 3.8 - The piston assembly with the sealing element

Rotary joint. Rotary joint is a very important of this installation. The rotary joint fixed to the top flange of the heat exchanger body is connected with a copper coil and a hot water supply pipe on the one hand, and also functions as a seal on the other hand. The rotary joint fixed to the bottom flange of the heat exchanger body is connected to the copper coil and the pulsation generator on the one hand, and the lower part of the coil is sealed on the other hand, prevented the hot water from leaking.

Figure 3.9 - Rotary joint.

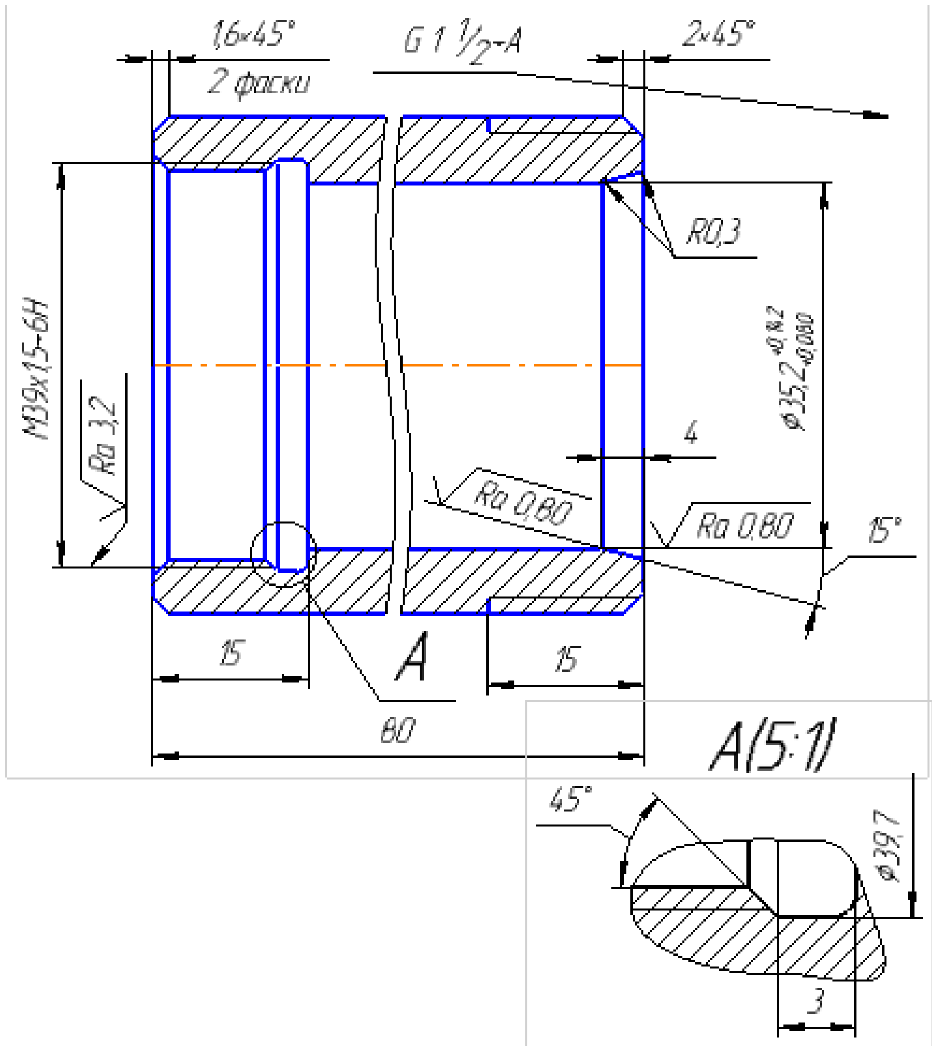


Figure 3.10 - Scheme rotary joint

Flow meter. A flow meter is a meter used to measure the flow of fluid in a pipe or open channel. The flowmeter is further divided into a differential pressure flowmeter, a rotameter, a throttle flowmeter, a slit flowmeter, a volumetric flowmeter, an electromagnetic flowmeter, an ultrasonic flowmeter, and the like. Classified by media: liquid flow meter and gas flow meter. In this paper use liquid flow meter.

The liquid flow meter is a precision instrument for measuring the flow of liquid, gas and steam in the sealed pipe according to the Karman vortex principle. Since the detecting element is sealed in the detecting body, the medium is not measured, and there is no movable part inside, and no on-site maintenance is required. Therefore, it is highly praised by the majority of users and is widely used in textile printing and dyeing, petroleum, chemical, metallurgical, pharmaceutical, thermoelectric, paper, fire industry measurement management and process control.

Figure 3.11 - Flow meter "SGV-15D" BETAR

The main technical characteristics of the flow meter "SGV-15D" BETAR are presented in table 1.

Table 3.1 - Technical characteristics of the flow meter "SGV-15D" BETAR

Indicator	Value
1	2
Diameter of nominal bore DN, mm	15
Nominal water consumption, $м^3$/h	1,5
Sensitivity threshold, no more than, $м^3$/h	0,015
Counter length with fittings, L1, mm	172
Designation of connection dimensions: water flow fittings'	 G ¾ G ½
Weight without a set of mounting parts, kg	0,5

Thermocouple temperature sensor. The thermocouple temperature sensor is one of the most commonly used sensing elements in current temperature measurement. The thermocouple temperature sensor has a simple structure, wide measuring range, high precision, low thermal inertia, and the output signal is an electrical signal, which is convenient for remote transmission or signal conversion. It can also be used to measure the temperature of a fluid and measure the temperature of solid and solid walls.

This experiment has 3 thermocouple temperature sensors, one at the hot water inlet, one at the hot water outlet, and one at the middle of the heat exchanger body.

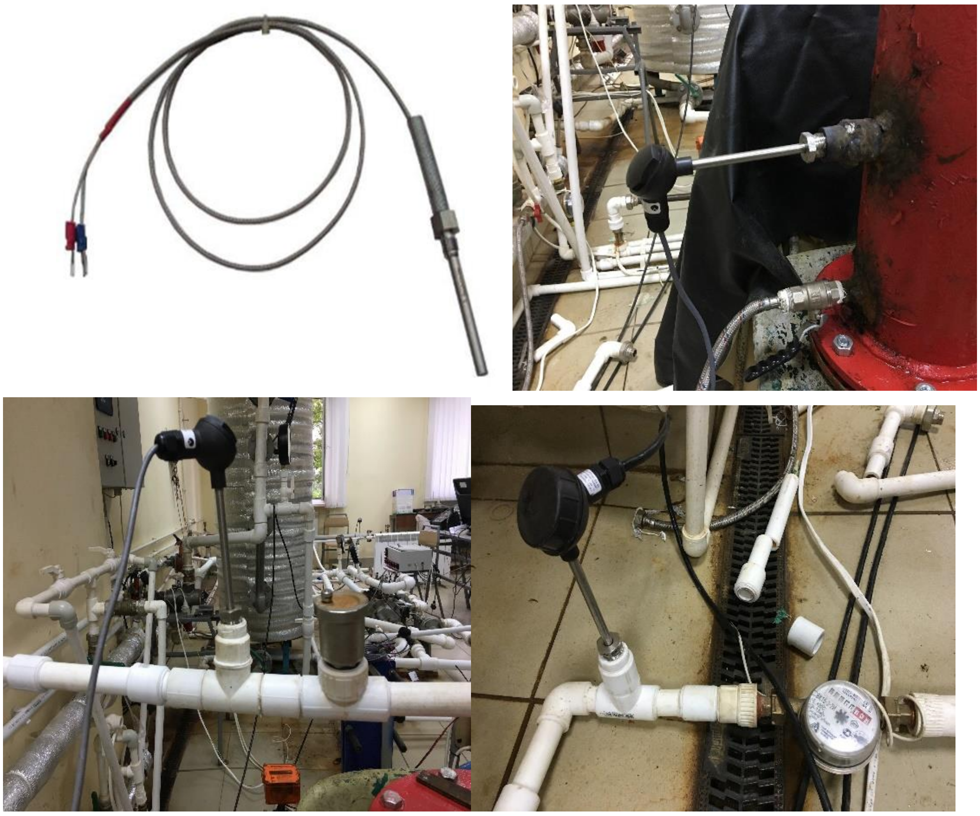


Figure 3.12 - Thermocouple temperature sensor

The basic principle of thermocouple temperature measurement is that two different material conductor combinations form a closed loop. When there is a temperature gradient at both ends, a current flows through the loop, and there is an electromotive force between the two ends - the thermoelectromotive force. This is the so-called Seebeck effect. The two different components of the homogeneous conductor are the hot electrode, the high temperature end is the working end, the low temperature end is the free end, and the free end is generally in a constant temperature state. According to the relationship between thermoelectromotive force and temperature, the thermocouple index table was compiled; the index table when the free end temperature was 0 °C was obtained. Different thermocouples have different index tables.

Thermocouple cold junction compensation calculation method:

From millivolts to temperature: measure the cold junction temperature, convert to the corresponding millivolt value, plus the thermocouple's millivolt conversion temperature.

From temperature to millivolts: measure the actual temperature and cold junction temperature separately and convert to millivolts, then subtract the millivolts to get the temperature.

The main technical characteristics of the resistance thermal Converter are given in table 3.2.

Table 3.2 Technical characteristics of the thermal resistance Converter «DTSO 35L-100M. 0. 5. 60»

Indicator	Value
1	2
The range of measured temperatures	-50...+180 degrees
Class of admission	B;C
Nominal pressure	10 MPa
Insulation resistance	at least 100 MOM
Cable output length	0,2 м
Thermal inertia indicator	no more than 10...30 s
performance of the sensor relative to the housing	isolated
Material of protective reinforcement	steel 12X18H10T
Degree of protection	IP54

4 Results of experimental studies

4.1 Description of the problem concerning this work and ways of its solution (from the analysis literary sources)

The theoretical significance and practical value of the topic

With the rapid development of modern industry and the continuous advancement of science and technology, the demand for energy from human society is increasing day by day. In recent years, energy issues have increasingly become issues of concern to countries around the world. In the area of energy utilization, heat exchangers, as a unit of heat exchange in high-energy-consuming industries, are key equipment for the rational use of energy and energy conservation. The development of high-efficiency, low-resistance, and high-performance heat exchangers can save energy and reduce the output value of the unit, and the use of advanced heat transfer enhancement technology is undoubtedly an effective way to achieve this goal.

The world energy crisis that occurred in the early 1970s strongly promoted the rapid development of heat transfer enhancement technology. To save energy and reduce consumption, and improve the economic benefits of industrial production, it is necessary to study various heat transfer process enhancement problems, develop heat transfer structures and high-efficiency heat transfer equipment that are applicable to different process industry requirements. This is not only a task that must be solved in the process of modern industrial development, but also an urgent task for the development of new energy and energy conservation.

The heat transfer enhancement of the heat exchanger is to make the heat exchanger transfer the most heat in the unit heat transfer area per unit time by changing various factors affecting the heat transfer process. The main purpose of enhanced heat transfer research is to increase the rate of heat transfer process and try to achieve the specified amount of heat in the most economical equipment (small weight, small size,) or faster if the equipment is the same size.Use the highest thermal efficiency to achieve the rational use of energy. Through the unremitting efforts of scholars from various countries, many technical methods for enhancing heat transfer have been proposed. For example: coarse processing of the heat exchange surface, expansion of the heat transfer surface, use of the inlet vortex generator, application of the electrostatic field, and insertion of some spiral ties in the heat exchange tube to increase the turbulence of the fluid, etc..

In practice, the vibration of the heat exchange wall is an unavoidable phenomenon, some of which are caused by the operation of the power plant during operation, and some are caused by fluid induction. People have long realized that the use of vibration can enhance heat transfer. As early as 1923, some scholars have done research on the heat transfer enhancement of the vibration heat exchange surface in the static fluid. The results of the study showed that vibration can theoretically be effectively applied to the actual heat exchanger structure. The vibration itself contributes no more to enhanced heat transfer than any other enhanced heat transfer method. Since then, vibration as a method that can enhance heat transfer has been used in a large number of experimental studies to investigate the effect of vibration on the convective heat transfer effect between the heat transfer surface and the fluid.

4.2 The research status and development trend of this topic

It is known that in convective heat exchangers, channels for the passage of hot and cold working bodies are most often made in the form of smooth-walled pipes [6]

The disadvantage of the known device is that when the contaminated liquid flows, suspended substances settle on the heat exchange surface, which worsens the heat exchange.

There are known heat exchangers in the channels of which complex surfaces – turbolizers-are placed to intensify heat exchange [7].

The disadvantage of the known device is the complexity of manufacturing.

Known heat exchangers that contain rubber pistons, polymer brushes, metal brushes, specially rotating impellers or drills for cleaning heat transfer surfaces [8].

The disadvantage of these devices is that during mechanical cleaning, the heat transfer surfaces may be partially damaged, which accelerates corrosion, and in addition, the heat exchanger must be stopped and disassembled for cleaning.

The closest technical solution is a heat exchanger containing a casing with inlet and outlet pipes, inside which a tubular system in the form of a coil with a heating circuit inlet pipe not rigidly connected to the casing, the coil is made in the form of a cone located in the center of the casing in hinged supports fixed rigidly to the casing, a shock node connected to an electric drive [9]. The disadvantage of the known device is the restriction of the movement of the cone coil when it is exposed to a hydraulic shock and, as a result, the heat transfer efficiency is not high enough.

The technical result is to increase the heat transfer coefficient in the heat exchanger between the heating and the heated medium, reduce the metal content and simplify the design, self-cleaning of the heat transfer surface.

The technical result is achieved due to the fact that the heat exchanger comprises a sealed casing with inlet and outlet pipe of the heating circuit, a tubular system, the heating circuit inlet, a cylindrical coil, the input and output of which is soldered pistons, installed the lower and upper chambers that perform the function of pivot bearings, a discharge nozzle with a shock site, and in the top chamber there is an additional spring.

The above review summarizes the experimental research and development of vibration enhanced heat transfer. From the published literature, there are many experiments or studies involving the principle of vibration enhanced heat transfer, but few can be put into practical engineering applications. Therefore, it is of great significance for the in-depth study of the vibration enhanced heat transfer device.

4.3 Project research content and research methods

Simplify the mathematical model of the vibration enhanced heat transfer device. The vibration-enhanced heat transfer device has a vibration source and a heat source, and affects the flow of the heat exchange medium during the work process. At the same time, the medium also generates corresponding damping and inertia.

Based on the principle of dynamics, a reasonable structure of the coil vibration system is simplified, and its theoretical calculations are analyzed. According to the results of simulation and theoretical analysis, the vibration characteristics are analyzed. At the same time, the heat transfer characteristics of the heat exchanger are analyzed and the dynamic parameters of the coil vibration system are optimized.

Based on the finite element method, modeling and simulating research on heat exchanger coil system and heat exchange system. Firstly, this device is reasonably simplified. According to the simulation research of heat exchanger working chamber, it is divided into three parts:

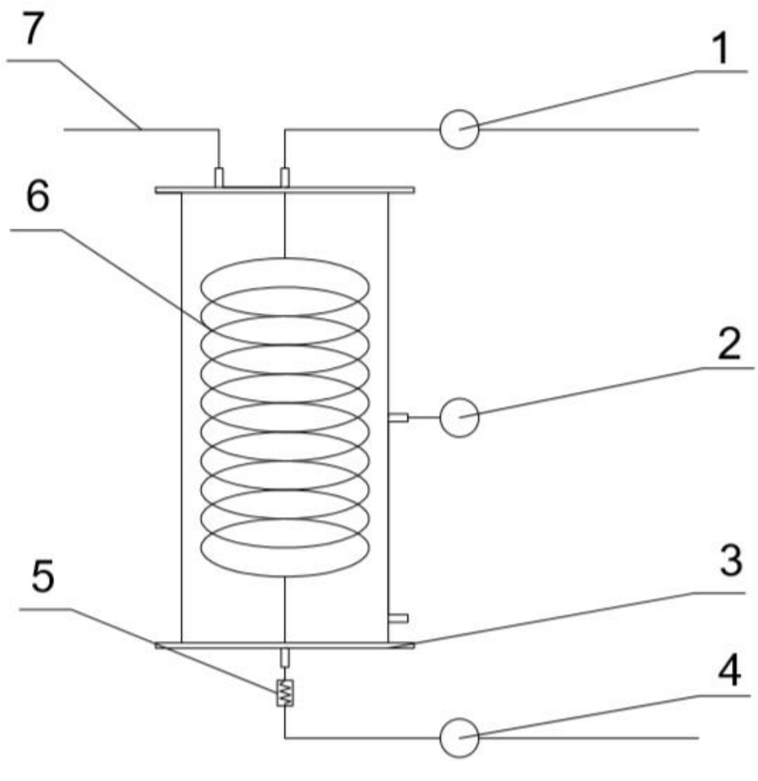
A model of vibration working chamber was established using modeling software. The finite element software (Comsol, Ansys, etc.) was used to mesh the structure, and the excitation characteristics of the excitation end were given.

The modeling software was used to establish the vibration-free working cavity model. Using finite element software (Comsol, Ansys, etc.), the structure was meshed, the excitation end load characteristics were given, and the simulation readout results.

For each group of models, the heat transfer effect under different parameters was obtained by changing the relevant parameters of the simulation model, and the heat transfer effect of each structure was compared with the application of the convective heat transfer coefficient evaluation method.

4.4 Preparation of the power circuit of the installation for hydraulics with a description of the individual links

The experimental device in this paper can be simplified as shown in the figure as follows:



1, 2 and 4 are temperature sensors; 3 is flange; 5 is hydraulic shock valve; 6 coil; 7 is feed pipe of cold water.

Figure 4.1 - experimental device diagram

4.5 Description of the test program

Installation of laboratory equipment includes assembly of structural components, such as:

- metal heat exchanger body;
- Copper coil, Ø 10 mm;
- flange;
- Rotary joint;
- electric engine;
- Polypropylene water pipe, Ø25mm;
- impact node;
- liquid flow meter;
- thermocouple temperature sensor;
- Drain valve, installed at the pipe outlet of the working environment;

The impact node is installed in a network behind the energy flow converter, the rotation of which is performed due to the operation of the 12V engine.

Once assembled, the installation will be installed on the network to provide a working environment. Multiple tests were performed by varying the flow rate of the working medium, the number of revolutions of the motor, and the rotation of the rolls of the impact unit.

4.6 Experiment planning

When choosing an experimental area, first of all, you need to evaluate the boundaries of the areas of determining factors. Several types of restrictions must be taken into account. The first type is the principle restrictions for the values of factors that can not be violated under any circumstances. For example, if the factor is temperature, the lower limit is absolute zero. The second type-restrictions related to technical and economic considerations, such as the cost of raw materials, the scarcity of individual components, and the time of the process. The third type of restriction that most often has to deal with is determined by the specific conditions of the process, Such as existing equipment, technology, or organization. In a reactor made of a certain material, the temperature cannot be raised above the melting point of this material or above the operating temperature of this catalyst. Optimization usually begins when the object has already been subjected to some research. The information contained in the results of previous studies will be called a priori (i.e. obtained before the experiment). We can use a priori information to get an idea of the optimization parameter, the factors, the best conditions for conducting the process and the nature of the response surface, i.e., how much the optimization parameter changes with small changes in the values of factors, as well as the curvature of the surface.

The amount of error in the measurement result of a physical quantity gives an idea of which numbers in the numerical value of the measured quantity are doubtful. Therefore, the measurement results should be rounded off before making further calculations with them.

Round the numeric value of the measurement result in accordance with the numeric digit of the significant error figure. They follow the General rounding rules.

For practical processing of measurement results, the following operations can be performed sequentially:

Planning an experiment

- Record the measurement results;
- Calculate the average value from n measurements:

$$a = \frac{1}{\text{т}} \cdot \sum_{i=1}^{n} a_i \qquad (4.1)$$

-To determine the error of the individual measurements:

$$V_i = a - a_i \tag{4.2}$$

- Calculate the squares of the errors of individual measurements V_i^2
- If several measurements differ sharply in their values from the rest of the measurements, then you should check whether they are a miss. If one or more dimensions are excluded, repeat step 1 ... 4;
- The average square error of the result of a series of measurements is determined

$$S_a = \sqrt{\frac{\sum_{i=1}^{n} V^2}{n(n-1)}} \tag{4.3}$$

- Sets the reliability value a;
- Student's coefficient is determined

for the selected reliability a and the number of measurements performed n;

- Limits of the confidence interval are found

$$\Delta x = t_a(n) \cdot S_a \tag{4.4}$$

If the magnitude of error of the measurements will be comparable to the value of d error of the instrument, the confidence limits should take the value:

$$\Delta x = \sqrt{t^2\,(n)S^2 + \left[\frac{t_{a(\infty)}}{3}\right]^2 \cdot \delta^2} \tag{4.5}$$

- Record the final result:

$$x = a \pm \Delta t \tag{4.6}$$

- Evaluate the relative error of the result of a series of measurements

$$a = \frac{\Delta x}{a} \cdot 100\% \tag{4.7}$$

4.7 Experimental test results

In this experiment, eight sets of data were measured with the same flow rate and with or without the pulsation generator. Below is the raw data.

Table 4.1 - Temperature change at a frequency of 16.6 rad/s

τ/min	with hydraulic shock/°C	without hydraulic shock/°C
0	20	20
0.5	24.8	23
1	29.4	27.4
1.5	34.1	31.8
2	38.4	36.1
2.5	42.2	39.8
3	45.3	43.2
3.5	48.2	46.6
4	51	49.1
4.5	53	51.6
5	55	53.9
5.5	56.7	55.7
6	57.8	57.3
6.5	59.6	58.6
7	60	59.8
7.5		60

Table 4.2 - Temperature change at a frequency of 20.6 rad/s

τ	with hydraulic shock	without hydraulic shock
0	20	20
0.5	24.7	23.9
1	30	28
1.5	34.9	32.3
2	39.2	36.4
2.5	43.8	40.5
3	47.7	44.1
3.5	50.2	46.8
4	53.1	49.4
4.5	55.5	51.9
5	57.1	53.8
5.5	58.7	55.9
6	60	57.7
6.5		59
7		60

Table 4.3 - Temperature change at a frequency of 24.8 rad/s

τ	with hydraulic shock	without hydraulic shock
0	20	20
0.5	25.2	24
1	31.2	28.5
1.5	37.1	32.5
2	41.9	36
2.5	45.9	39.2
3	49.7	42.4
3.5	52.9	44.7
4	55.8	47.1
4.5	57.8	49.4
5	59.4	51.2
5.5	60	53
6		54.8
6.5		56.3
7		57.5
7.5		58.9
8		60

Table 4.4 - Temperature change at a frequency of 28.4 rad/s

τ	with hydraulic shock	without hydraulic shock
0	20	20
0.5	26.7	24.8
1	32.7	29.4
1.5	38.2	33.5
2	43.2	37
2.5	46.5	40.2
3	50.4	43.4
3.5	53.9	45.9
4	56.1	47.8
4.5	58.2	50.2
5	60	52.2
5.5		53.8
6		55.3
6.5		57
7		58.4
7.5		59.5
8		60

Table 4.5 - Comparison of temperature changes at different frequencies

τ	16.6 rad/s	20.6 rad/s	24.8 rad/s	28.4 rad/s
0	20	20	20	20
0.5	24.8	24.7	25.2	26.7
1	29.4	30	31.2	32.7
1.5	34.1	34.9	37.1	38.2
2	38.4	39.2	41.9	43.2
2.5	42.2	43.8	45.9	46.5
3	45.3	47.7	49.7	50.4
3.5	48.2	50.2	52.9	53.9
4	51	53.1	55.8	56.1
4.5	53	55.5	57.8	58.2
5	55	57.1	59.4	60
5.5	56.7	58.7	60	
6	57.8	60		
6.5	59.6			
7	60			

4.8 Analysis of test results

As is shown in figure above, at a frequency of 16.6 rad/s, the temperature change of the heat exchanger is slightly faster when there is a pulsating shock, but it is not obvious enough. From 20 degrees Celsius to 60 degrees Celsius, it is less 0.5 minute than without pulsation.

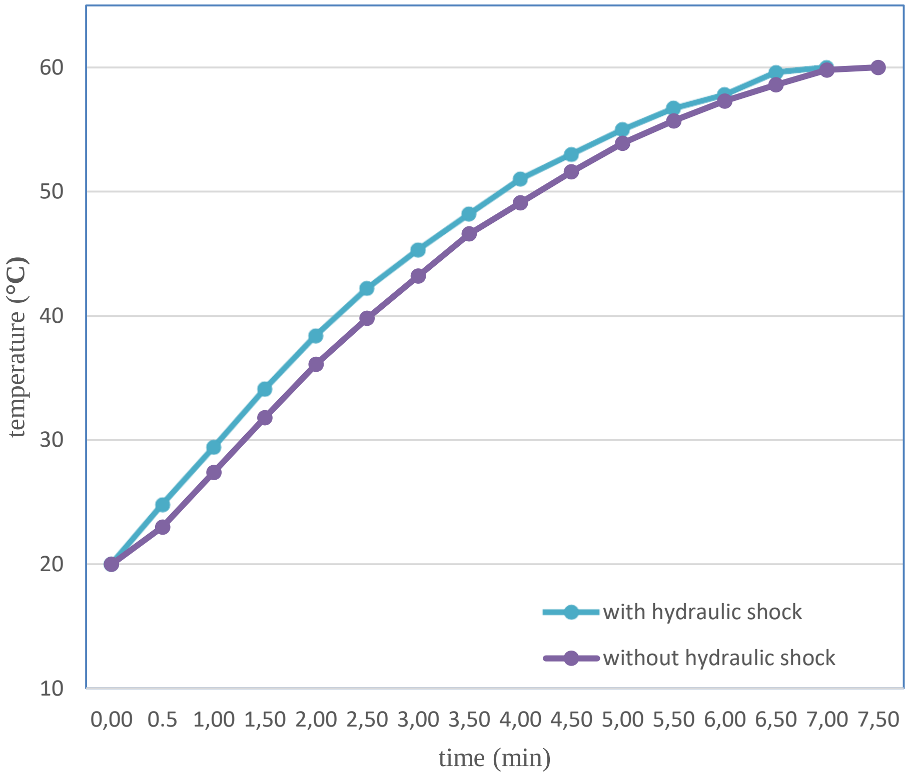


Figure 4.2 - Comparison of temperature changes at a frequency of 16.6 rad/s

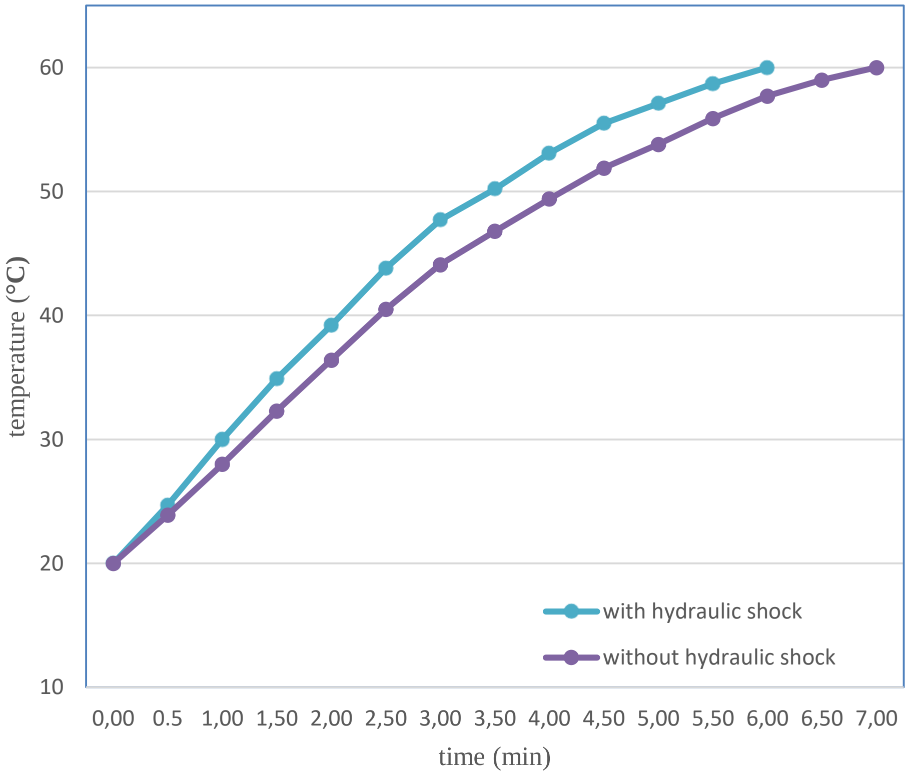


Figure 4.3 - Comparison of temperature changes at a frequency of 20.6 rad/s

As can be seen from the above figure, at a frequency of 20.6 rad/s, the temperature change of the heat exchanger is faster when there is a pulsating shock, which is more obvious than at 16.6 rad/s, from 20 degrees Celsius to 60 degrees Celsius, less 1 minute than without pulsation.

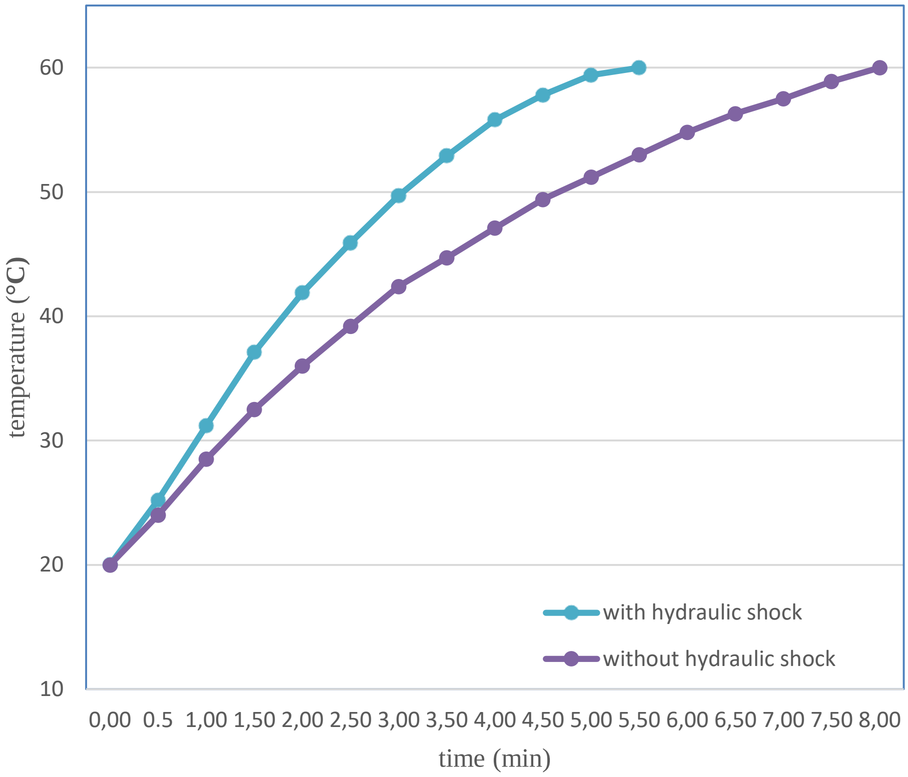


Figure 4.4 - Comparison of temperature changes at a frequency of 24.8 rad/s

It is not difficult to see from the above figure that at a frequency of 24.8 rad/s, the temperature change of the heat exchanger is more rapid when there is a pulsating shock, which is more obvious than at the above two frequencies. From 20 degrees Celsius to 60 degrees Celsius, it is less 2.5 minute than without pulsation.

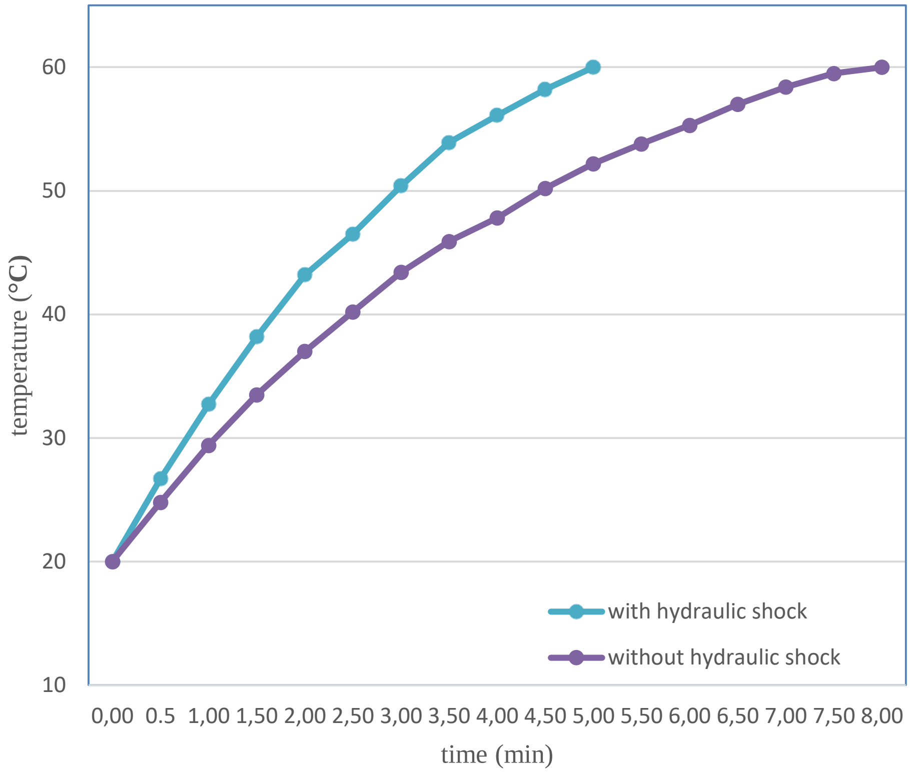


Figure 4.5 - Comparison of temperature changes at a frequency of 28.4 rad/s

It is easy to see from the above figure that at a frequency of 28.4 rad/s, the temperature change of the heat exchanger is very obvious when there is a pulsating impact. In this experiment, the contrast with the pulsation-free impact is the strongest, from 20 degrees Celsius to 60 degrees Celsius. Use less 3 minutes than without pulsation.

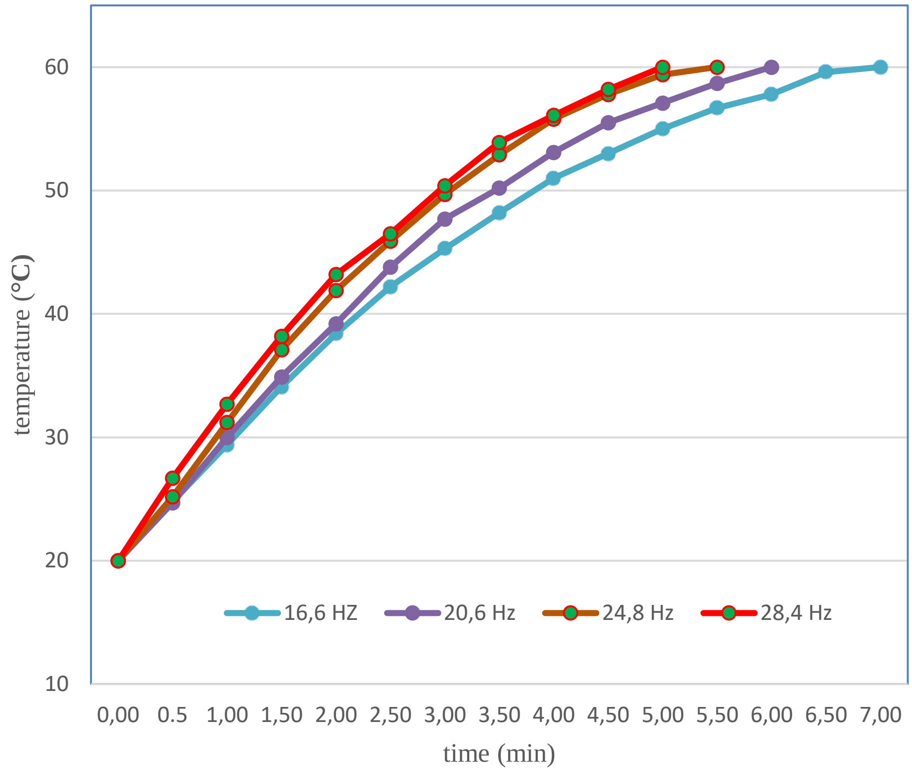


Figure 4.6 - Comparison of temperature changes at different frequencies

As can be seen from the above figure, the temperature change is the fastest when the pulsation frequency is 24.8 rad/s, and the temperature change is the slowest when the pulsation frequency is 16.6 rad/s. The slowest time is 2 minutes longer than the fastest.

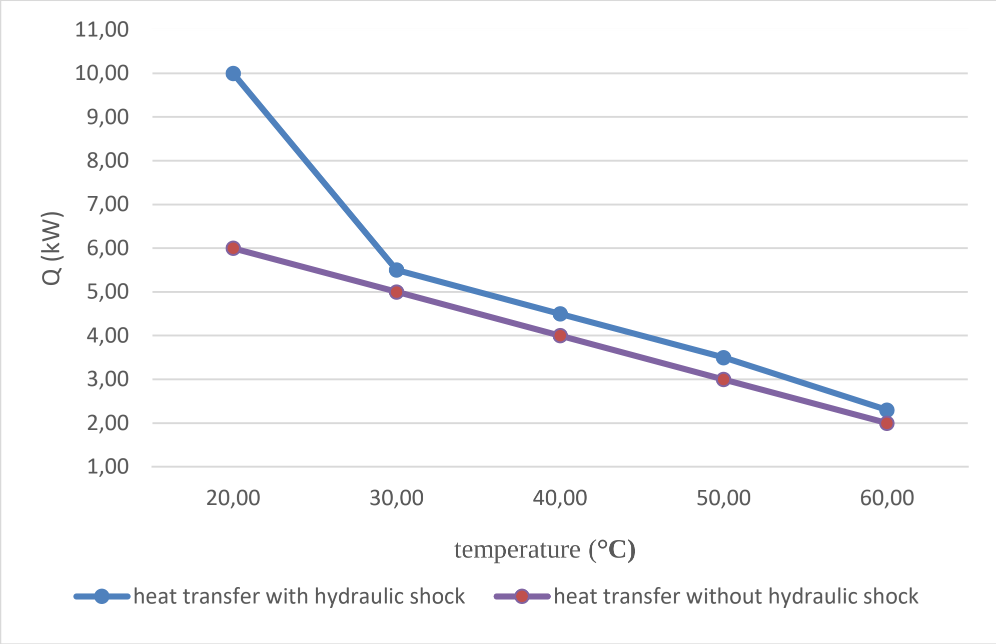


Figure 4.7 - Comparison of heat exchange per second when the flow rate is 0.143 L/s

It can be seen from the figure that when the flow rate is 0.143 L/s, the heat exchange amount is slightly larger than the waterless impact when there is hydraulic shock, but it is not obvious enough.

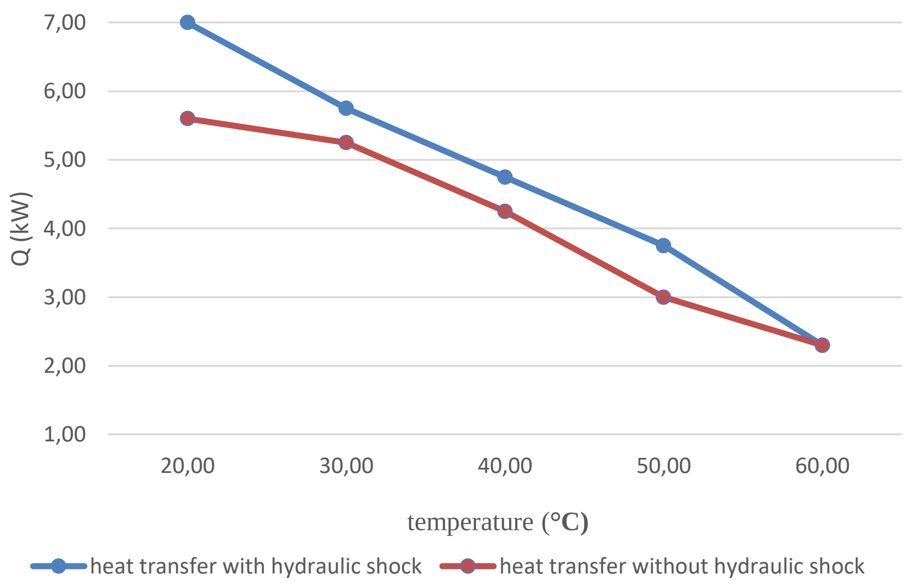


Figure 4.8 - Comparison of heat exchange per second when the flow rate is 0.182 L/s

It can be seen from the figure that when the flow rate is 0.183 L/s, the heat exchange amount is significantly larger than the waterless impact when there is a hydraulic impact. As the temperature of the cold water in the heat exchanger increases, the gap is gradually reduced.

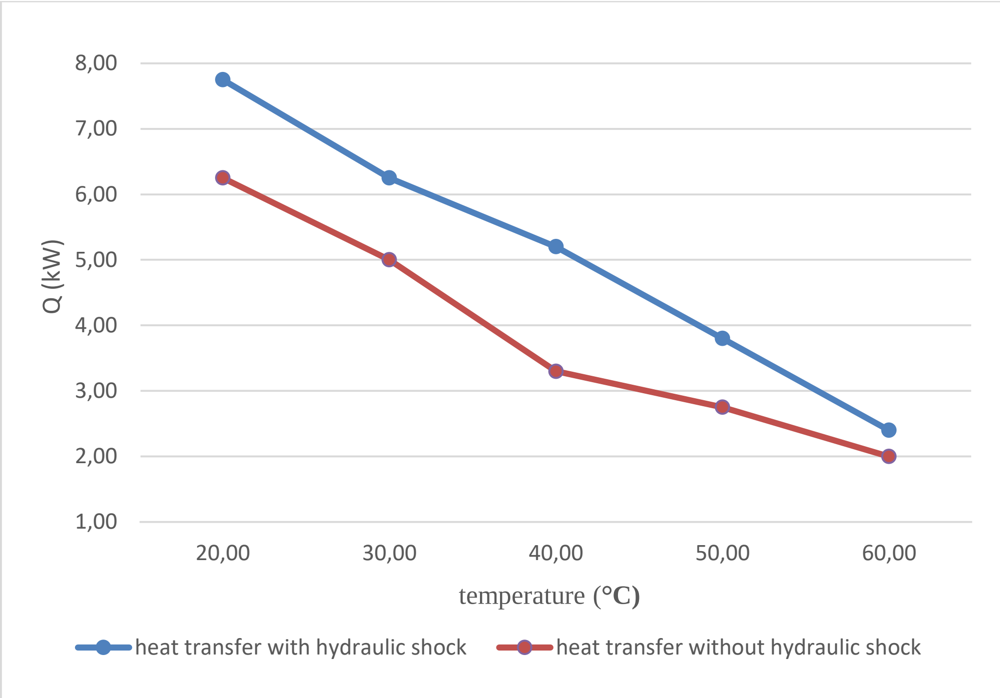


Figure 4.9 - Comparison of heat exchange per second when the flow rate is 0,222 L/s

It can be seen from the figure that when the flow rate is 0,222 L/s, the heat exchange amount is larger than that of the waterless force in the case of hydraulic shock, and the difference is obvious when the flow rate is 0.182 L/s. And as the temperature of the cold water in the heat exchanger increases, the gap is also gradually reduced.

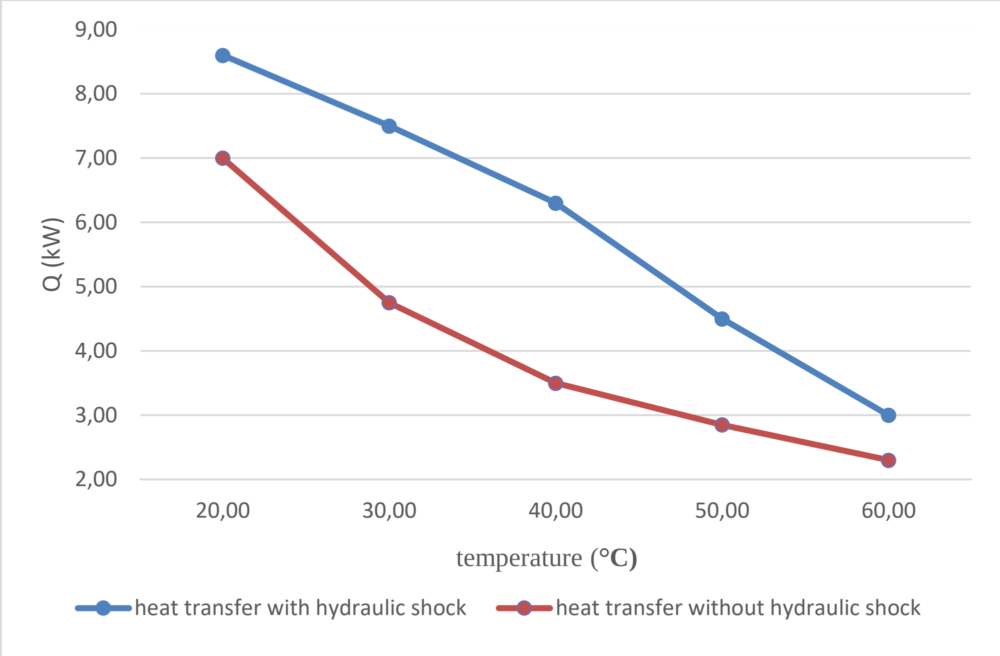


Figure 4.10 - Comparison of heat exchange per second when the flow rate is 0.286L/s

It can be seen from the figure that when the flow rate is 0.286L/s, the heat exchange amount is larger than the waterless impact under the condition of hydraulic shock, and the difference increases first and then decreases with the increase of the cold water temperature in the heat exchanger.

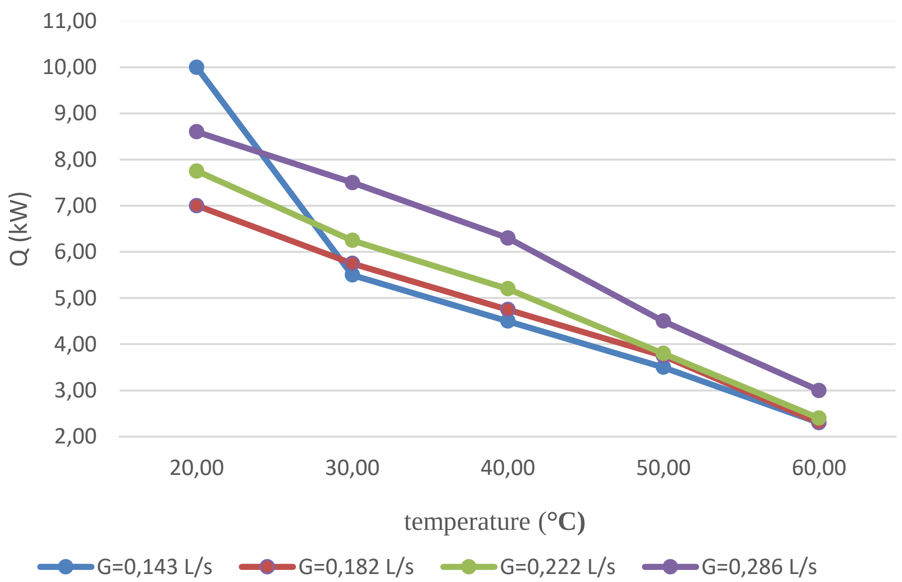


Figure 4.11 - Comparison of heat transfer with different flow rates as a function of cold water temperature

It can be seen from the figure that the heat exchange per unit time under different flow rates decreases with the increase of the cold water temperature in the heat exchanger. On the whole, the heat exchange rate is the lowest when the flow rate is 0.143L/s, and the heat exchange amount is the most when the flow rate is 0.286L/s, and the heat exchange amount increases with the increase of the flow rate.

CONCLUSION

In well-known systems for heating hot water for industrial and household needs with high uneven consumption, heat exchangers-battery are widely used, whose energy efficiency is low. A promising method for increasing their heat transfer is to create forced vibrations of the coil in the low frequency band. To create a coil oscillation, the energy of the braking flow is used, which in a coil with one degree of freedom of oscillation has shown a 50% or more increase in heat transfer. More significant results can be achieved when the coil oscillates in two planes.

A model sample of a heat exchanger-supercharger with a capacity of 8 l/h with a copper coil that can oscillate simultaneously in two planes has been developed. For this technical solution, a patent for invention № 2701788

The scheme of the laboratory installation is developed, which is a circuit dependent on the heat source with a pulse circulation of the hot coolant. The installation allows testing of the heat exchanger-accumulator at different performance at the frequency of fluctuations of the heat carrier from 0.5 to 2 Hz.

Two mathematical models of a laboratory installation with a heat exchanger-accumulator in the form of an energy chain have been developed, which allow predicting the mechanics of vibrations and heat transfer of processes. The oscillation rate was estimated using a hydrodynamic model and showed a stable value in the region of stable oscillation frequencies of the coil at the level of 7.15 m/s.

As a result of thermal tests, comparable graphs of the time to reach the calculated temperature of hot water equal to 60 in the static and proposed modes are obtained. In the pulse mode, the heat transfer intensity improves with the increase in the frequency of the coil vibrations. The shortest water heating time corresponds to a frequency of 4.5 Hz.

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