Journal of the Technical University of Gabrovo

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INTENSIFICATION OF TRANSFER PHENOMENA IN TECHNOLOGICAL PROCESSES DUE TO THE USE OF CAVITATION IMPACT

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ARTICLE INFO

Article history:
Received 10 September 2020
Accepted 23 November 2020

Keywords:
transfer phenomena, transfer coefficient, system consideration levels, foaming, cavitation

ABSTRACT

The article deals with the cavitation process from the perspective of the transfer phenomenon. For the first time, an attempt was made to link two physical processes - cavitation and the transfer phenomenon. As a result, new opportunities open up for the intensification of working processes in cavitation devices and, as a consequence, the possibility of deep control of the operating characteristic of the system. It is shown that taking into account the transfer phenomena and accompanying processes depends on the state of the liquid and is determined by the transfer coefficients (viscosity, density, pressure). The processes in the cavitation apparatus of the hydrodynamic type are experimentally investigated, the mechanism of intensification is proposed, the regularities of mass transfer in liquid media under conditions of hydrodynamic cavitation are studied. The influence of ultrasonic cavitation on the process of electrolysis of a liquid medium has been investigated. The comparison of the obtained results of visualization with experimental dependences is carried out.

INTRODUCTION

The physics of the transfer phenomenon is known to be an effective means for solving problems associated with the intensification of various technological processes. As an example, we can cite the prospects of taking into account the features of the transfer phenomenon when considering cavitation processes. The peculiarity of this approach is that the transfer coefficients are variable and depend on a number of factors - temperature, viscosity, density, pressure drop, and fluid compressibility. Due to the effect of cavitation on the working medium, these coefficients will be variable. An analysis of modern trends in the development of cavitation devices, which are used in oil refining, chemical, pharmaceutical and food technologies, shows that the direction of development of new technologies for processing liquid media using hydrodynamic (hydroacoustic) emitters is very effective [1-7].

Such well-known domestic and foreign scientists as R. Knepp, K. Fedyaevsky, L. I. Sedov, G. Flynn, L. D. Rosenberg, A. D. Pernik, Roy made a great contribution to the development of this direction and the study of cavitation processes.

Studies by Margulis M., Fedotkin I., Yakhno O., Lugovsky A., show that cavitation creates conditions for unsteady mass transfer [4], activates molecules of a liquid medium and gases dissolved in it, as well as leads to the dissociation of liquid media.

Under severe cavitation regimes, hydroluminescence [8], high-voltage discharges, sound phenomena, ionization, X-ray and other types of radiation are observed, chemical reactions are initiated, and a biological effect is observed [4].

It is obvious that all of the above processes depend significantly on the energy introduced into the system. This energy is divided into two parts.

One part E_A is spent on the activation of the medium, the second E_N, due to dissipation, leads to its heating [7]:

$$E = E_N + E_A . \qquad (1)$$

The energy expended in heating can be calculated using the heat balance equation, measuring the change in temperature over time:

$$E_N = mc\left(T_k - T_0\right) \qquad (2)$$

The needs for the development of modern science and technology give rise to the need for in-depth studies of the features of the transfer process. In this regard, the problem of studying complex processes of information and energy transfer, which play an important role in fluid mechanics, in hydraulic drive, in mechatronics, in electronics, etc., is of particular importance. The physical characteristics of a substance in the processes of mass transfer are the transfer coefficients - kinematic and dynamic viscosity, internal friction of the moving layers of the medium [1-7]. They, as a rule, are determined experimentally depending on the factors that characterize the state of the substance (temperature, pressure drop, etc.). A change in the nature of the transfer coefficients, as well as the physical and

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chemical characteristics of the working fluid (viscosity, density, thermal conductivity) manifests itself in the instability of the operation of individual units and affects the organization of work processes, which leads to a change in the functional and performance characteristics of the hydraulic drive elements and the system as a whole. The transfer phenomenon, in a first approximation, can be described by three main transfer coefficients - the friction coefficient, the heat transfer coefficient, and the mass transfer coefficient in the context of the boundary layer theory.

As you know, the physical state of a body is determined by its energy resource, i.e., first of all, by the combination of mechanical, internal, surface and chemical energies, as well as the energies of electrostatic and electromagnetic fields. Academician LI Sedov Formulated a postulate, according to which energy is the main characteristic of the state of any physical object in accordance with the law of conservation of energy [4].

EXPOSITION

Change in viscosity of a liquid from temperature. Transfer of momentum, Newton's law of viscosity [9-14]:

$$\tau = -\mu grad\gamma \,, \tag{3}$$

μ - the coefficient of internal friction (dynamic viscosity), γ - the velocity of the medium in space.

The change in the density of the liquid from temperature.

Mass transfer, Fick's diffusion law [11]:

$$q_t = -DgradC \,, \tag{4}$$

where D - the diffusion coefficient, C – the concentration of molecules in the substance.

Change in temperature, heat transfer.

Heat transfer (thermal conductivity Fourier law) [11]:

$$q_e = -Q_\lambda gradT \,, \tag{5}$$

where Q_λ - the coefficient of thermal conductivity, T - the temperature of the medium.

Let's find the dependence of the energy resource for the transfer of information, A_i in vector form according to the above laws. The law of information transfer: the amount of information that is transferred through a plane perpendicular to the direction along which the energy gradient is observed is directly proportional to the transfer signal, the area of the plane to the energy gradient [14]:

$$A_i = -vgradE \,, \tag{6}$$

where v - signal, E - energy ("energy complex").

Depending on the characteristics of the transfer coefficients, a change in the intensity of the transfer amount may occur. The diffusion coefficient depends on a number of factors, for example, the dependence of viscosity on temperature, pressure and flow rate gradient, (non-Newtonian fluid).

The approximate dependence of the diffusion coefficient on temperature in liquids can often be found using the Stokes - Einstein equation:

$$\frac{D_{T_1}}{D_{T_2}} = \frac{T_1 \mu_{T_2}}{T_2 \mu_{T_1}} \,, \tag{7}$$

where: D is the diffusion coefficient; T_1 and T_2 - absolute temperatures; μ - dynamic viscosity.

For diffusion in gases at two different pressures (but at the same temperature), the following empirical equation was proposed:

$$\frac{D_{P_1}}{D_{P_2}} = \frac{\rho_{P_2}}{\rho_{P_1}} \,, \tag{8}$$

where: ρ is the mass density of the gas; P_1 and P_2 - the corresponding pressures.

Diffusion coefficient values (liquid, l)

A couple of species	T,C°	D, cm^2/c
Air - water	25	$2{,}00 \times 10^{-5}$
Hydrogen - water	25	$4{,}50 \times 10^{-5}$
Oxygen - water	25	$2{,}1 \times 10^{-5}$

Thus, the diffusion coefficient in the general case is a function that depends on a number of factors, which in turn characterize the rate of transfer.

The heat transfer coefficient can depend on a number of factors and can be represented by the structure of the medium.

Among these factors, the cavitation effect on the medium under consideration is significant. As you know, the cavitation effect can be realized using hydrodynamic or acoustic (ultrasonic) cavitation. The intensity of cavitation is characterized by the cavitation number and the size of the resulting cavity.

Viscosity, as one of the transport phenomena, in this case can be determined as a function of temperature and velocity gradient.

Thus, the decrease in viscosity observed during cavitation treatment can contribute to a decrease in hydraulic resistance and an intensification of the transfer phenomenon.

As for ultrasonic cavitation, its effective use is associated with local effects of ultrasound on limited volumes of liquid, which contributes to an increase in the efficiency of spraying, mixing, extraction, dispersing, and destruction of continuous media, for example, in apparatus for producing hydrogen.

Hydrogen energy is very promising if we take into account the environmental problems of the use of hydrocarbons. Obtaining hydrogen by electrolysis of water is rational, especially in the case of low gas consumption. However, this method is less energy efficient than others. Electrolyzers are widely used in hydrogen power engineering.

The electrolysis of water differs from other methods of hydrogen production in the simplicity of the technological scheme, the availability of water as a raw material, the ease of maintenance of the units, and high operational reliability.

An experimental prototype of a HHO generator has been created, the scheme of which is presented in Fig.1. A measurement system and a methodology for conducting research were developed.

The circuit includes an electrolyzer with the ability to supply voltage to the plates both directly from the power supply unit (PS) and through the pulse width modulation (PWM) module. Te pulse frequency of the module is - 60 V 100 Hz.

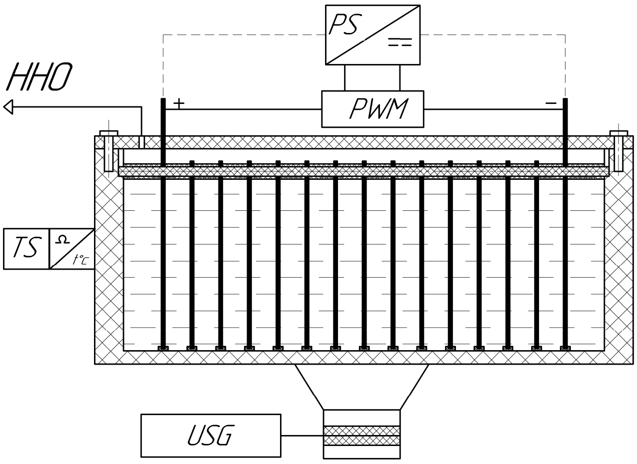

Fig.1. Connection diagram of the test cell under investigation: PS - power supply unit, PWM - pulse width modulator, TS - temperature sensor, USG - ultrasonic generator

Ultrasonic cavitation has the following effect on the electrolysis process:

- cleans the plate-electrodes from surface deposits by dispersing;
- mixes the electrolyte;
- additionally breaks up water molecules;
- carries out degassing and separation of bubbles from the plate-electrodes;
- activates water due to the formation of free radicals when cavitation bubbles collapse.

The amplitude of pulses, the duty cycle is 50%. Number of plates - 25 pcs. The dimensions of the plates are 60x75x1 mm. The plates are made of AISI 316 stainless steel.

By means of an experimental booth it was proved that the use of ultrasound cavitation in the volume of the electrolyte allowed to increase the efficiency of the electrolyzer by 30% Fig. 2.

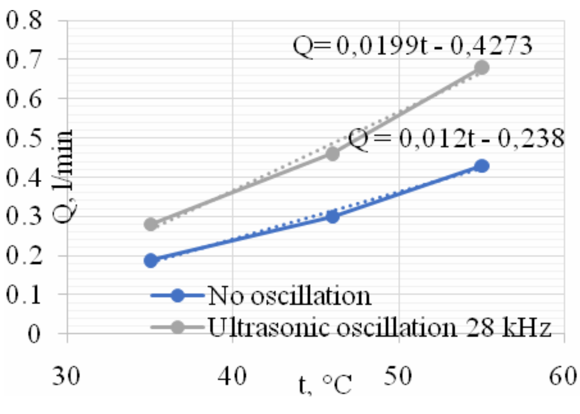

Fig.2. Comparison of the performance of the electrolyzer without the effects of vibration, with vibration and with the use of ultrasonic cavitation ($\mu = 0.05$)

The most effective is the operation of the electrolyzer at a temperature of 50-55°C, that is, the efficiency depends directly on the temperature regimes. In order to prolong the period of stable operation of the electrolyzer, it is necessary to cool the electrolyte. It has been experimentally established that with an increase in the temperature of the electrolyzer over 55-60°C, instability of the technological process is observed.

The ability of operation and efficiency of the electrolyzer with small dimensions is experimentally confirmed.

Similar processes of cavitation action can be observed when solving problems of heat and mass transfer. The use of transfer coefficients in a number of hydraulic systems has shown the change in dynamic parameters in this case, one of the most effective methods of energy transfer during cavitation treatment is the method of mixing two rheological media. Which are not supplied to high-quality mixing by a mechanical method (emulsions of various kinds).

The equation of longitudinal oscillations of a piezoelectric composite converter in general form can be written as [9]:

$$S\frac{\partial^2 U}{dt^2} = C^2 \frac{\partial}{\partial x}\left(S\frac{\partial U}{\partial x}\right), \quad (9)$$

where U is the longitudinal displacement, C is the speed of sound, and S is the cross-sectional area.

Ultrasonic cavitation is of great importance, for example, in biology and medicine. Spherical shock waves and high-energy cumulative jets arising from the collapse of cavitation bubbles destroy microorganisms harmful and dangerous to human health, that is, they disinfect liquid media.

In hydrodynamic transmitters, cavitation occurs when the pressure in the liquid drops locally below the pressure of saturated vapor at a given temperature. Such conditions arise when a high-speed flow around a stationary obstacle or when a high-speed jet outflow from a nozzle. The main difference between hydrodynamic and ultrasonic cavitation is the presence of one or several rather large cavities. Hydrodynamic cavitation makes it possible to intensify the process of mass transfer due to the destructive action of shock waves and cumulative jets.

For in-depth study of light emission, a schematic diagram of the experimental stand has been developed (Fig. 3). The stand is built on the basis of a hydraulic station and contains measuring equipment for fixing the pressure drop on the model and the costs. Visualization of the flow occurs with the help of a high-speed camera with a fixing frequency of up to 1000 fps.

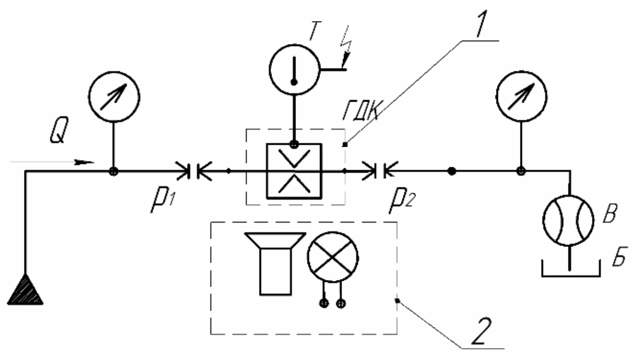

Fig. 3. The basic hydraulic circuit diagram of the stand for the study of the hydrodynamic cavitator (1-cavitation nozzle, 2-high-speed camera)

To determine the critical values of flow parameters (pressures and velocities) at which cavitation starts, a dimensionless cavitation number (Euler number) was used [3]:

$$\chi = \frac{2 \cdot (p_1 - p_2)}{\rho \cdot V_1^2}, \tag{10}$$

where p_1, V_1 - pressure and velocity at the input, p_2 - the pressure of the saturated vapor of the liquid at ambient temperature.

As a result of the experiment, the dependence of the flow coefficient on the temperature of the working fluid was obtained (Fig. 4).

The dependence has a character close to linear and in the first approximation it can be expressed by linear equation. And with a temperature change from 20 ° C to 50 ° C, the flow coefficient has changed almost to 2,5 times.

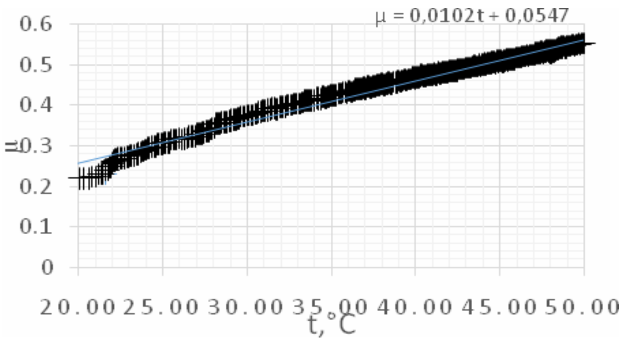

Fig.4. Discharge coefficient (μ) as a function of the temperature (t°C) (Δp = 50 bar, nozzle diameter d_2 = 0,8 mm)

The pressure drop across the cavitator was kept constant at 50 bar.

The experiment began at a temperature of 20 °C. At this temperature, the flow velocity in the section of channel d_2 was 24 m/s. The experiment was completed at a temperature of 50 °C, at which the flow velocity in the section of channel d_2 was 60 m/s.

A significant (up to 5 times) change in viscosity with increasing fluid temperature was observed.

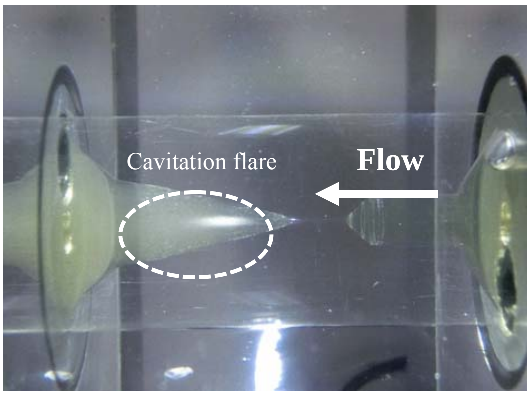

Fig. 5. The process of cavitation in the nozzle (t=20 °C)

At a velocity of more than 30 m/s, a pronounced cavitation flare was observed (Fig. 5).

As the temperature increased, the cavitation processes intensified in the cross section d_2 (Fig. 6 and Fig. 7). At a temperature of flow more than 50 °C, the effect becomes maximum Fig. 6.

It should also be noted that in real conditions used in transfer processes, working fluids can have a rather complex structure and be presented taking into account, for example, the viscosity transfer coefficient, which, however, does not completely determine the main transfer characteristics. In this regard, Reiner proposed models of rheological complex fluids, which allow taking into account not only the viscosity transfer coefficient, but also other rheological coefficients, which makes it possible to consider more complex working media. These models are based on Newton's law, Hooke's law and Senvenant's laws for dry friction with the corresponding transfer coefficients. Thus, for rheological complex fluids that can be considered in transfer processes, in addition to viscosity coefficients, it becomes necessary to take into account Hooke's law.

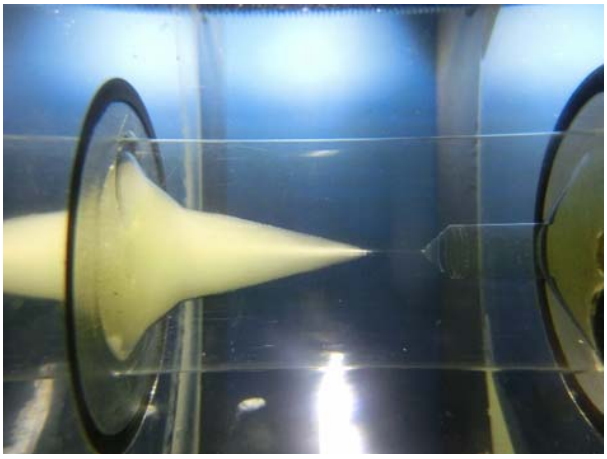

Fig. 6. The process of cavitation in the nozzle (t=40 °C)

CONCLUSION

Thus, energy is the main characteristic of the state of a physical object. Taking into account the processes of transfer and transfer of information makes it possible to evaluate at the stage of research and design the processes occurring in mechanical and hydromechanical systems. The possibility of using information-energy transfer (6) of a signal through an energy gradient is shown.

Thus, the process of cavitation is considered from the point of view of the transfer phenomenon. It is proposed to link two physical processes - cavitation and the transfer phenomenon. What can be positively reflected in the intensification of work processes. The processes in the cavitation apparatus of the hydrodynamic type are experimentally investigated, the mechanism of intensification is proposed, the regularities of mass transfer in liquid media under conditions of hydrodynamic cavitation are studied.

Based on the results of the analysis of the experiment, it can be concluded that with an increase in temperature, the number of cavitation nuclei increases, and the value of the transfer coefficients also changes significantly.

The study of the influence of ultrasonic cavitation on the process of electrolysis of a liquid medium showed that ultrasonic cavitation can intensify the process of electrolysis in general.

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