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Sonochemical Reactor for Water Treatment in the Food Industry

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Abstract : **-** The article presents a new development of the Moscow State University of Technology and Management **-** sonochemical reactor for water processing. A mission of sonochemistry is described and her factors that can effectively apply her to the food industry, disclosed. The results of studies of the food sonochemistry described, mainly for technology of dairy industry. Considered the problems of sonochemical reactors, which prevent the use technology of nonparametric amplification of cavitation in the food industry. The project of reactors of the cylindrical wave and nonparametric amplification of cavitation, which can be effectively used for the industrial preparation of the mixtures from dry dairy components proposed and was compared with the known reactors.

Keywords: *- High Energy Chemistry, Sonochemistry, Sonochemical Reactor, Nonparametric Increasing Energy of Cavitation, Thermodynamically Non-equilibrium State of Water and its Relaxation, Hydration of Biopolymers.*

I. INTRODUCTION

Sonochemistry refers to high-energy chemistry. In that art of chemistry through the epithermal exposure on reactants in the endothermic liquid-phase reactions without heating of all solution containing this reagents, provides significant economic effect even in its industrial-scale.

The main factor of sonochemical reactions is the cavitation, at which in a fluid is generated a huge pulses of pressure from the cavitation bubbles. They in a phase of contraction is compressed to nanometer dimensions, and gas-vapor mixture inside them is heated to high temperatures and turns into a plasma. This condition is accompanied by the emission of photons and called the sonoluminescence [1]. These photons even under normal conditions can be as high energy how ultraviolet. Known are even attempts to implement in cavitation bubbles filled with pairs of deuterated acetone, inertial fusion [2]. Since the process of cavitation proceeds in adiabatic conditions, and the total volume of bubbles, compared to the volume of the liquid is negligible, therefore the sonochemical reactions which occurring in the gas phase have little practical importance. Found that cavitation in water hardly generates harmful factors that would hinder application of sonochemistry the food industry. In the course of the certification tests sonochemical reactors have detected immutable values the 'permanganate oxidation' after treatment with a sample containing 0.4 mg/l of free humic acids. This indicates that the readily oxidizable compounds such as humic acid is not transformed into other oxygenated compounds which are reducing agents with respect to potassium permanganate. But the speed of dissolution of a tablet of chemically pure sodium chloride in the water after the treatment was significantly increased [3]. The originating in the gas phase of cavitation bubbles thermal dissociation of water molecules resulting in only occur a slight shift of pH into the alkaline region, and the synthesis of hydrogen peroxide in amounts which at most intensive processes make up ppm in weight units of water.

Applicable in practice the sonochemical reactions in the liquid phase occur as a result of the pressure pulses which formed from pulsations are therein bubbles what is stimulating the reaction of solutes through a mechanical impact on the structure of their hydrate shell and on the water. Are developed the methods of influence on the intensity of cavitation, which give the opportunity to make these processes controllable [4].

The transformation of the energy of cavitational pressure pulses in the water implements of epithermal mechanism of the destruction of molecular associates of water, of hydration shells of ions and colloids of dissolved substances that prevent their entry into chemical reactions, and is accompanied by a slight increase the temperature of the medium. The water at the same time acquires a thermodynamically non-equilibrium state, which is characterized by its anomalously high solvency. It lasts as long as the received energy gradually would be returned in the form of heat of hydration. That hydration flows between the water molecules, and again restoring the hydrogen bonds and the corresponding to thermodynamic equilibrium structure of the water, if after cavitation treatment her empty-handed not mix [5]. That is, over time, inevitably comes the relaxation of non-equilibrium state. If immediately after the cavitation in the water dissolve the dry biomass, e.g., dry milk or whey, the electrolytes there almost completely dissociates into ions, which undergo immobilize water monomolecule and protein molecules acquire dense shells of the monomolecule. This will increase the mass of the protein, because the water be connected thereto it through the mechanisms similar to those that occur in nature in the process of synthesis and almost as well, how in the structure of protein. The binding energy of the water to a protein that characterizes its strength has the largest value when the protein hydration shell is constructed from the individual water molecules which are not related to each other. A tunneling microscopy is studies have shown that even at room temperature, the structure of water is identical to structure of ice [6]. The reaction of hydration in the water which responsible for the forming of her structure are reversible and is in the appropriate to temperature thermodynamic equilibrium $(H_2O)_n \leftrightarrow nH_2O$. When heated, the mutual immobilization of molecules is reduced, as one can see by change in its viscosity, and theoretically should completely to disappear at the 60 ... 70ºC, since the energy of the hydrogen bonds is little more than half the energy of steam at atmospheric pressure. Therefore, it seems that the water can be prepared for the reaction of hydration, simply heating it. But join in reaction water starts likely with itself (!) Therefore the sonochemical method of epithermal impact most suitable to divide water on separate molecules without increasing their kinetic energy, that is, without heating water.

Was experimentally investigated the possibility of using technology sonochemical preparation of water in the recovery of milk powder and whey. The processing of water was carried out at continuous recirculation through a laboratory sonochemical reactor. Food safety was tested by bioassay method of toxicological evaluation of food products [7]. Have compared the number of species of ciliates *Tetrahymena pyriformis* in the samples recovered from restored cottage cheese whey spray drying at certain intervals. In the serum which restored at the water after cavitation process throughout the experiment the number of ciliates was higher than in the serum, the recovered plain water. And, moreover, the increase amount the simplest with the time there also was. This is because that cavitation treatment significantly alters the physicochemical properties of the water and not creates negative factors affecting growth and reproduction of protozoa. Dry whey is more soluble in water and the nutritional value of the solution turns above. The increased growth of the culture of ciliates determined in a solution of higher concentration of nutrients which available for the simplest. Some characteristics of the solutions are shown in Table.

Mass fraction of the component in the reduced serum, %	On the untreated water			On the treated water		
Sample No.	1	2	3	1	2	3
Protein	2.23	2.22	2.22	2.35	2.34	2.34
Nonfat dry milk solids	5.95	5.92	5.92	6.26	6.25	6.25

To the professionals of dairy industry is known that the small temporary hardness of water favors the production of high-quality remanufactured mixtures [8]. Cavitation at the expense of the epithermal energy transfer mechanism makes it easy to convert the soluble bicarbonates an insoluble carbonate form [9]. The mechanism of reactions is based on destruction to pressure pulses from cavitation of hydration shells of the dissolved and existing in the form ions of bicarbonates $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$, that is on the dehydration of the ions and thereby transformation this hardness salts into amorphous colloidal form $CaCO_3$, and $MgCO_3$.

II. REVIEW OF THE TECHNICAL AND PATENT LITERATURE

There is sonochemical reactors which besides ultrasonic waves in water create in it the acoustic cavitation by means of overcoming the amplitude of the sound pressure named cavitation threshold. To do this, ultrasonic transducers mounted on the water pipes through which water is supplied [10]. Thus, the sections of pipe, with mounted on them sources of ultrasonic vibrations by definition represent the cavitation reactors of flow type [11], to design of which can be impose specific requirements and ensure compliance with these requirements.

These requirements are fulfilled in a reactor [12], which is designed for intensification of chemical reactions under the influence pulses of the pressure generated by the pulsation of the cavitation bubbles. It can be used for water softening, as it is destroyed dipole-dipole interactions between the water molecules and ion-dipole interactions between the molecules and the ions of dissolved substances. The reactor contains a single source of plane wave. Size of the front this wave is strictly limited. This reactor allows for enhanced cavitation to improve its efficiency only by changing the chemical composition of the water, as is done, for example, in [13]. But this is don'ts if the water used in the food industry in the foodstuff.

However, the cavitation can be strengthened without changing the parameters of the fluid through controls of phases of the several existing in the reactor volume independent ultrasonic waves the same frequency, i.e. through nonparametric amplification of multibubble cavitation with maximum in the predetermined point of liquid volume because of superposition there emitted pressure pulses bubbles. The easiest way to implement such amplification can be in the geometric center of the volume, if the acting there waves symmetrically arranged relative to this center and have position of their fronts parallel to the axis of flow of water [14].

Such reactors are patented. For example, in one of them [15] several acoustic resonators of one frequency located for example in a row along the axis of water flow and emit in him a plane-elastic acoustic waves which are symmetrical about him central point. The phases of these waves are set ahead each other by an amount which depends on the size of the resonators and their mutual location in the reactor. In [16] in order to simplify the control circuit, each next under account from the center, the pair of resonators works in antiphase to the previous pair. For these sizes of the radiating surfaces in resonators defined. But both of these designs of reactors at the expense of acoustic resonators are distort profile section of the pipe through which flows a stream of water. This leads to form to so-called "dead zones" which doing difficulties in the purification. This limits their application in food industry, where except to water can doing processing and other liquids such as milk.

Better than in considered above reactors geometrically connected with tube for the water the housings of acoustic resonators in reactor [17], which also has a nonparametric control of intensity of the cavitation without phase control of resonators. The reactor contains an even number arranged in a row on the axis of the flow of water passing through the geometric center of his internal volume, acoustic resonators of plane wave of one size. They cause the perpendicular of this axis the elastic oscillations of water equal frequency and phase. Moreover, points of intersection of rays waves created in lying on each side of the center of the internal volume of the reactor resonators located at predetermined intervals, which are dependent on number the resonator and the number of pressure antinodes therein. But, nevertheless, in this reactor the formation of "dead zones" in the working volume takes place due to interchanges of acoustic transducers with the pipe and making it difficult to its periodic internal cleaning.

III. HYPOTHESIS

Judging from FIG. 8 of [14] auto gain cavitation can also be done in the cavitation reactor with one acoustic resonator in which there is only one an elastic wave with a solid front if:

- make the acoustic resonator of the reactor from the integrating transformer of acoustic wave and cylindrical wall of the tube on which it is mounted. They will convert a planar oscillation of few electro-acoustic transducers arranged along the perimeter of the transformer into the cylindrical oscillations of tube wall;
- integrating transformer establish on the pipe with a mechanical force corresponding to the radial deformation of walls, which exceeds the amplitude of its radial vibrations in the absence of water in tube;
- doing a length of transformer on pipe axis of from one to two wavelengths of radiation in water.

IV. EXPERIMENTS USING THE MATHEMATICAL MODEL

For comparison of such reactor with reactor [17] was carried out by computer simulation using a mathematical model of the spatial distribution of erosive power of the multibubble cavitation, of the theory of cavitation reactor and the similarity of cavitation processes [18]. How a shell of the chamber for cavitation reactor [17] (Fig. 1) was used part a pipe circular diameter one inch.

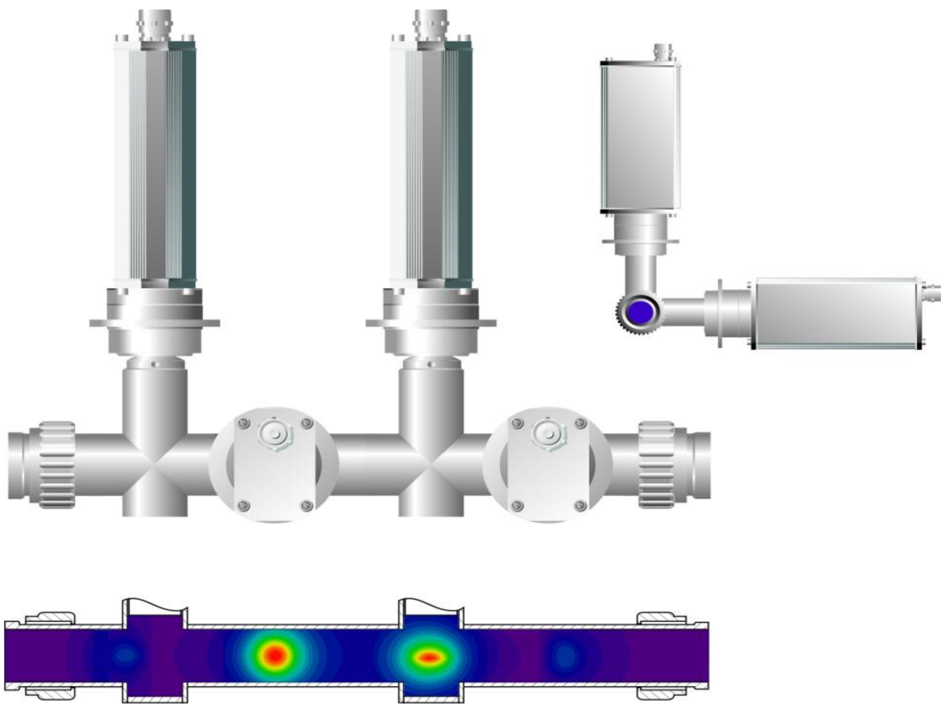

Fig. 1. Design of the cavitation reactor [17], corresponding to patent RU 2422371, 2011.

The reactor had four half-wave acoustic resonators of elastic waves with ultrasonic processor UIP-250 (Hielscher Systems GmbH) as sources of vibrations, (a diameter of 24 *mm*, the frequency of 20 *kHz*, power 250 *W*). These sources were inserted to the pipe through nipples and had the reflectors. They created in water a cavitation with density of distribution of the erosive power in the axial section of the reactor shown on the axial plane.

The experimental reactor (Fig. 2) had the same size working volume and was made of pipe too. His acoustic resonator was formed by integrational transformer [19] with axial holes for exceptions from the stresses along the lines of the circles, with five transducers type MPI-2525D-28H (28 *kHz*, 200 *W*), and also by the pipe wall. A cylindrical wave transformer was fixed to the pipe with tension, the force of which corresponded to the radial deformation of the pipe which above the amplitude of its oscillations in the absence of water in it. Thus, the radiation power and the volumes at the reactors were the same. This allowed to use a similarity theory of cavitation processes is very just.

Five transducers of the experimental reactor, connecting to the common generator power of 1 *kW*, are transforming electric energy into energy of synchronous elastic waves of the integrational transformer which mounted with an interference fit on the outer wall of the tube. Therefore, through this wall, they are transmitted without any loss to the water as a cylindrical wave in the direction of the axis of flow of water. The water flow passing through reactor undergoes the action of the erosive power of pressure pulses from pulsations the cavitation bubbles in this wave. The bulk density of erosive power has the spatial distribution in the water, as shown in axial section in Fig. 2.

This illustration clearly shows that near the geometric center of the reactor due to nonparametric amplification of cavitation in a cylindrical wave is formed a single maximum power density distribution. That is, the flow, passing through the reactor, will experience the impact an accruing to the center of the power density. Distribution in the flow of water an erosive power will effectively do the work against of the forces of adhesion hydration shells with the ions salts of bicarbonates, destroying these shells. Jonah deprived of hydration shells, receive a higher surface charge density and form the insoluble carbonates. In this case, the reactor of nonparametric amplification of acoustic cavitation in single resonator which transmit ultrasonic vibrations directly through the wall of the pipeline will have a simple design that allows easy periodically clean the interior of the tube where has no "dead zones."

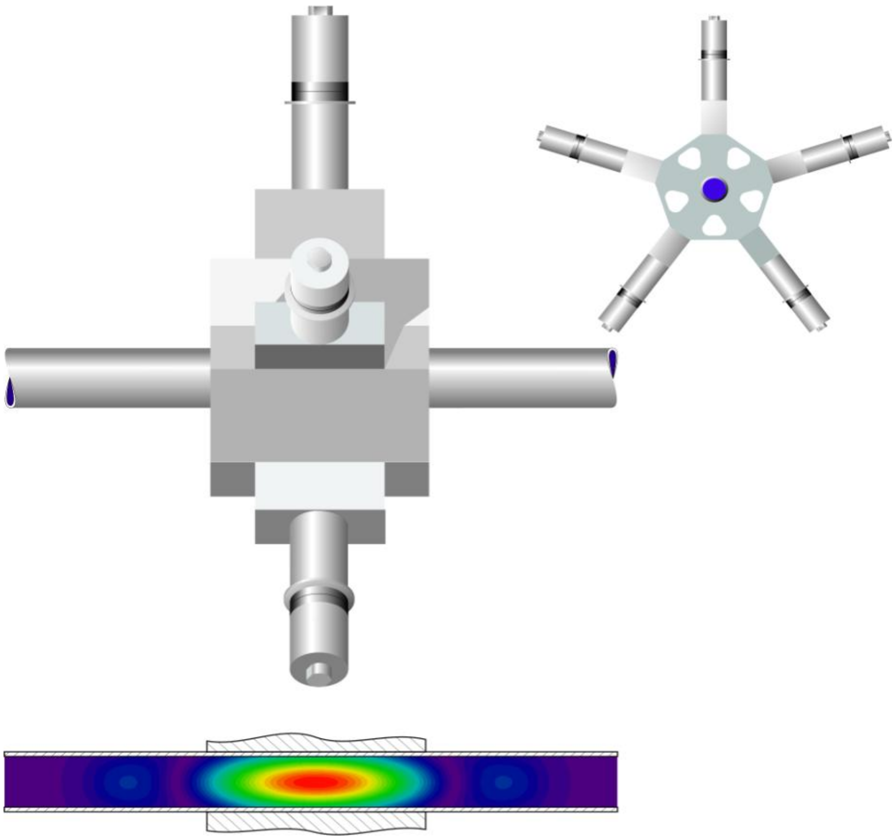

Fig. 2. Experimental cavitation reactor.

Average in the working volume the power density of cavitation erosion in the experimental reactor was in 1.46 times greater than in the reactor from article [17].
The reactor was similar to that described can be effectively used in the production of dairy systems from the dry components [20] instead the industrial processor UIP4000 (*Hielscher Systems GmbH*).

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