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RESEARCH OF ENVIRONMENTAL AND TECHNOLOGICAL PROBLEMS OF CAVITATION

Abstract: *The comparative analysis of systems of conversion of electric energy into mechanical and mechanical into thermal with realization of effect of cavitation in a stream of the liquid transported in a closed circuit is carried out. The optimal dimensions and relief of working surfaces of swirlers in tubular and rotary cavitators are determined. The regularities of the change of the coolant temperature depending on its nature, the intensity of cavitation, which is determined by the rotational-translational and rotational motion in cavitators of two types – tubular and rotary.*

Keywords: *oil reprocessing, cavitation, pressure, whirlwind, rotation, purification, efficiency.*

Introduction

The need for priority implementation of energy development and its integral part of environmental security is due today not only for Ukraine but also for industrialized countries such as China, USA, Japan, Russia and most European countries.

Despite the significant progress in the field of environmental safety achieved by leading developers of production, nuclear energy, oil and coal industry, the search and solution of non-traditional and alternative technologies for electricity generation, heat and disposal of human products are becoming increasingly important today. The rescue of the population of the planet Earth from energy "hunger" and environmental pollution is given increased attention, the reflection of which is found in new developments of devices and technologies [1-10].

In non-traditional technologies, the manifestation of cavitation energy is considered mainly for heat production [5]. At the same time, a number of studies are devoted to solving environmental problems [11]. Given the established effect of the double action of cavitation energy on liquids: changes in properties, chemical composition while releasing heat, the need to improve cavitation systems and technologies is obvious. A number of researches are devoted to this direction, the results of which are presented in the offered work.

The first tests of cavitation of liquids in order to reduce the cost of heating were performed in 1998 at the Dnieper HPP-1 in Zaporozhye and positive results were obtained within 4 years. Despite the advantages in the work (for subjective reasons) in recent years continues to improve heating systems, wastewater disinfection, regeneration of transformer oils. At this stage, the accumulated research material and the availability of existing pilot samples give grounds for a proposal to implement in the production of developed samples of heat supply at state enterprises.

Literature review

Cavitation, as a phenomenon of erosive destruction of the surface of metal structures (turbine wheels, pumps, propellers) is known for over a hundred years [1]. Research of the last 50 years is devoted to the issues of determining the conditions of cavitation destruction of metal and technological developments that ensure the prevention of this destruction [12]. In most studies, the effect of cavitation is considered as a negative factor influencing the service life of the product. The most intensive work has been carried out since 1985 to identify the possibility of studying the results of the manifestation of the action of cavitation energy as a source of heat production [12-14]. Over the past 10 years, the number of publications with positive test results of cavitators in technological processes has increased significantly [11, 15-17]. In addition to changes in the main technological parameters that occur after cavitation, the publications have virtually no information about the actual operational stability of the working chambers of cavitators. This condition indicates that in the works of the first – used a laboratory (or pilot) sample of the cavitator and the second – the operational stability of the working chamber of the cavitator is not advertised for commercial reasons or insufficient hours of machine hours. This conclusion arises in view of the known data given in 2003 by NASA (USA) on the characteristics of cavitation bubbles with a diameter of 10 μm, which when destroyed emit ozone in a micro-pulse, the oxidizing ability of which for structural low-carbon steel is known – is its intense dissolution, leading role in which is played primarily by corrosion damage. The energy of "collapse" of the cavitation bubble itself is directed not at the metal, but at the product of the corrosion process, the oxidized film ($Fe_2O_3 \cdot nH_2O$), for the destruction of which the energy consumption of the cavitation flow is negligible.

Reports that cavitation devices (especially rotary ones made of structural steel) have been operating for a number of years (3-7) are more than doubtful due to the implementation of the above-mentioned fracture mechanism.

The lack of reliable and reliable information on the actual operational stability of the working chambers of cavitators when using water as a coolant necessitated the development of such autonomous vortex energy systems, which could simultaneously use the cavitator as a tool to solve environmental or technological problems by influencing the intermediate structure and solution of the problem of heat production during cavitation for heating and hot water supply.

In addition, a number of recent publications have debated two main issues:

- lack of a clear method of calculating economic efficiency from the use of cavitators in one and two, three-circuit systems;
- unproven persecution of authors who explain and show in their experiments the presence of processes of "CNF" (cold nuclear fusion) during cavitation of water [5, 14, 18-20].

These two fundamental questions necessitated the implementation of these studies.

Problem formulation

The object of study – tubular and rotary fluid energy converters, i.e. cavitators.

The purpose of the study – to determine the optimal size and relief of the working surfaces of the vortices in tubular and rotary cavitators.

To achieve this goal you must perform the following tasks:

1. To determine the coolant, the physicochemical properties of which do not change during long-term cavitation and when using which the greatest thermal effect is obtained.
2. Determine the temperature regimes for waste transformer oils.
3. Determine the timing of cavitation of wastewater to its complete disinfection.

The study was conducted using as energy and the object of study network and wastewater, technical glycerin (GOST 6824-96) and its solutions, waste transformer and motor oils, thermolan (TU 24.1-0025601-099-2001), polymethylsiloxane mixtures of two brands PSM-500, PSM-1000 (GOST 13032-77).

Studies on laboratory installations of tubular (SEW-0) and rotary (PCT-1) were performed using an active energy meter (EMP134.02.1, No. 65067, 2002), and flow meters (VSKM-16/40), capillary thermometers (SB 15), clock.

In the study of wastewater, waste transformer oils before and after cavitation used standard methods of laboratories of state enterprises: Right-Bank Separate Subdivision of the Zaporizhia Regional

Laboratory Center of the State Sanitary and Epidemiological Service of Ukraine ("Ukrainian Research Design and Technology Institute of Transformer").

When performing experiments, temperature sensors recorded the current temperature before and after the release of the test liquid in the first and second circuits of the cavitators. The change of the radio on the route of the flow was recorded by a radiometer through a special cell with a transparent shielding glass, which eliminates the distortion of the γ-radiation. With the help of an electric active energy meter, instant, accumulated readings of the consumed energy were recorded. All characteristics of the studied liquids are obtained by varying two factors: time and cavitation temperature.

Direct assessment of the influence of time and limit temperatures of cavitation was carried out based on the results of determining the specific consumption of electricity, maximum changes in its properties and chemical composition when selecting two (before and after cavitation) or several (up to seven) to identify extreme changes in properties.

The main indicators determined in the experiments of the heat engineering direction were chosen: specific electricity consumption W_b, W/m^{2}h, the amount of heat Q_p kcal/h, the amount of electricity consumed W_3, kW/h; thermal equivalent of 1 kW ≈ 860 kcal ≈ 3600 kJ.

During the experiments of technological and ecological direction, the degree of water disinfection and regeneration of transformer oils was determined by the change (±Δ) of the indicators of the studied liquids during their cavitation.

The final evaluation of the efficiency of cavitation in existing heating systems was determined in advance after control measurements of heat and electricity consumed in a constant mode of automatic thermal cycling without taking into account the efficiency of the electric pump (Table 1). The calculation of KPI (energy conversion factor) was made for a facility with a volume of 2000 m^3 without the use of night tariff.

TABLE 1. *Example of calculation of KPE AMK-3 for double-circuit heating system and hot water*

Name of indicators	Symbol	Units of measurement	Number	Notes
The installed power of the electric motor	$N_в$	kW	11×2	2 pumps
Minimum power consumption when output in cycling mode	W_3	kW	9	–
Water outlet temperature from the accumulator tank heat exchanger	$t_{П}^{II}$	°C	65	battery tank V = 580 liter
Water return temperature to the heat exchanger	t_0^{II}	°C	53	–
Performance of the circulating pump of the second circuit	Q_{II}	liter/hour	580	–
Average daily electricity consumption per cycle $\tau_p = 50 : \tau_c = 50$	W_{cc}	kW/hour	4.5	–
Heat productivity: $Q = e \cdot m \cdot \Delta t$	Q	kcal/hour kW/hour	6960 8.1	2 tubular cavitators $Q = 1{\cdot}580{\cdot}12$
$\text{COP} = \frac{Q}{W_3} = \frac{8.1}{4.5}$	KPE	–	1.8	I-th heat exchanger – a solution of water and glycerin 50:50, II – water

Results and Discussions

Schematic diagrams of laboratory and industrial pilot designs developed by the authors of the systems for the use of tubular and rotary cavitators are based on the well-known principle of separation of the moving flow of the working fluid in the Ranke-Hillsha tube, which forms conditionally "hot" and "cold" transport zones in a closed loop. In addition to the separation of the flow in all areas of energy movement, the main attention is paid to different structures of the relief of the working surface to enhance the effect of nucleation and "collapse" of cavitation bubbles in the flow of liquid energy.

In the opinion of the authors, in fact, the cavitator, as a device for intensive production of cavitation bubbles, should be called a converter of vacuum energy, which actually implements the process of vacuuming the fluid flow by destroying its continuity, i.e. by forming gaps – caverns (actually microbubbles) pressure. This process is provided with a special relief of the working surfaces, which in the reaction zones of the device created the conditions for the rupture of the flow continuity. A special relief mimics the structure of shark skin.

To ensure the stability of the cavitation process, the design of the cavitator is a vacuum energy converter connected by a closed pipeline to an electric pump (in the case of a pipe type) or to a housing (rotor type); on the inlet fitting in front of the cavitator is a temperature sensor 6, which ensures the operation of a single-circuit system in automatic mode (Fig. 1).

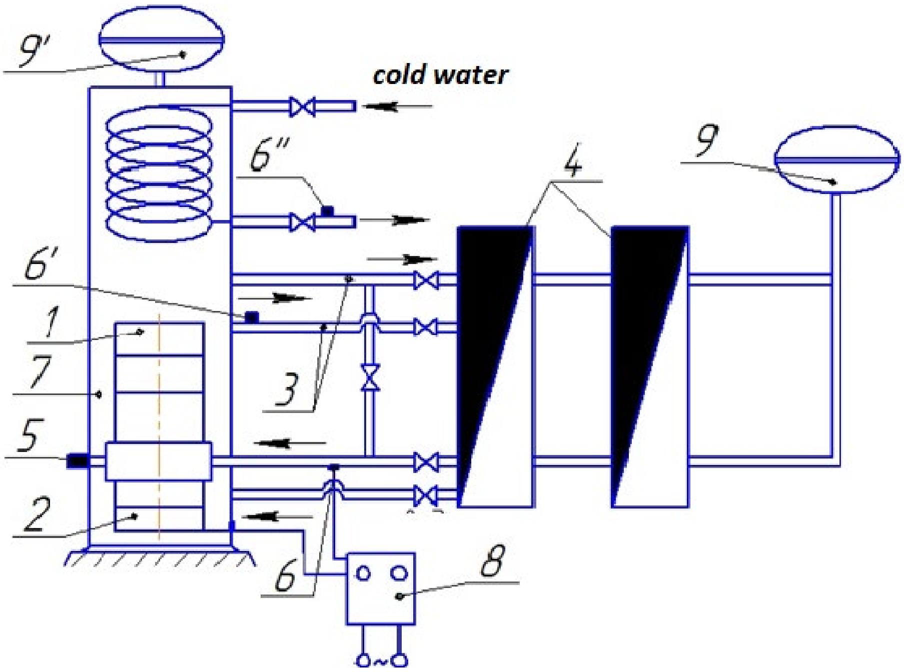


FIGURE 1. *Schematic diagram of the use of a cavitator for heating and hot water*

This scheme of the AISW is tested and is in operation for heating more than 1000 m^2 using two circuits: in the first circuit (actually "cavitation") as a heat carrier is a solution of technical glycerin and water (50:50), in the second circuit, including a heat exchanger, placed in the body of the cavitator, water is used. There is a possibility of using 2 heat exchangers in the second circuit – for heating water and for consumed water. In this case, the temperature sensor of the 1st heat exchanger is installed on the water supply pipe (6') in the 2nd heating circuit, and in the second heat exchanger the temperature sensor is installed on the hot water supply (DHW) pipe (6'').

The composition of the AISW (Fig. 1) includes: cavitator 1 (tubular or rotary), electric pump 2 (or electric motor for rotary cavitator), supply hot pipe 3, radiators 4, pressure gauge 5, temperature sensors 6 of the primary circuit 6', 6'' – for two consumers of the second heating circuit and the consumed hot water, the accumulator 7, the control unit and automatic control 8. The increase in pressure in the circuit when heating the liquid is compensated by the expansion tank 9'(first) and 9 (second) circuits.

An additional reduction of (1.5-2) times the electricity consumption is achieved when using liquids as a heat carrier, in which thermal conductivity, viscosity, boiling point are maximum possible, and heat capacity is minimal.

Such liquids include technical glycerin, polymethylsiloxane mixture (PSM-1000), thermolan, etc., the use of which significantly (2-3 times) increases the rate of temperature rise than the use of water (Fig. 2). When heated by cavitation, in particular, PSM-1000 there is no odor and corrosion of the working area of the converter.

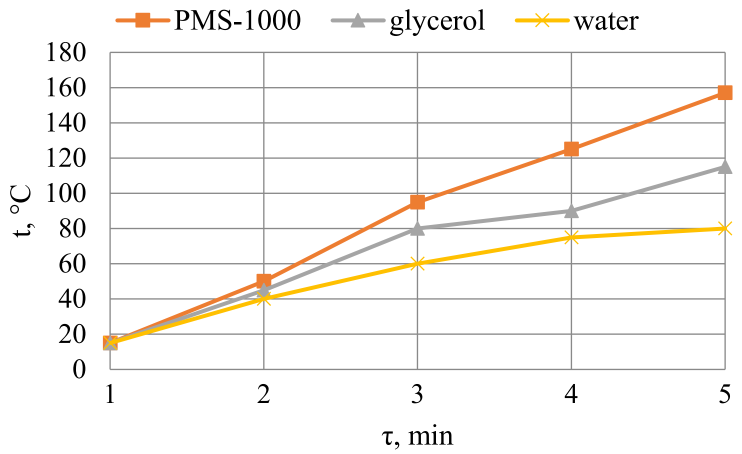


***FIGURE 2.** The rate of temperature rise of the coolant in the cavitator (without load II circuit)*

The established dependences of the influence of the nature of the coolant on the dynamics of temperature change and specific costs in the process of its cavitation in a closed volume are manifested in determining the end result of the heating system. In the second circuit – water. The calculation data are given in Table 2.

***TABLE 2.** Comparative data of indicators of thermal efficiency of AMK-2 (double-circuit)*

The coolant in the primary circuit	Heating rate in the circuits, deg/min		*t* °C boiling	Viscosity ν, cCт	Conversion efficiency ratio (CE)
	I	II			
Water	2.50	0.40	100	1	>1.86
Technical glycerin	5.60	0.77	265	450	>2.46
Polymethylsiloxane mixture	10.80	1.62	317	1000	>3.89

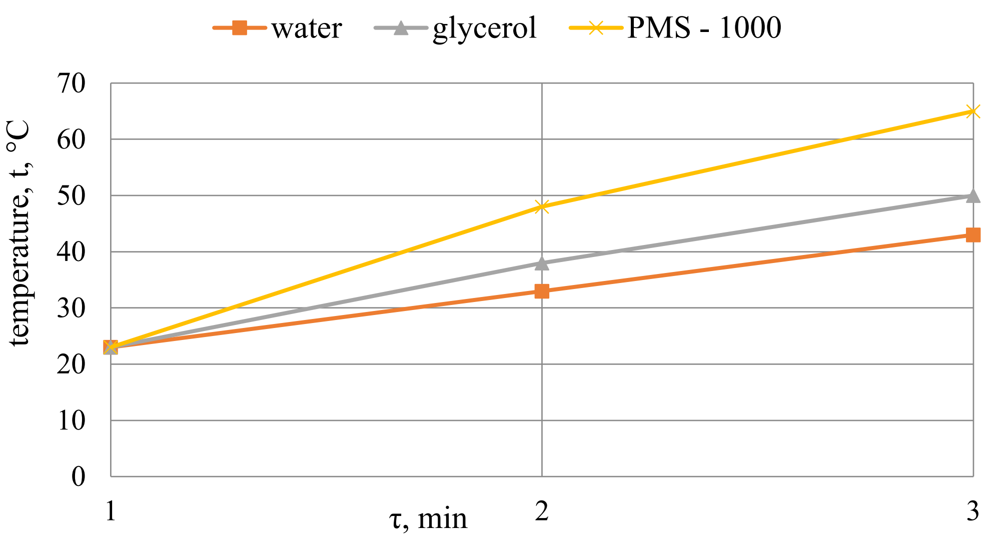
The greatest efficiency of using PSM-1000 as a heat carrier is obvious. There is a direct relationship with a high degree of correlation ($r \approx 1$), between the boiling point, viscosity, heating rate during the implementation of the cavitation effect.

In Figure 3, and presents the results of determining the rate of temperature rise in the first circuit after the cavitator when used as a heat carrier water, glycerin and polymethylsiloxane mixture (PSM-1000). Analysis of the results of temperature measurements and electricity consumption with increasing temperature showed that the use of high-temperature coolants significantly reduces the cost of heat production. The decline in electricity consumption is determined by three main changes in the structure and properties of the coolant:

- when heated, the viscosity of all tested coolants drops markedly;
- similarly manifested change in heat capacity and wettability;

- saturation of the liquid volume of the coolant in the primary circuit with cavitation bubbles, "collapse" of which in the existing design in two stages, partly on the vortex (or brake) and in the relaxer, i.e. saturation of the fluid volume with billions of microcavitation bubbles, transition from single-phase) in two-phase (liquid + cavitation bubble) led to a significant (2-4 times) reduction of hydraulic resistance and a corresponding reduction in energy consumption when consuming an electric drive (Fig. 3b). Simultaneous manifestation of these changes in liquid-gas energy leads to a reduction in costs, in particular, for heating by 3 times. The data were obtained during the operation of a two-circuit system with tubular cavitators.

a)



b)

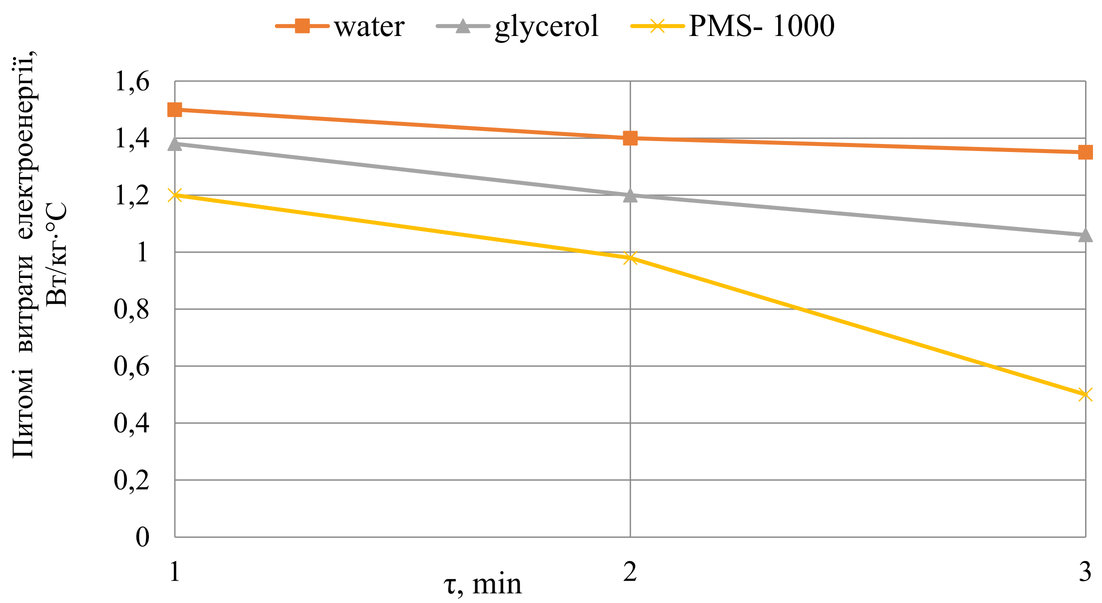


FIGURE 3. *Influence of the nature of heat carriers: a) on speed of heating of liquid in a cavitator (with the loaded II circuit); b) on the specific cost of electricity (at the start)*

Long-term (more than 4 years) operation of tubular cavitators on pilot samples of heating systems showed that the special relief of structural elements of working surfaces in the zone of intensive nucleation and destruction of cavitation microbubbles excludes cavitation destruction characteristic of traditional forms of turbine blades, propellers and propellers. as the origin and destruction of microbubbles occurs out of contact with the surface of the structure, and in the volume of the mobile coolant, the nature of which must ensure compliance with two requirements:

- do not cause corrosion inside the structure;
- not to polymerize at detailed repeated action of effect of cavitation.

Among the previously tested as coolants of the primary circuit of waste oils, hydrocarbon compounds with water, the most effective was polymethylsiloxane mixture. Two brands of the mixture were tested: PSM-500 and PSM-1000.
Actually, a complete explanation of the increase in cavitation efficiency is confirmed by the graphs in Figure 4, obtained from measurements of changes in temperature, pressure and electric current on a single-circuit system with a tubular cavitator connected to an electric pump (power N = 32 kW, n = 3000 rpm) pumps in a closed circuit 800 l of water.

The pressure drop in the circuit in 4 times, electricity consumption almost 2 times at a temperature of 90°C provide the possibility of using cavitators to solve technological problems.

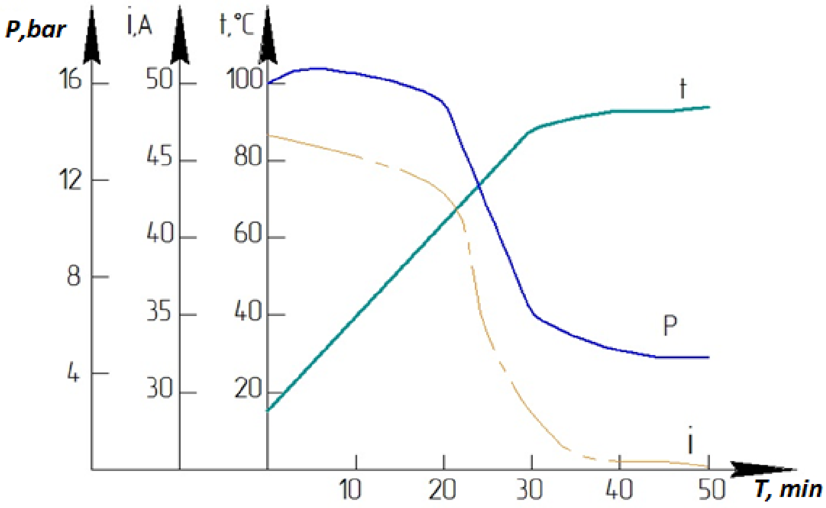


***FIGURE 4.** Dynamics of change of indicators at heating of water in a tubular cavitator*

In Figure 5 shows a diagram of the technological use of cavitators (rotary and tubular) consisting of: cavitator – 1, electric motor – 2, pipeline 3, bypass – 4, swirler – 5, thermocouple – 6, tank for intermediate – 7, tank for finished product – 8, and control and automatic control unit – 9.

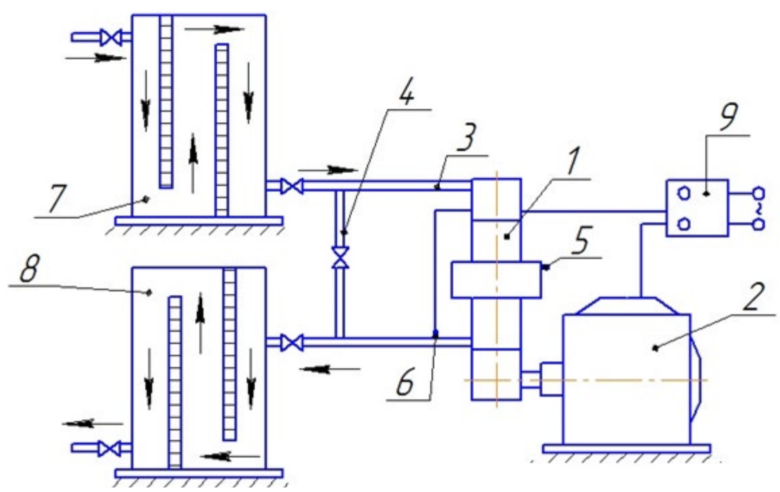


***FIGURE 5.** Schematic diagram of the use of the cavitator to solve technological problems*

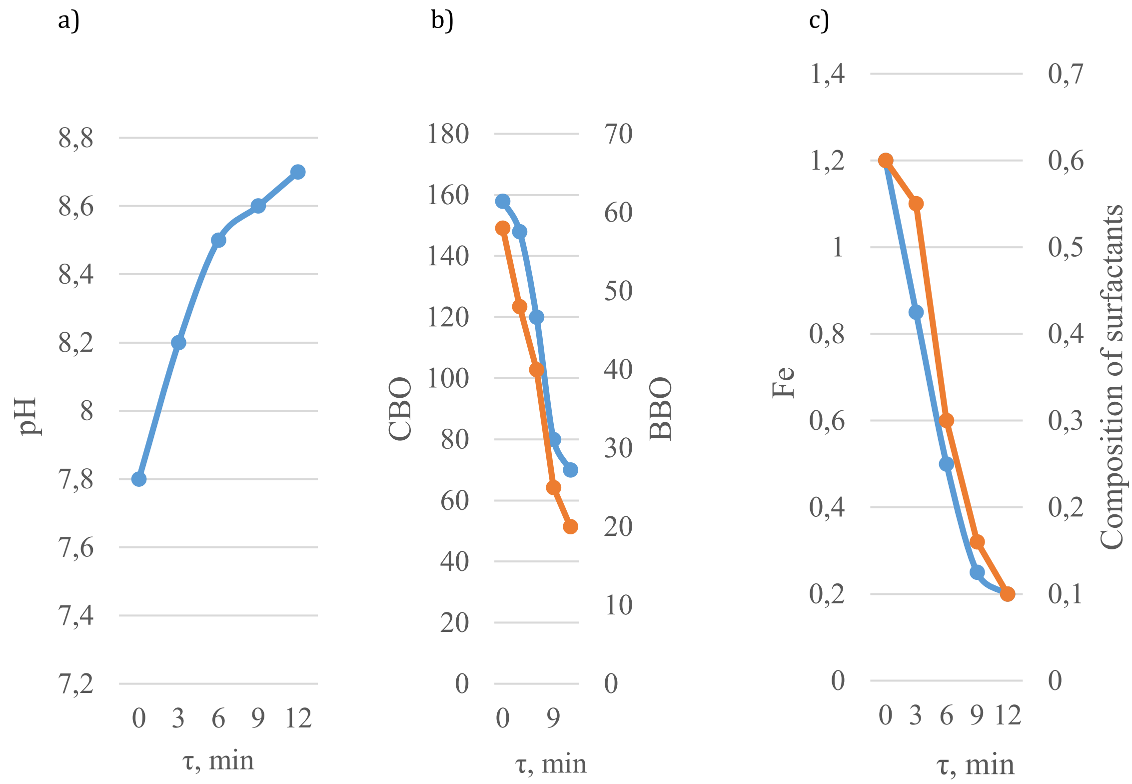
When the conditions of use of the converter in a closed system, heat arises primarily as a result of the destruction of many microbubbles of cavitation nature during the passage through all structural elements. The liquid is heated by implementing the following processes:

- destruction of cavitation microbubbles, in which at the same time with a high rate of "collapse" of microbubbles is the removal (discharge) of the electric potential between the surrounding liquid bubble and the vapor-gas space, which has a negative pressure;
- internal friction of the layers of the working fluid (liquid);
- friction of the liquid on the surface of the structural elements of the transducer and pump;
- weakly expressed cold nuclear fusion (CNF) (with existing limited liquid motion), the occurrence of which is confirmed by changes in the physical and chemical properties of the liquid working fluid (during prolonged use) and a slight but still increase in the radio (5 on 10 μR at P900 = 0.8 MPa).

The latter process (CNF), despite the numerous "revelations" of its absence, is confirmed by no less numerous studies of its presence in the operation of cavitation systems [21-24].

Many works with different contradictory results and the only correct statement from the point of view of the authors of the article have been devoted to the CNF process over the last twenty years: the CNF process cannot but exist in the nature around us, because it is, in terms of temperature, an intermediate modification of nuclear reactions. To confirm this real existence of CNF, it is enough to give an example from the study of Academician B.V. Bolotov, who proved the reality of HY reactions in the stomachs of chickens that ate sand (SiO_2) and the absence of shells on eggs of chickens that did not have sand in their diet [2].

To show the primary effect of cavitation on the coolant and determine the effect of cavitation on changes in fecal wastewater on laboratory equipment, work was performed (on a rotary cavitator) to determine pH, chemical composition of water, biological contamination, tg dielectric loss angle, water content in spent transformer oils before and after cavitation (on a tubular cavitator). The results of analyzes of samples for wastewater are shown in Figure 6, changes in the main components of water are shown in Table 3.



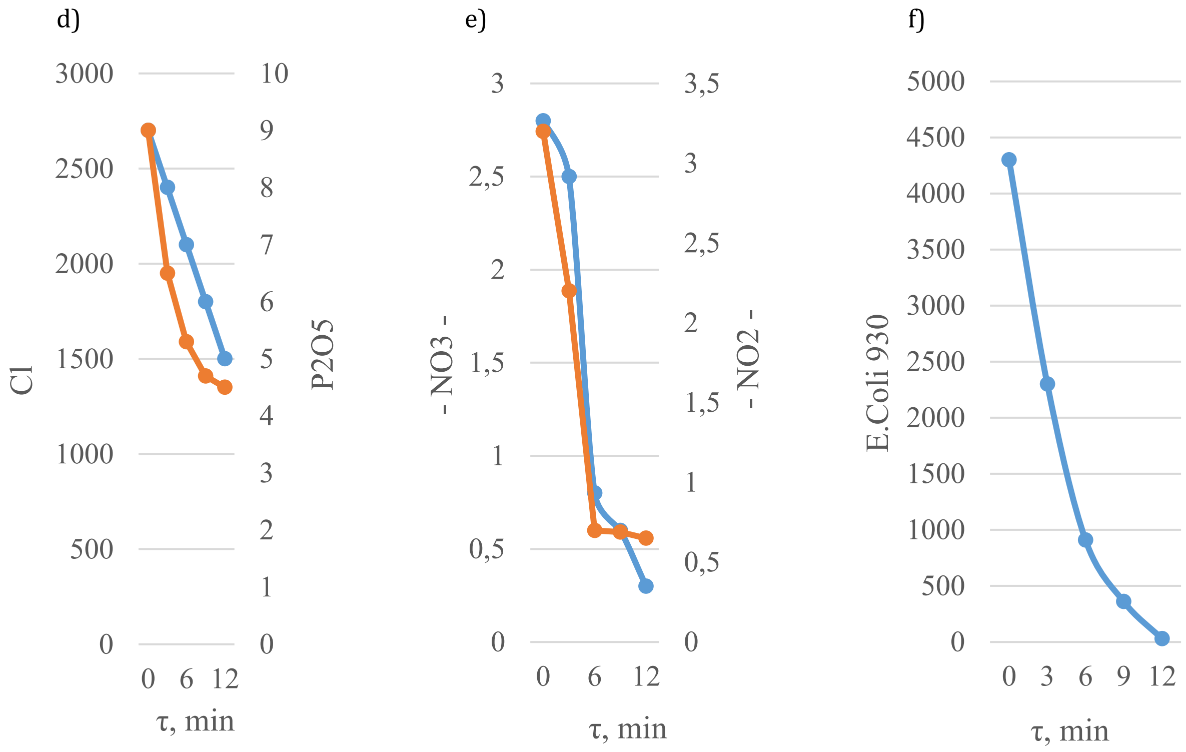


FIGURE 6. *Dynamics of changes in the results of cavitation of wastewater: a) pH; b) CBO (chemically bound oxygen), BBO (biologically bound oxygen); c) Fe, Composition of surfactants; d) Cl, P_2O_5; e) NO_2, NO_3; f) E-coli 930*

TABLE 3. *Change of the basic parameters of water after 12 minutes of cavitation*

Parameter	Up to, mg/dm³	After, mg/dm³	±Δ, %
pH	7.8	8.6	+10
BSK-5	150.0	88.0	-170
CBO	180.0	80.0	-225
Dry residue	3712.0	1370.0	-270
Iron	0.9	0.2	-450
Chlorides	2680.0	1670.0	-160
Nitrites	2.75	1.50	-183
Nitrates	2.7	0.5	-675
Composition of surfactants	1.0	0.2	-500
Phosphates	9.8	4.8	-204
LKP index (E-coli 930)	4300	≤300	-1433

The obtained results testify to the efficiency of using cavitation systems for activation, purification and disinfection of water.

Changes in the state of transformer oils before and after cavitation are presented in Table 4.

TABLE 4. The results of cavitation of waste transformer oil

Features		Units of measurement	Indicator		Change
			Up to	After	
Ignition temperature		°C	135	148	+9.1
Acid number		per 1 g of oil 1 mg of KOH	0.064	0.025	-256
Water-soluble acids		%	0.0042	0.0015	-280
Dielectric strength	Dnipro HPP, transformer substation	kW	19	33	+42.5
	Dniprospetsstal Plant, arc furnace transformer	kW	1.5	64	+97.7
	Zaporizhstal plant, arc furnace transformer	kW	12	69	+82.6
	Coke plant, arc furnace transformer	kW	15	40	+62.5
tg of the angle of dielectric loss		%	7.5	4.8	-156
Changes in the composition of gases					
H_2		%	0.06053	0.00147	-4117
O_2		%	0.34804	0.15793	-220
N_2		%	5.0632	4.3033	-117.6
CH_2		%	0.01568	0.003	-11.1
CO		%	0.03024	0.04079	+31.8
CO_2		%	0.17294	0.19977	+15.5
C_2H_6		%	0.00553	0.00086	-643
C_2H_4		%	0.00107	0.00268	+250
C_2H_2		%	0	0	0
General content		%	5.69	4.17	-20.8

The results obtained indicate the fundamental possibility of using cavitation of waste oils and a significant reduction in the cost of the regeneration process and ensuring compliance with environmental requirements in the implementation of the proposed technology at the facilities and industries listed in Table 5.

TABLE 5. Objects and main areas of use of cavitators

Heat supply	Technologies	Ecology
Residential buildings	Homogenization and heat treatment (TO) technologies	Water management
Housing and communal services of AMK for heating of hot water	Production of perfumes	Disinfection of wastewater
Industrial and domestic premises	Paint and varnish production	Disinfection of intake water
Farms and greenhouses	Paper industry	Increased humus activity
Sports complexes	Regeneration of transformer oils	Disinfection and regeneration of therapeutic muds
Schools and kindergartens	Restoration of properties of motor oils	Increasing the activity of irrigation water
Hospitals, sanatoriums	Biofuel production	Methane production in the processing of waste livestock complexes
Sleeping railway cars	Increase the activity of binding mortars	Defecation of water in fish farms, reduction of acidity
Barracks	Beet processing in distilleries	Increasing the growth of microalgae in fisheries
Cafe bar	Pasteurization of food products	Mixing of immiscible liquids
Dining rooms	Beer and wine production	Regeneration of technical alkaline solutions for washing of axles of railway cars

Conclusions

In comparative experiments of the choice of the heat carrier the most corresponding to performance of the set task is a number of polymethylsiloxane mixes, in this case, the PSM-500 and PSM-1000 brands are tested.

Temperature regimes for spent transformer oils are determined. The optimum regeneration temperature for transformer oils type T-1500 is 90°C. Cavitation time on laboratory devices -30÷60 minutes. The obtained results of the characteristics of cavitary oil are given in Table 4.

The terms of cavitation of wastewater to its complete disinfection are determined, the results of which are given in Table 3, and the dynamics of disinfection – in Figure 6.

The results of experiments performed on laboratory devices of cavitators (tubular and rotary) indicate the efficiency of cavitation of wastewater (Table 3), regeneration of transformer oil (Table 4). At the same time, the manifestations of the thermal effect during the cavitation of liquids confirmed the possibility of using the same device to obtain increased economic efficiency in heating and hot water (Table 1). At the same time, a significant influence of the nature of the heat carrier on the heat generation index was established (Table 2).

Implementation in one unit of two mechanisms: the transformation of the structure of the liquid and its simultaneous heating can significantly increase the list of objects and areas of use of cavitators (Table 5).

The authors of the article consider it possible to attribute the positive results of the study of the cavitation process in solving thermal, environmental and technological problems to the advantages of the developed devices.

The disadvantages of cavitation devices offered for different industries include noise pollution, the reduction of which requires their use in isolated rooms.

In general, the usefulness of the proposed developments can be obtained with greater effect in areas where it is necessary to simultaneously solve, say, thermal and environmental problems. The ultimate potential goal of the performed research may be the development of an autonomous heat generator, i.e. a system for the production of heat and electricity at the same time.

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