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Implementation of pulse heat supply for dependent connection of customers

Обеспечение импульсного теплоснабжения для зависимого присоединения абонентов

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Ключевые слова: система теплоснабжения; тепловая сеть; система теплопотребления; тепловой пункт; ударный узел; импульсная циркуляция теплоносителя; пульсирующая циркуляция теплоносителя; трансформация располагаемого напора

Abstract. This article deals with organization of pulsed and fluctuating circulation of heat-carrying agent in separate sections of heat supply system with dependent connection of customers. These types of oscillatory motion of the heat-carrying agent are proposed to be carried out in a self-sustained operation on the basis of the hydraulic ram operation principle. The relevance of the subject-matter is determined by the influence of oscillating flows on the intensity of heat exchange processes and by the possibility of using the circuit design of hydraulic ram in order to improve energy efficiency of heat supply systems. Analysis of the technical solution of a single-fluid hydraulic ram is carried out and conditions for ensuring its possible operation in a closed hydraulic circuit are determined. A sequential transition is shown for the use of this water-lifting device in the heat supply system with dependent connection of customers for organization of pulsed and fluctuating circulation of the heat-carrying agent in its separate sections. The research results form a unified view of technical realization method of the vibrational circulation of the heat-carrying agent in a self-sustained operation in separate sections of the heat supply system with dependent connection of heat consumption systems. Taking into account the achievement of intensification of heat exchange processes in these conditions, self-cleaning of heat exchange surfaces and possible strengthening of pressure in the heat consumption system only at the expense of the available pressure of the heat network, it is concluded that application of the circuit design of the hydraulic ram in the heat supply system can be used to increase its energy efficiency.

Аннотация. В статье рассматривается организация импульсной и пульсирующей циркуляции теплоносителя на отдельных участках системы теплоснабжения с зависимым присоединением абонентов. Указанные виды колебательного движения теплоносителя предлагается осуществлять в самоподдерживающемся режиме на основе принципа действия гидравлического тарана. Актуальность тематики обусловлена влиянием колеблющихся потоков на интенсивность теплообменных процессов, а также возможностью использования схемного решения гидравлического тарана применительно к повышению энергетической эффективности систем теплоснабжения. Выполнен анализ технического решения одножидкостного гидравлического тарана, определены условия для обеспечения его возможной работы в замкнутом гидравлическом контуре. Показан последовательный переход к использованию данного водоподъемного устройства в системе теплоснабжения с зависимым присоединением абонентов для организации импульсной и пульсирующей циркуляции теплоносителя на ее отдельных участках. Результаты исследования формируют единое представление о способе технической реализации колебательной циркуляции теплоносителя в самоподдерживающемся режиме на отдельных участках системы теплоснабжения с зависимым присоединением систем теплопотребления. С учетом достигаемых в этих условиях интенсификации теплообменных процессов, самоочищения теплопередающих поверхностей и возможного усиления напора в системе теплопотребления только за счет располагаемого напора тепловой сети, делается вывод о том, что применение схемного решения гидравлического тарана

в системе теплоснабжения может быть использовано к повышению ее энергетической эффективности.

1. Introduction

Intensification of heat exchange is one of the priority directions of development and optimization of the design of any heat exchange equipment [1, 2]. Passive and active methods for improving heat exchange process are widely used and they were discovered and studied in various fields of science and technology [3, 4].

Taking into account this tendency research works in the study of the influence of oscillating flows on the intensity of the course of heat exchange processes [5, 6], both in individual heat and power devices [7, 8], and in entire systems based on them are actualized [9, 10].

Among such systems there is a heat supply system where along with the heat exchange intensification, the potential of the oscillating circulation of the heat-carrying agent can be used to redistribute the available head from one hydraulic circuit to another and also realize the self-cleaning effect of heat exchange surfaces from scale and sludge (slum) [11].

In the context of this article it is proposed to provide the oscillatory circulation of the heat-carrying agent in the heat supply system in a self-sustained operation according to the principle of single-fluid hydraulic ram action – with generation of pulsed and fluctuating circulation of liquids. Heat supply system with dependent connection of customers was chosen as the object for the indicated possibility realization.

The purpose of the scientific work is to realize the essence of organization of pulsed and fluctuating circulation of the heat-carrying agent in self-sustained operation in separate sections of heat supply system with dependent connection of customers due to the principle of single-fluid hydraulic ram operation.

Within the objectives to be achieved the following problems have been solved:

- analysis of peculiarities of single-fluid hydraulic ram operation in order to determine the conditions under which its operation in a closed hydraulic system is possible;
- finding a circuit solution for integrating the scheme of single-fluid hydraulic ram into a heat supply system with dependent connection of heat consumption systems;
- installation of a laboratory setup and conducting experimental studies to assess the stability of the proposed technical solution;
- protection of intellectual activity results obtained by solving above mentioned tasks by the patents of the Russian Federation for inventions and utility models;
- summing up the results of the scientific research.

2. Methods

The present work has its own scientific research containing explanation of theoretical data on the topic of effective use of technologies and tools for organizing pulsed motion of the heat-carrying agent in heat and water supply systems regarding to increase their energy conservation.

While carrying out this work the following scientific methods are used.

1. Analysis of a self-sustaining water-lifting device work based on a single-loop hydraulic ram (Figure 1), which made it possible to establish the pulse and fluctuating nature of the working medium flow in its individual sections. As a result of this analysis the conditions are also determined for ensuring the possible operation of a hydram water-lifting device in a closed hydraulic circuit with a pumping supply of working medium through its feed supply pipeline.

2. Synthesis of a technical solution that will ensure the operation of a water-lifting device based on a single-loop hydraulic ram in a closed hydraulic circuit with a pumped supply of working medium for creating pulsed and fluctuating circulation of liquid in certain sections of this circuit. The synthesized technical solution is presented in Figure 2. According to that scheme the development (Figure 3) and the installation (Figure 4) of the experimental setup for testing the adequacy of the theoretical positions obtained at the analysis and synthesis stage were made on the basis of a shock unit of an opposing construction [12].

3. A scientific experiment that ensures the reproduction of the hydraulic ram work in a closed hydraulic circuit with a pumping supply of the working medium in created and controlled conditions. The present work was carried out on the basis of the educational and scientific laboratory" Pulse heat and water

supply systems "of the Federal State Budgetary Educational Institution of Higher Education “Ogarev Mordovia State University" (Figure 4).

4. The measurement including a set of actions which are performed with the help of certain means to find the numerical value of the measured values. The volume consumption of the working medium by the shock unit was determined by the electromagnetic converter "Master Flow MF-5.2.2-B-15" which is installed at the output of the shock unit through the system of back-flow valves and rectifying hydraulic accumulators "Wester premium WAV-12" [13]. The pointing error of the flow converter is 0.05 %.

The volume consumption of the injected medium was determined by the method of draining the liquid into the measuring container at the outlet of the pressure regulator "Danfoss 003H6616 AVA" included in the injected line after the hydraulic accumulator "Dzhileks 24G " (Figure 3). The pointing error in this case is $\pm$ 0.05 %.

Pressure converters "OVEN PD100–DI1.6–171–0.5" with the output current of 4–20 mA were used to estimate the pressure changing quantity at individual points of the hydraulic circuit. These pressure transmitters are designed for a maximum pressure of 1.6 MPa and are made with a connecting male thread G1 / 2. The error in measuring this measuring equipment is $\pm$ 0.5 %.

The output signal from the converters was processed через блок токовых шунтов "Reallab! NL-8CS" with the help of the "L-Card" software and hardware complex on the basis of the analogous-digital module converter "E14-440". The limit of permissible error of measuring the dc (direct current) while using the analog-digital converter "E14-440" is $\pm$ 0.05 % in the range from 2.5 V to 10 V. The pointing error of the current shunt block (current signal converter to a voltage) "Reallab! NL-8CS" is $\pm$ 0.02 %.

Graphs of pressure pulsations in individual sections of the hydraulic circuit are shown in Figure 5 and obtained by exporting data from the hardware and software complex L-Card in Excel.

5. Statistical processing of the experimental data was carried out in the following sequence. The average value of the measured quantity was determined by the formula:

$$\overline{x} = \frac{\sum_{i=1}^{N} x_i}{N}, \quad (1)$$

where x_i – parameter value which was determined with a period of time 300 sec.

N – quantity of parameter changing, $N \geq 10$.

The mean square deviation was determined:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N} (\overline{x} - x_i)^2}{N}}. \quad (2)$$

Then the lower x_{low} upper x_{hight} of interval boundary 3σ were calculated:

$$x_{low} = \overline{x} - 3\sigma, \quad x_{hight} = \overline{x} + 3\sigma. \quad (3)$$

The value of the measured parameter that overreach x_{low} or x_{hight} was dropped and the changes were repeated. The obtained numerical values of the results of the experiment are given in the text of this work below the Figure 5 when describing the obtained pressure pulsation graphs at individual points of the hydraulic circuit.

6. The analogy of the principle propagation of the action of the technical solution presented in Figure 2 and made it possible to obtain a fundamentally new scheme of the heat supply system with pulsed and fluctuating circulation of the heat-carrying agent at its separate sections (Figure 6), which can be used to increase the efficiency of heat supply systems taking into account the analysis of information sources reflected in the list of literature. According to the technical solution presented in Figure 6, from 28.05.2018 the application # 2018119526 "Heat supply system" for the invention of the Russian Federation was registered.

3. Results and Discussion

3.1. Analyses of peculiarities of the self-sustained water-lifting device on the basis of the single-liquid hydraulic ram

The use of hydraulic ram for the purposes of water supply to various customers is widely known in the world practice [14, 15]. Mass distribution of the water-lifting device is caused by simplicity and reliability of its design, as well as possibility of working in self-sustained operation over the years in the condition of automatic generation of periodic pressure shocks and subsequent use of their energy [16, 17].

Currently there is a number of technical solutions of this water-lifting device but all of them can be classified into two groups: for working with one liquid or with two unmixed liquids [18]. Within the topic of the article, the most interesting is the hydraulic ram, which works only with one liquid. According to Figure 1 let us consider the principle of its operation in details and analyze the character of the liquid circulation in its individual structural elements.

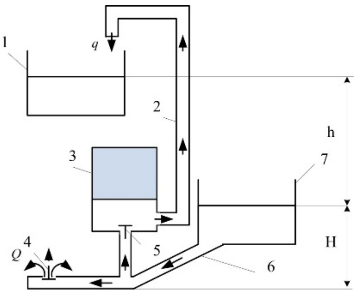


Figure 1. Hydraulic ram for working with one liquid: 1 – upper tank; 2 – discharge pipeline; 3 – air case; 4 – shock valve; 5 – discharge valve; 6 – feeding pipeline; 7 – feeding reservoir; h – water lifting height; H – water lifting height

First of all, there is selection of the weight of the impact valve 4 so that the static pressure in the feeding pipe 6 keeps it in the closed state and when the liquid flows through it so then it automatically closes. Then the shock valve 4 is put into operation by a single forced opening (manually or mechanically) and in the feed pipe 6, under the pressure action H, m a movement of water with an average consumption Q, m^3/s is generated and discharged through this valve. When the force of the flowing water balances the weight of the shock valve 4 it will close and a hydraulic shock will occur in the feed pipeline 6 [19, 20].

The positive wave of this hydraulic shock will open the back-flow valve 5, through which some water with average consumption q, m^3/s will flow into the air case 3. The liquid injection into the air case 3 will continue until the energy of the positive wave of hydraulic shock is sufficient to overcome the resistance of the compressed air which is located in it. Then, the injected medium will flow from the air case 3 into the upper tank 1 through the injection pipeline 2 overcoming the water head $h > H$.

After the positive wave of the hydraulic shock is reflected from the input to the feeding pipeline 6 it will be replaced by a negative wave. As a result of this, the pressure in the feeding pipeline 6 below the shock valve 4 becomes less than the static pressure. At this moment the back-flow valve 5 closes and the shock valve 4 opens under its own weight. Later on it will ensure the renovation of water supply through the feeding pipeline 6 and repetition of the operation cycle in the sequence which is described above.

According to the theory of hydraulic ram which is practically confirmed by the results of experimental studies, the work stability of a shock unit in a self-supported regime is ensured by stable parameters of maintained hydraulic system. The most important of these parameters are the stable damping properties of the air cap, the feed supply head and the feed rate of the working medium for the operation of the shock unit and also the height of the liquid injection. At the same time, the influence of the shock unit and pressure increase amplitude at the moment of hydraulic shock is determined by the length and diameter of the feeding pipeline. The diameter and length of the discharge pipeline and also its resistance determines the productivity of the water-lifting device [18].

With periodic complete stoppage of moving water flow in the feeding pipeline 6 and the subsequent renovation of its movement fluctuating circulation of liquid is provided. It is characterized by the change in the velocity of water from 0 to a certain maximum at which the shock valve automatically closes.

Fluctuating circulation of liquid is observed in the discharge pipeline 2. It is characterized by the change in the rate of its outflow from minimum to maximum relating to a certain average value which is the result of smoothing the pulses of pressure increase and accumulation of their energy in the air case 3.

Productivity of the hydraulic ram q, m³/s (see Figure 1) can be determined by the formula [18]

$$q = \eta Q \frac{H}{h}, \qquad (4)$$

where η – coefficient of water-lifting installation performance [18];

Q – liquid consumption through the shock valve, m³/s;

H – feeding head, m;

h – injected head, m.

The lower value of the heads ratio is associated with the threshold of the hydraulic ram stability. According to the condition of ensuring of automatic work it is assumed to be equal $h/H = 1$. In this case the coefficient of performance can reach the value $\eta =$ 0.45–0.5, and the discharge flow will be up to $q = 0.5Q$

The upper value of the heads ratio is associated with decrease in the coefficient of performance of the water-lifting device. For example, with the heads ratio $h/H = 30$, the efficiency is varied in the range of $\eta = 0.15 \div 0.20$. It means that the discharge flow will be only $q = 0.005 \div 0.006Q$ [18].

The change in the ratio of the hydraulic ram performance q to the consumption of liquid Q which is thrown through the shock valve depending on the ratio of the injected h and feeding H head, with the average value of the coefficient performance of the water-lifting device is given in Table 1.

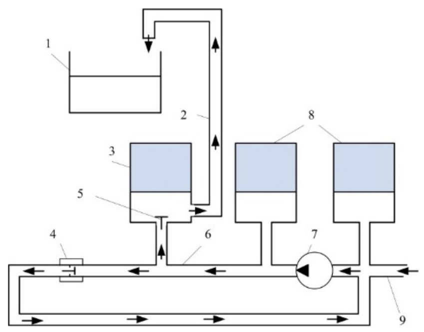
Table 1. Hydrotended water-lifting installation productivity

q/Q	0.225	0.1125	0.075	0.0563	0.045	0.0375	0.0321	0.0281	0.025	0.0225
h/H	2	4	6	8	10	12	14	16	18	20

3.2. Technical solution for ensuring operation of a single-fluid hydraulic ram in a hydraulic system with pumping water supply

The scheme of the hydraulic ram which is discussed above assumes its use only in open water storages and it is not entirely suitable for the use in the heat supply system where the heat-carrying agent is supplied by an electric pump. It is explained by the following circumstances. Firstly, for operation of the shock valve it is necessary to have a drain of the working medium (liquid) from the hydraulic ram's feeding pipeline into the environment medium below the geometric level of its entry. For the heat-carrying agent in a closed heat supply system the fulfillment of this condition is not rational. Secondly, to ensure the automatic operation of the shock unit, the open feeding basin and / or equalizing tower needs to be available [18], by which the required length of the feeding pipeline is ensured. Otherwise, the stable operation of the shock valve is not guaranteed as duration and alternation of the phases of the hydraulic shock can be disrupted. Thirdly, it is necessary to periodically inflate air to the air case which dissolves in liquid as the water-lifting unit is in operation [18]. The latter circumstance will only promote corrosion of pipelines and heat-and-power devices of the heat supply system.

Taking into account the revealed features of the self-support water-lifting installation based on the hydraulic ram, we replace the shock valve by a special shock unit, the design of which is adapted to working with pumping water supply. We also limit the working length of the supply pipeline by one hydraulic accumulator, and we will use an additional hydraulic accumulator as an air case (to eliminate air dissolving). As a result, we obtain the scheme of a hydrodynamic water-lifting device based on a single-fluid hydraulic ram for its joint operation with an electric pump in a closed hydraulic system (Figure 2).



a

b

Figure 2. Hydrodynamic water-lifting device on the basis of a single-fluid hydraulic ram for working in conditions of pumping water supply: a – schematic diagram; b – version of the shock valve with possibility of its installation in the inter-flange connection of a pipeline: 1 – upper tank; 2 – discharged pipeline; 3 – hydraulic accumulator; 4 – shock unit; 5 – discharged valve; 6 – feeding pipeline; 7 – circulating pump; 8 – additional hydraulic accumulators; 9 – makeup (intake) pipeline

The scheme of the presented technical solution works in the following way. Firstly, the feeding pipeline 6 which is made in the form of a closed hydraulic circuit is filled with the working medium until the air is completely removed from it. Then the pump 7 installed on the feeding pipeline 6 is put into operation. Thus, the working medium moves in the feeding pipeline 6 in a closed contour.

In case of gained velocity of the working medium loss through the shock unit 4, which is installed on the feed pipeline 6 after the pump 7 it will close. In front of the shock unit 4, a positive wave of hydraulic shock will arise that will spread to the pump output 7 while supplying the working medium through the discharge valve 5 to the hydraulic accumulator 3 and from there to the discharge pipeline 2 and the upper tank 1.

Considering that additional hydraulic accumulators 8 are installed at the input and output of the pump 7, its operation with a closed contour of the feeding pipeline 6 will be closed and will remain practically unchanged during the time of this closure, and a positive wave of hydraulic shock which is reflected from the hydraulic accumulator 8, at the output of the pump, will change the sign to negative and will head to the shock unit 4. As the result of the pressure drop before the shock unit 4, the valve will open under its own weight. The movement of the working medium in the feeding pipeline 6 in a closed contour will be renovated under the influence of the displaced air of the volume of liquid which is stored in the hydraulic accumulator 8 which is installed at the output of the pump 7, and also under the action of the pressure being created by the pump 7. Moreover, a new portion of the working fluid (liquid) equivalent to the volume displaced into the hydraulic accumulator 3 will flow through the make-up (suction) pipeline 9 to the feeding line 6. With the subsequent closure of the shock valve 4, the operation of the water-lifting device using the energy of the hydraulic shock will be repeated in the sequence which is described above and will be cyclically repeated until the circulation of the working medium due to the pump is present 7.

It should be noted that in the feeding pipeline with the installed shock unit 4 the heat-carrying agent will move impulsively with generation of pulses of the amount of its movement, and the fluctuating character of its movement will dominate in the discharge pipeline 2 due to the smoothing of the pulses by the hydraulic accumulator 3. Thus, organization of pulse circulation of the working medium is primary in relation to its fluctuating circulation.

The scheme of the experimental setup was developed for practical confirmation of the above operation theory of a water-lifting device based on a hydraulic ram with pumping supply of working medium through its supply pipeline which is shown in Figure 3. The experimental installation is a hydraulic circuit on the basis of a single-fluid hydraulic ram with pumping supply of working medium (water) through its supply pipeline and made of metal pipes with a diameter of 45 mm and wall thickness 2 mm with polypropylene "PP-R" pipes G 1/2, G 3/4 , G 1 and G 2. The length of the pipes L is indicated in mm. The length of each undefined area is less than 50 mm. Such short sections of pipes are used for connection of the separate elements of the hydraulic circuit to each other.

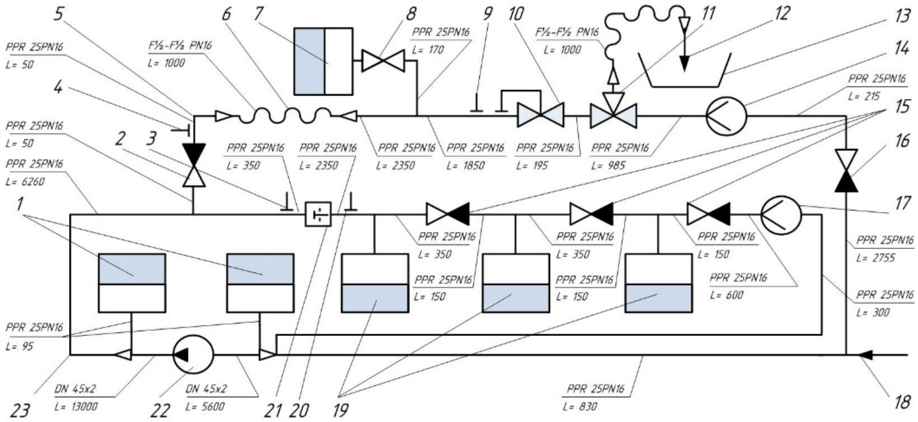


Figure 3. The scheme (schematic drawing) of the experimental setup: 1 – hydraulic accumulators for stabilizing the work of the pump; 2 – a non-return valve of the injected medium in the hydraulic accumulator of the injected medium; 3 – pressure transducer at the entrance of the shock unit; 4 – pressure transducer at the inlet of the hydraulic accumulator of the injected medium; 5 – section PP-R of the pipeline with fluctuating circulation of the injected medium; 6 – flexible pipeline of fluctuating circulation of the working medium; 7 – hydraulic accumulator of the injected medium; 8 – tap for disconnecting the hydraulic accumulator of the injected medium; 9 – pressure transducer at the outlet of the injected medium from the hydraulic accumulator; 10 – pressure regulator; 11 – a tap of a switching of a flow direction of the injected medium; 12 – discharge of the injected medium through a flexible pipeline; 13 – metering capacity; 14 – mechanical water meter; 15 – check valves of the rectifying system of an oscillations of the working medium flow consumption; 16 – a non-return valve at the inlet of the injected medium to the suction pipeline of the pump; 17 – electromagnetic flow transducer; 18 – feeding pipeline of the hydraulic circuit; 19 – hydraulic accumulators of the rectifying system of an oscillations of the working medium flow consumption; 20 – pressure transducer at the output of the shock unit; 21 – shock unit; 22 – the pump; 23 – feeding pipeline of a shock unit

This experimental setup works as follows. The pump 22 circulates the working medium along the closed hydraulic circuit through the feed pipeline 23, the shock unit 21, check valves 15 which are connected in series through the rectifying hydraulic accumulators 19 and the electromagnetic flow transducer 17. From there the pump 22 supplies the working medium through the feed pipeline 23 to the shock unit 21, which automatically closes at a certain flowrate of the working medium through it, and then it opens after generation of a hydraulic shock. A hydraulic shock occurs at the moment of the shock unit 21, the positive propagation wave which ensures that the injected medium is supplied through the inlet check valve 2 to the PP-R section of the pipeline with the pressure transducer 4, and then by the flexible line 6 through the tap 8 into the hydraulic accumulator 7. Then the injected medium is discharged through the pressure regulator 10 through the flexible pipeline 12 to the metering tank 13 for measurement the pumping amount of liquid or through the PP-R pipeline section to the pump inlet 22 through the indicating mechanical water meter 14 and the non-return valve 16. The direction of flow of the pumped medium is established by the flow switching tap 11. The hydraulic accumulators 1 which are installed at the pump inlet and outlet serve to protect the pump 22 against the hydraulic shock, the residual wave of that pump can propagate to it within an incomplete use of the hydraulic shock energy. The pressure pulsations at the individual points of the hydraulic circuit are measured with the help of flow converters 3, 4, 9, 20.

The volume consumption of the working medium was provided by the pump "K 80-50-200A" with the asynchronous motor " AIR 132M2Y2" with the power of 11 kWt. The change in pump capacity as well as frequency and amplitude of generation of local hydraulic hammers in the shock unit was carried out by the frequency converter "OVEN PCHV-2".

According to the scheme presented in Figure 3, in the educational and research laboratory "Pulse heat and water supply systems" of the Federal State Financed Academic Institution of Higher Education "Ogarev Mordovia State University" the experimental setup was assembled. Its fragment with a shock valve, back flow valve and a hydraulic accumulator connected to the discharge line is shown in Figure 4.

Evaluation of the operational capacity of this experimental setup is shown in Figure 5, where the graphs of the pressure variation in its individual sections are given.

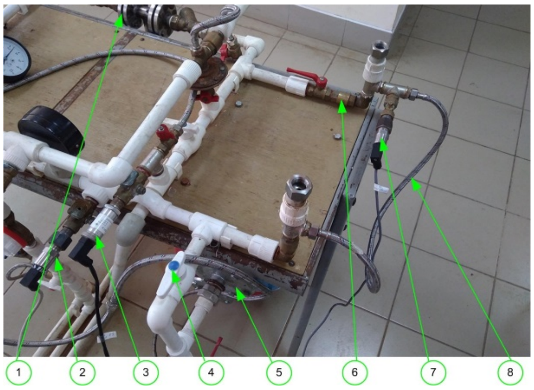


Figure 4. Appearance of a part of the experimental setup: 1 – shock unit; 2 – pressure transformer at the output of the hydraulic accumulator; 3 – pressure transformer at the input of the shock unit; 4 – handle for disconnecting the hydraulic accumulator; 5 – hydraulic accumulator; 6 – back-flow valve for injecting the medium into the hydraulic accumulator; 7 – pressure transformer at the input of the hydraulic accumulator; 8 – the line of fluctuating circulation of the injected medium

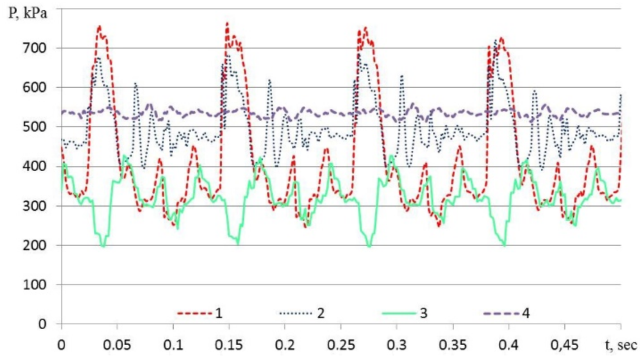


Figure 5. Graphs of pressure fluctuations: 1 – at the input of the shock unit; 2 – input of the injected medium into the hydraulic accumulator; 3 – behind the shock unit; 4 – output of the injected medium from the hydraulic accumulator

As it is seen from presented figure, the system works steadily in automatic mode with the shock valve's flow frequency of 8.74 Hz. Conditions under which these dependences are obtained are the following: the available head at the shock unit 118 kPa; discharge height provided by the pressure regulator, 512 kPa; volume consumption of the working medium through the shock valve 3.475 litter/minute; discharge consumption is 0.517 litter/minute.

Thus, with the ratio of injection and feeding heads h/H = 4.340, the ratio of injection and feeding discharges is $q/Q =$0.149. These indicators are complying with the theoretical data of Table 1 with the coefficient of performance of the water-lifting installation $\eta =$0.65.

We can see from Figure 5 that when the shock valve closes on the pipeline section a positive wave of hydraulic shock of the working medium appears in the front of it (the pressure increases above the value 750 kPa) and behind the shock valve there is a negative wave (the pressure drops below the value 200 kPa). A positive wave of propagation of the hydraulic shock ensures that the working medium is displaced into the hydraulic accumulator at the maximum pressure in the pulse about 670 kPa. The magnitude of this pressure cutoff is provided by damping the pulse by compressed air in the hydraulic accumulator (Figure 3). From the hydraulic accumulator, the liquid enters the discharge line and leaves it, overcoming the resistance in 512 kPa, created by the pressure regulator.

The results of the experiment which presented in Figure 5 allows to visually ascertain that the oscillatory processes occurring on separate sections of the hydraulic circuit are characterized by relatively good repeatability while maintaining a constant oscillation frequency generated by the shock unit in a self-sustaining mode. This fact shows the restoration of the initial parameters of the hydraulic system every time after a local hydraulic shock created by the shock unit. In this case the stability of the system in a self-sustaining pulse mode is determined by the stability of the inlet parameters (feeding head and the feed flowrate of the working medium) and outlet parameters (lift height and consumption of the injected medium).

The generation of pressure oscillations and their propagation in the hydraulic circuit raises the question of possible resonance. An investigation of this effect is possible with a change in the frequency of generation of the pulses of the momentum (movement quantity) of the working medium, which in the conditions of using a self-supported shock unit depends on the working medium consumption. However, the flow rate of the working medium also determines the amount of pressure increase at the hydraulic shock moment. The higher the flowrate of the working medium, the higher the frequency of generation of the pulses of pressure increase and their amplitude and also the other way around. For instance, for the water, a change in its speed per each 1 m/sec leads to an increase in pressure by 100 m [18]. Under the conditions of such proportional dependence of the pulse generation frequency, the flow rate of the working medium and the magnitude of the resonance pressure increase are not observed in practice.

As for the beats, the occurrence is possible in a result of superposition of oscillations; theoretically they occur at the point of the hydraulic circuit where the pulsating and fluctuating flows are merging (Figure 3). However, taking into account the fact that the impulse component and the fluctuating component of the vibrational motion are smoothed and scattered as they move away from the source of the disturbance (shock unit) on the way to the point of confluence, including hydraulic accumulators which are installed in the system, then directly at the point of combining these flows the beating effect does not occur. For eliminating this effect, when connecting two oscillating streams an additional hydraulic accumulator should be used at the point of their merging.

The graphs of the pressure pulsations shown in Figure 5 make it possible to visually establish the characteristics difference between pulsed and fluctuating liquids flow in pipelines. Fluctuating circulation (graphs 1 and 3) is characterized by an instant increase of the working medium pressure before the closed shock unit and the creation of conditions for its cavitation behind it (graph 2). Fluctuating circulation (graph 4) of the injected fluid by the character of the pressure pulsations is more smoothed and, with some assumptions, closer to the shape of a sinusoid.

Taking into account the practical evaluation of the efficiency of the above scheme, it can be confirmed that application of the circuit solution of a single-fluid hydraulic ram in a heat supply system with dependent connection of customers will allow possibility of pulsed and fluctuating circulation of the liquid in certain areas.

3.3. Heat supply system for independent connection of customers with pulsed and fluctuating circulation of the heat-carrying agent

Based on the scheme of a single-fluid hydraulic ram operation in a pumping water supply system we obtain a schematic diagram of the heat supply system for dependent connection of customers with pulse and fluctuating moving of the heat-carrying agent in its separate elements. For doing this operation, we use the example of the scheme shown in Figure 2, the discharge pipeline 2 is connected to the make-up pipeline 9 and we install heating devices on the sections of the supply and discharge pipelines. As a result, the hydraulic system will be completely closed and can be successfully used for the purposes of heat supply with connection of customers according to the dependent scheme (Figure 6).

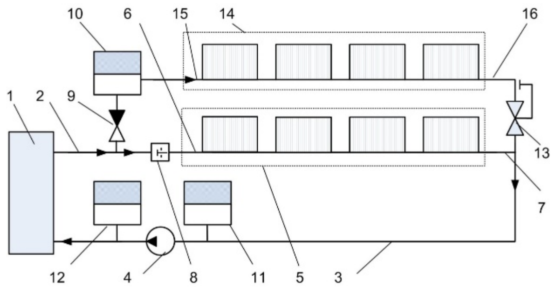


Figure 6. Heat supply system with pulsed and fluctuating circulation of the heat-carrying agent for the dependent scheme of heat consumption systems connection: 1 – heat source; 2 and 3 – supply and back-flow pipelines of the heating network; 4 – the network pump; 5 – heat consumption system with supply 6 and back-flow 7 pipelines for organization of fluctuating circulation of the heat-carrying agent; 8 – shock unit; 9 – back-flow valve; 10, 11, 12 – hydraulic accumulators; 13 – pressure regulator; 14 – thermal load with supply 15 and back-flow 16 pipelines for organization of fluctuating circulation of heat-carrying agent

The circuit which is shown in Figure 5 works in the following way. At first it is filled with a heat-carrying agent until the air is completely removed from it. The pressure regulator 13 is configured to maintain a larger pressure in the zone of the additional heat load 14 than the available head in the heat network generated by the network pump 4. Then, the heat-carrying agent is heated in the heat source 1 and its circulation through the supply pipeline 2 and return 3 pipelines of the heat network with the help of the network pump 4 is carried out. Under the conditions of different hydraulic resistance of the heat-carrying agent escaping in the heat consumption system 5 and the additional zone of heat load 14, heated the heat-carrying agent in the source 1 with the open cross-section of the shock unit 8 will flow only to the heat consumption system 5 through its supply line 6. So after giving the stored heat the heat-carrying agent leaves the heat consumption system 5 through the return line 7 and rushes into the return pipeline of the heat network 3 to the input of the network pump 4, and from there will again arrive to the source of heat.

At some point in time the shock valve 8 which is tuned to a certain flow velocity of the heat-carrying agent will automatically close, so in such case it provokes appearance of a hydraulic shock in the pipeline of the heat network. The positive wave of this hydraulic shock will begin to supply the heated heat-carrying agent through the back-flow valve 9, the first hydraulic accumulator 10 to the additional zone of the heat load 14 along its supply line 15. So after giving the stored heat the heat-carrying agent leaves the heat load zone 14 through the return pipeline 16 and passing through the pressure regulator 13 will enter the return pipeline of the heat network 3.

At the same time a positive wave of hydraulic shock, reflected from the second 11 and the third 12 hydraulic accumulators will be replaced by a negative one. In such case the passage section of the shock unit 8 opens to expire the heated heat-carrying agent into the supply pipeline 6 of the heat consumption system 5, and the back-flow valve 9 closes, as a result the flow of the heated heat-carrying agent from the heat source 1 to the first hydraulic accumulator 10 will be stopped. The proportional distribution of the heat-carrying agent flow in the main 5 and additional 14 zones of the heat load will be determined on the basis of the calculated equation (1) for determining the productivity of a single-fluid hydraulic ram.

With the subsequent closing of the flow section of the shock unit 8 the operation of the heat supply system will be repeated in the sequence which is described above. At the same time the fluctuating circulation of the heat-carrying agent will be observed in the heat consumption system 5 which is characterized by a change in the velocity of the heat-carrying agent from zero to the set maximum. In the additional heat load zone 14 circulation of the heat-carrying agent will be fluctuating, which is characterized by a change in the circulation speed from minimum to maximum while saving its average value of more than zero by smoothing the pulse speed by the first hydraulic accumulator 10.

Pulse and fluctuating circulation of the heat-carrying agent can be used for the purpose of heat exchange intensifying [21] and realization of self-cleaning effect of scale [22] in various elements of the heat supply system.

In order to optimize the structural elements and links of the heat supply system, organization of pulsed and fluctuating circulation of the heat-carrying agent can be realized only within the heat point for connecting of customers according to the dependent scheme [23]. At the same time it is recommended to use technical solutions of heat exchanging devices with an oscillating heat exchange surface [24] from the usage of the pulse movement quantity of the heat-carrying agent for reducing the metal consumption and mass-dimension parameters of heat-consumption systems. When designing such systems, it is also necessary to take into account the increase in standard losses of thermal energy in heat networks [25] and heat consumption systems [26].

4. Conclusion

Investigating the principle of a single-fluid hydraulic ram operation we can conclude that its action is accompanied by differentiation of the steady flow movement into pulsed and fluctuating. In such case, the pulsed circulation of the liquid is primary in relation to the fluctuating circulation, which is provided by the air case due to smoothing of the pressure peaks of the hydraulic shock.

This self-sustaining water-lifting device initially used only for water supply purposes can be used with a closed-countour hydraulic system with a pumping supply of the working medium to organize its pulsed and fluctuating circulation in certain sections of the system. For that operation it is necessary to use special designs of shock units and hydraulic accumulators instead of the air case and the equalizing tower.

In the conditions of integration of the single-fluid hydraulic ram circuit solution into the heat supply system for dependent connection of customers the following become available:

– possibility of creating a pulsed circulation of the heat-carrying agent on the source of heat and in the heat network in a self-sustained regime;

– possibility of using the impulse movement quantity of the heat-carrying agent in the heat network in relation to the increase the available pressure of the heat consumption systems which are connected to it by the dependent scheme;

– possibility of organizing the fluctuating circulation of the heat-carrying agent in a heat consumption system.

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References

1. Butun, H., Kantor, I., Marechal, F. A heat integration method with multiple heat exchange interfaces. ENERGY: 30th International Conference on Efficiency, Cost, Optimisation, Simulation and Environmental Impact of Energy Systems (ECOS). 2018. Vol. 152. Pp. 476–488.
2. Zhang, Y., Zhang, YP., Wang, X. Thermodynamic optimization of coupled heat work conversion and heat transfer energy systems by applying inverse problem and variation method. Heat transfer research. 2017. Vol. 48. No. 18. Pp. 1637–1649.
3. Laukkanen, T., Seppala, A. Interplant heat exchanger network synthesis using nanofluids for interplant heat exchange. Applied thermal engineering. 2018. Vol. 135. Pp. 133–144.
4. Mohammadshahi, S., Nili-Ahmadabadi, M., Samsam-Khayani, H., Salimpour, M.R. Numerical study of a vortex-induced vibration technique for passive heat transfer enhancement in internal turbulent flow. European Journal of Mechanics, B/Fluids. 2018. Vol. 72. Pp. 103–113.
5. Abdel-Aziz, M.H., Nirdosh, I., Sedahmed, G.H. Mass and heat transfer behavior of oscillating helical coils in relation to heterogeneous reactor design. Aiche journal. 2017. Vol. 63. No. 7. Pp. 3141–3149.
6. Valueva, E.P., Purdin, M.S. Heat exchange at laminar flow in rectangular channels // Thermo-physics and aeromechanics. 2016. Vol. 23. No. 6. Pp. 857–867.
7. Olayiwola, B.O., Schaldach, G., Walzel, P. CFD simulations of flow and heat transfer in a zigzag channel with flow pulsation. ASME 2010 International Mechanical Engineering Congress and Exposition, IMECE 2010. Vancouver, Canada. 2010. Vol. 7. No. PARTS A and B. Pp. 1531–1541.
8. Sultan, Q., Lalizel, G., Fenot, M., Dorignac, E. Influence of coolant jet pulsation on the convective film cooling of an adiabatic wall. Journal of Heat Transfer. 2017. Vol. 139. No. 2. UNSP 2556160.
9. Levtzev, A.P., Makeev, A.N., Kudashev, S.F Pulsating heat transfer enhancement in the liquid cooling system of power semiconductor converter. Indian Journal of Science and Technology. 2016. Vol. 9(11). Pp. 1–5.
10. Sedighi, E., Amarloo, A., Shafii, B. Numerical and experimental investigation of flat-plate pulsating heat pipes with extra branches in the evaporator section. International Journal of Heat and Mass Transfer. 2018. Vol. 126. Pp. 431–441.
11. Makeyev, A.N. Vybor skhemy tekhnologicheskogo prisoyedineniya abonentov k teplovoy seti v usloviyakh perekhoda k impulsnoy tsirkulyatsii teplonositelya v oborudovanii teplovykh punktov [The choice of the technological connection of subscribers to the heat network in the transition to a pulsed circulation of the coolant in the equipment of heat points]. Vestnik Dagestanskogo gosudarstvennogo tekhnicheskogo universiteta. Tekhnicheskiye nauki. 2017. № 3(44). Pp. 72–82. (rus)
12. Levtsev, A.P., Makeev, A.N., Makeyev, S.N., Khramov, S.I., Kudashev, S.F., Zyuzin, A.M., Narvatov, Ya.A. Udarnyy uzel [Shock knot]: pat. 2558740, № 2014107201/06 ; zayavl. 25.02.2014 ; opubl. 10.08.2015. Byul. No. 22. 6 p. (rus)
13. Makeev, A.N. K voprosu lokalnoy organizatsii impulsno-koleblyushcheysya tsirkulyatsii teplonositelya v sisteme teplosnabzheniya [To the question of the local organization of the pulse-vibration circulation of the heat-supplyer in the heat supply system]. Byulleten nauki i praktiki. 2018. Vol. 4(5). Pp. 254-262. (rus)
14. Harith, M.N., Bakar, R.A., Ramasamy, D., Quanjin, M. A significant effect on flow analysis & simu-lation study of improve design hydraulic pump. IOP Conference Series:

Литература

1. Butun H., Kantor I., Marechal F. A heat integration method with multiple heat exchange interfaces // ENERGY: 30th International Conference on Efficiency, Cost, Optimisation, Simulation and Environmental Impact of Energy Systems (ECOS). 2018. Vol. 152. Pp. 476–488.
2. Zhang Y., Zhang Y.P., Wang X. Thermodynamic optimization of coupled heat work conversion and heat transfer energy systems by applying inverse problem and variation method // Heat transfer research. 2017. Vol. 48. № 18. Pp. 1637–1649.
3. Laukkanen T., Seppala A. Interplant heat exchanger network synthesis using nanofluids for interplant heat exchange // Applied thermal engineering. 2018. Vol. 135. Pp. 133–144.
4. Mohammadshahi S., Nili-Ahmadabadi M., Samsam-Khayani H., Salimpour M.R. Numerical study of a vortex-induced vibration technique for passive heat transfer enhancement in internal turbulent flow // European Journal of Mechanics, B/Fluids. 2018. Vol. 72. Pp. 103–113.
5. Abdel-Aziz M.H., Nirdosh I., Sedahmed G.H. Mass and heat transfer behavior of oscillating heli-cal coils in relation to heterogeneous reactor design // Aiche journal. 2017. Vol. 63. № 7. Pp. 3141–3149.
6. Valueva E.P., Purdin M.S. Heat exchange at laminar flow in rectangular channels // Thermo-physics and aeromechanics. 2016. Vol. 23. № 6. Pp. 857–867.
7. Olayiwola B.O., Schaldach G., Walzel P. CFD simulations of flow and heat transfer in a zigzag channel with flow pulsation // ASME 2010 International Mechanical Engineering Congress and Exposition, IMECE 2010. Vancouver, Canada. 2010. Vol. 7. № PARTS A and B. Pp. 1531–1541.
8. Sultan Q., Lalizel G., Fenot M., Dorignac E. Influence of coolant jet pulsation on the convective film cooling of an adiabatic wall // Journal of Heat Transfer. 2017. Vol. 139. № 2. UNSP 2556160.
9. Levtzev A. P., Makeev A. N., Kudashev S. F Pulsating heat transfer enhancement in the liquid cooling system of power semiconductor converter // Indian Journal of Science and Technology. 2016. Vol. 9(11). Pp. 1–5.
10. Sedighi E., Amarloo A., Shafii B. Numerical and experimental investigation of flat-plate pulsating heat pipes with extra branches in the evaporator section // International Journal of Heat and Mass Transfer. 2018. Vol. 126. Pp. 431–441.
11. Макеев А.Н. Выбор схемы технологического присоединения абонентов к тепловой сети в условиях перехода к импульсной циркуляции теплоносителя в оборудовании тепловых пунктов // Вестник Дагестанского государственного технического университета. Технические науки. 2017. № 3(44). С. 72–82.
12. Левцев А.П., Макеев А.Н., Макеев С.Н., Храмов С.И., Кудашев С.Ф., Зюзин А.М., Нарватов Я.А. Ударный узел: пат. 2558740 Российская Федерация, № 2014107201/06 ; заявл. 25.02.2014 ; опубл. 10.08.2015, Бюл. № 22. 6 с.
13. Макеев А.Н. К вопросу локальной организации импульсно-колеблющейся циркуляции теплоносителя в системе теплоснабжения // Бюллетень науки и практики. 2018. Т. 4. № 5. С. 254–262.
14. Harith M.N., Bakar R.A., Ramasamy D., Quanjin M. A significant effect on flow analysis & simu-lation study of improve design hydraulic pump // IOP Conference Series: Materials Science and Engineering. 2017. Vol. 257. № 1. UNSP 012076.
15. Hussin N.S.M., Gamil S.A., Amin N.A.M., Safar M.J.A., Majid M.S.A., Kazim M.N.F.M., Nasir N.F.M. Design and analysis of hydraulic ram water pumping system //

Materials Science and Engineering. 2017. Vol. 257. No. 1. UNSP 012076.

15. Hussin, N.S.M., Gamil, S.A., Amin, N.A.M., Safar, M.J.A., Majid, M.S.A., Kazim, M.N.F.M., Nasir, N.F.M. Design and analysis of hydraulic ram water pumping system. International conference on appli-cations and design in mechanical engineering (ICADME 2017). Journal of Physics Conference Series. 2017. Vol. 908. UNSP 012052.
16. Inthachot, M., Saehaeng, S., Max, J.F.J., Muller, J., Spreer, W. Hydraulic ram pumps for irrigation in Northern Thailand. 1st international conference on Asian highland natural resources management (asiahi-land) and 2nd idrc-searca upland fellowship and conference. 2015. Vol. 5. Pp. 107–114.
17. Lee, S.H., Yoon, H., Kim, D.H., Shin, E., Kim, Y., Ko, K.S., Ha, K. Evaluation of Field Feasibility and Efficiency of Hydraulic Ram Pump. Economic and environmental geology. 2016. Vol. 49. No. 3. Pp. 243–248.
18. Ovsepyan, V.M. Gidravlicheskiy taran i tarannyye ustanovki [The hydraulic RAM and RAM setup]. Moscow: Mashinostroyeniye, 1968. 124 p. (rus)
19. Ahn, B., Ismailov, M., Heister, S. Experimental Study Swirl Injector Dynamic Response Using a Hydromechanical Pulsator. Journal of Propulsion and Power. 2012. Vol. 28, No. 3. Pp. 585–595.
20. Xie, H.B., Chen, J., Liu, F., Liu, Z.B., Yang, H.Y., Lin, S.Y., Zhang, J. Analysis and Optimization of Pressure Shock and Cylinder Stroke Deviation in Open Circuit Hydraulic System of Concrete Pump. Journal of the Chinese society of mechanical engineers. 2018. Vol. 39. No. 2. Pp. 153–161.
21. del Rio, J. A., Lopez de Haro, M., Castillo-Romero, E.S. A plausible approach to heat transfer enhancement: non-Fourier heat transfer in fluids under oscillating conditions. Journal of physics communica-tions. 2018. Vol. 2. No. 5. UNSP 055006.
22. Nussupbekov, B.R, Khassenov, A.K., Karabekova, D.Z., Stoev, M., Beysenbek, A.Z., Kazankap, B.I. New technology for the recovery of heat exchangers. Bulletin of the university of karaganda-physics. 2017. Vol. 1. No. 85. Pp. 67–72.
23. Makeev, A.N. Teplovyye punkty sistem teplosnabzheniya s impulsnoy tsirkulyatsiyey teplonositelya [Substations of district heating systems with pulse coolant circulation]. Vestnik Dagestanskogo gosudarstvennogo tekhnicheskogo universiteta. Tekhnicheskiye nauki. 2017. No. 1(44). Pp. 26–47. (rus)
24. Samana, T., Kiatsiriroat, T., Nuntaphan, A. Air-side performance analysis of a wire-on-tube heat exchanger with an oscillating heat pipe as an extended surface under natural convection conditions. Heat transfer engineering. 2012. Vol. 33. No. 12. Pp. 1033–1039.
25. Akhmetova, I., Chichirova, N., Derevianko, O. Revisiting heat losses calculation at district heating network. International Journal of Civil Engineering and Technology. 2017. Vol. 8. No. 12. Pp. 694–702.
26. Gorshkov, A., Murgul, V. Calculation of Heat Energy Consumption by a Typical Historical Building with a Courtyard. Advances in Intelligent Systems and Computing: 9th International scientific conference Energy Management of Municipal Transportation Facilities and Transport, EMMFT 2017. Khabarovsk; Russian Federation. 2018. Vol. 692. Pp. 577–591.

International conference on appli-cations and design in mechanical engineering (ICADME 2017). Journal of Physics Conference Series. 2017. Vol. 908. UNSP 012052.

16. Inthachot M., Saehaeng S., Max J.F.J., Muller J., Spreer W. Hydraulic ram pumps for irrigation in Northern Thailand // 1st international conference on Asian highland natural resources management (asiahi-land) and 2nd idrc-searca upland fellowship and conference. 2015. Vol. 5. Pp. 107–114.
17. Lee S.H., Yoon H., Kim D.H., Shin E., Kim Y., Ko K.S., Ha K. Evaluation of Field Feasibility and Efficiency of Hydraulic Ram Pump // Economic and environmental geology. 2016 JUN. Vol. 49. № 3. Pp. 243–248.
18. Овсепян В.М. Гидравлический таран и таранные установки. М.: Машиностроение, 1968. 124 с.
19. Ahn B., Ismailov M., Heister S. Experimental Study Swirl Injector Dynamic Response Using a Hydromechanical Pulsator // Journal of Propulsion and Power. 2012. Vol. 28. № 3. Pp. 585–595.
20. Xie H.B., Chen J., Liu F., Liu Z.B., Yang H.Y., Lin S.Y., Zhang J. Analysis and Optimization of Pressure Shock and Cylinder Stroke Deviation in Open Circuit Hydraulic System of Concrete Pump // Journal of the Chinese society of mechanical engineers. 2018. Vol. 39. № 2. Pp. 153–161.
21. del Rio J. A., Lopez de Haro M., Castillo-Romero E.S.A plausible approach to heat transfer enhancement: non-Fourier heat transfer in fluids under oscillating conditions // Journal of physics communica-tions. 2018. Vol. 2. № 5. UNSP 055006.
22. Nussupbekov B.R, Khassenov A.K., Karabekova D.Z., Stoev M., Beysenbek A.Z., Kazankap B.I. New technology for the recovery of heat exchangers // Bulletin of the university of karaganda-physics. 2017. Vol. 1. № 85. Pp. 67–72.
23. Макеев А.Н. Тепловые пункты систем теплоснабжения с импульсной циркуляцией теплоносителя // Вестник Дагестанского государственного технического университета. Технические науки. 2017. № 1(44). С. 26–47.
24. Samana T., Kiatsiriroat T., Nuntaphan A. Air-side performance analysis of a wire-on-tube heat exchanger with an oscillating heat pipe as an extended surface under natural convection conditions // Heat transfer engineering. 2012. Vol. 33. № 12. Pp. 1033–1039.
25. Akhmetova I., Chichirova N., Derevianko O. Revisiting heat losses calculation at district heating network // International Journal of Civil Engineering and Technology. 2017. Vol. 8. № 12. Pp. 694–702.
26. Gorshkov A., Murgul V. Calculation of Heat Energy Consumption by a Typical Historical Building with a Courtyard // Advances in Intelligent Systems and Computing: 9th International scientific conference Energy Management of Municipal Transportation Facilities and Transport, EMMFT 2017. Khabarovsk, 2018. Vol. 692. Pp. 577–591.

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Makeev A.N. Implementation of pulse heat supply for dependent connection of customers. Magazine of Civil Engineering. 2018. 83(7). Pp. 114–125. doi: 10.18720/MCE.83.11.