Journal of Siberian Federal University. Engineering & Technologies 1 (2008) 76-85
~ ~ ~

УДК 532.528; 621.1

Nanotechnology Cavitational Effects in the Heat-and-Power Engineering and Other Branches of Production

Vladimir A. Kulagin*, Tatyana A. Kulagina and Ludmila V. Kulagina
Siberian Federal University, 79 Svobodny, Krasnoyarsk, 660041 Russia [1]

Received 1.02.2008, received in revised form 12.05.2008, accepted 30.05.2008

This paper is concerned with developing and introducing into industry new technologies of producing multi-component media (emulsions, suspensions, aqueous solutions and systems) with the use of cavitation, which allows to obtain considerable positive results in heat-and-power engineering, building industry, agriculture, and other industries, sciences and engineering. Power efficiency and environmental safety of the processes based on cavitation effects have been show, promising further research is expected.

Keywords: cavitation nanotechnology, cavitation emulsification process, oil-bearing water, mineral oils, high-concentrated polydisperse systems, erosion mechanism of destruction and intensive turbulent micro mixing, emulsions, suspensions, aqueous solutions and systems.

Introduction

The use of hydrodynamic and thermo physical effects of cavitation (cavitation technology) [1] facilitates mechanical thermolysis of the water structure with free hydrogen bonds production, dispersion and solution annealing treatment to produce resistant emulsions, suspensions, and mixtures finally promising to improve and intensify the processes in various industries.

Presented in this paper are the results of experimental research in studying the effects of cavitation hydro thermodynamic features on the change of fuel-water mixtures characteristics and thermo physical features at their burning in various furnace plants. The results of the cavitation treatment effect on the properties of water which at times is a dispersed phase and at other times is a dispersion medium are presented. The cavitation technology uses in other industries and engineering to determine energy-supply-saving, ecological, and other effects are discussed. It has been stated that cavitation technology use allows obtaining a number of important results.

* Corresponding author E-mail address: v.a.kulagin@mail.ru

Conclusions

In changing the characteristics of water it has been established that as a result of hydrodynamic treatment its physical characteristics change considerably and are kept long enough (up to 7-10 days) whereby the modified water can be used in various processes.

Fast oxygenation is observed in the air environment, which can be explained by the presence of the kinetic mechanism of saturation of water with the oxygen resulting in a noticeable non-equilibrium of its dissolution process as well as diffusion mechanism (due to a high degree of compressing the steam-to-gas contents of a cavitation micro bubble).

Fig. 1 shows the increase of the oxygen equilibrium concentration in the medium of inert gases and nitrogen influencing the intensity and nature of the oxygenation process kinetics. The nature of oxygenation change in the nitrogen medium is determined by the formation of NO, NO_2, HNO_2, HNO_3 binding oxygen and hydroxyl radicals. This is verified by the results and conclusions of the investigations of ultrasonic cavitation. An activated molecule of water alongside with radiation and dissipation of excess energy into heat, can dissociate. The O_2 concentration is increased due to both the hydrodynamic cavitation thermolysis of water onto $H\cdot$ and $\dot{O}H$ and the respective reactions behavior [2].

Fig. 2 shows the dependence of chemiluminescence's intensity for a redistillate. The change of water pH following the cavitation treatment takes place due to the production of various chemical compounds which output depends on the operating mode, on the presence of impurities and gas content in the water. The water thermolysis results in the synthesis of H_2O_2, which makes for pH decrease. The treatment in the nitrogen medium increases the system acidity due to the production of HNO_2 and HNO_3. The concentration of CO_2 has a considerable effect on acid-base qualities, which quantity can change as a result of the treatment. The respective pH change under a hydrodynamic cavitation effect depending on the treatment time is shown in Fig. 3.

Thus, under the cavitation effect in the aqueous solution containing inert and active gases, it is possible to realize various chemical reactions. Their cavitation initiation is just the ionization and

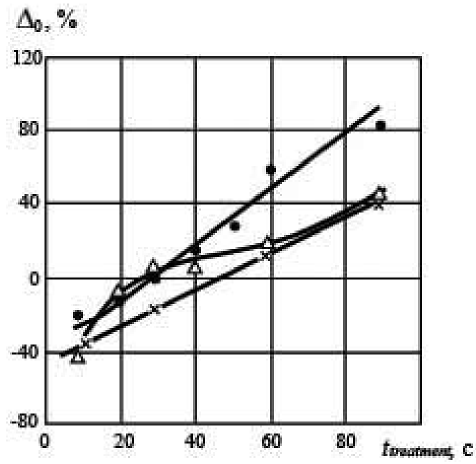

Fig. 1. The dependence $\Delta_0 = f_{(t_{treatment})}$ for the unsettled tap water: ● – Ar; Δ – N_2; x – He. Under the initial O_2 concentration 40 %

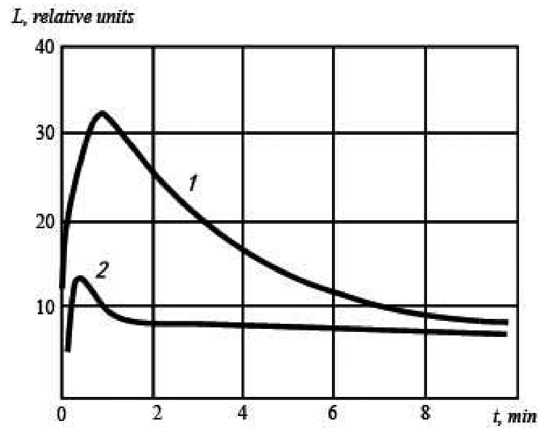

Fig. 2. The kinetic curves of chemiluminescence's intensity in the redistill ate (C_0 = 100 %): *1* – redistill ate treatment in free air, $t_{treatment}$ = 60 s; *2* – raw redistill ate

activation of water molecules, rare and active gases, and also the water molecules dissociation. Each of these processes is realized in a definite time $t{\sim}10^{-14}$ s. In connection with the fact that the time of the bubble collapse final stage is $t{\sim}10^{-9}{-}10^{-8}$ s, there can be realized power transfer and overcharge processes involving inert gases molecules, which develop in a gas phase according to the equations

$$Ar^*(He^*) + H_2O \rightarrow H_2O^* + Ar(He)$$
$$Ar^+(He^+) + H_2O \rightarrow H_2O^+ + Ar(He)$$

Along with the above mentioned reactions in the cavitation cavity there are also reactions of radicals transformation that involve chemically active gases and radicals recombination's in the time $t \sim 10^{-7}{-}10^{-6}$ s. As a result of these processes after the cavitation bubble collapse, the products of radical decomposition of H_2O molecules and radicals recombination's detected with the help of a spin traps procedure pass on to a solution. As a result the water accumulates molecular O_2, H_2O_2, and other compounds. High speed of reactions proceeding is an evidence of their occurring directly in the zone of cavitation destructions intensifying the process of cavitation erosion that is essentially important at various hydro-and-power equipment operations [3].

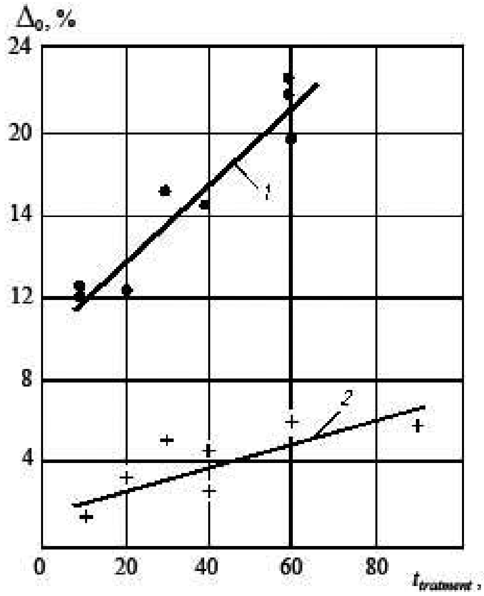

Fig. 3. The dependence $\Delta_0 = f\,(t_{treatment})$ in free air (C_0 = 100 %): 1 – redistillate, pH_0 = 5,4; 2 – the unsettled tap water, pH_0 = 7,0

In fuel and water-fuel emulsions and suspensions preparation to increase complete combustion of fuel and suppress the formation of harmful substances in technological emissions there have been investigated: water-fuel-oil emulsion (WFOE), water-coal suspension (WCS), mixtures "water diesel fuel" (WDF) and "water-gasoline", etc. The effect of fuel drops sizes on the physical processes of evaporation, heat exchange, and carburetion taking into consideration the fuel complete combustion has been determined. We also have developed construction and investigated hydrodynamic, consumption, and dispersive characteristics of cavitation technological apparatus depending on the operating mode parameters and on some external factors to determine optimum constructive and technological parameters [4].

Engaging the cavitation treatment of fuel oil in the fuel preparation process has considerably decreased the limits of humidity and dispersion ability fluctuations of the fuel water phase (with miniaturizing the absolute average diameter of water drops in WFOE, it being 10-15 times smaller, about 10-15 microns), which is clearly enough verified by micro photos of WFOE samples [2]. On getting into a furnace capacity, fuel drops due to their secondary crushing (as a result of a micro-explosion) are essentially miniaturized. As a result, the residence time of drops in the reaction furnace capacity increases due to their trajectory lengthening in the turbulent mixing process; the specific reaction surface of fuel drops increases; the combustion speed of fuel as fine drops increases and is accompanied by separating smaller amounts of solid products than with large drops of fuel oil. Along with stabilization of humidity-dispersive characteristics of fuel, another important effect of dispersion is the destruction of resinous and asphaltene structures and increasing the homogeneity of fuel oil.

The results of investigating smoke fumes samples at burning M100 and WFOE fuel oils have shown that the WFOE use instead of plain fuel oil allows to decrease in smoke fumes the concentration of nitrogen oxides by a factor equal to 3-5 times, sulphurous anhydride – to 2-4 times, carbon oxide – to 2-2.5 times. The use of WFOE with $W^p \approx$ 15-20 % is the most expedient. The suppression of hydrocarbons cracking occurs as a result of not only fuel-oil drops miniaturizing but also due to heat removal by evaporating water and also as a result of additional reactions between dissociated water molecules and carbon.

The WCS investigations have proven its usage promising. Various coal fractions have been used: 0-100, 100-1000, 1000-1600, 1600-2500 microns and the coal of various source grain-size distribution estimated by the abundance of fractions smaller than 100 microns – 15, 30, 45, 90 %. The experimental charges of coal of various grain-size distribution and breakup have been prepared in sequence as the following: coal coarse grinding; averaging; serial stages of fine grinding estimated by the conversion efficiency parameter of (EC), Fig. 4. The efficiency of conversion is a ratio of the coal breakup fraction (0-100 microns) to a total load of all the fractions of sample coal.

Fig. 4 illustrates that the increase of the coal conversion efficiency not only increases the value of the specific surface of particles due to their miniaturizing, but also considerably reduces heterogeneity of distribution of particles, i. e. advances the WCS by this parameter to a usual mono-substratum that differs from a fractionated one by heterogeneity of chemical composition.

The efficiency of the WCS use rises by pipeline transportation of source coal as well as by using oil-bearing water or water polluted by other mineral oils. In this connection the ecological effect from the recycling and fire sterilization of waste products increases. The WCS demixing was not observed within the span of time up to 50 days with the volume content of coal up to 60 %. The fuel saving is due to the increase in complete combustion, operating the atomizers with the minimal excess air and the decrease of emitted fumes temperature. We have obtained positive results in coal briquetting after the cavitation treatment (strength characteristics of the obtained briquettes are higher by approximately 20-30 % than by traditional procedures).

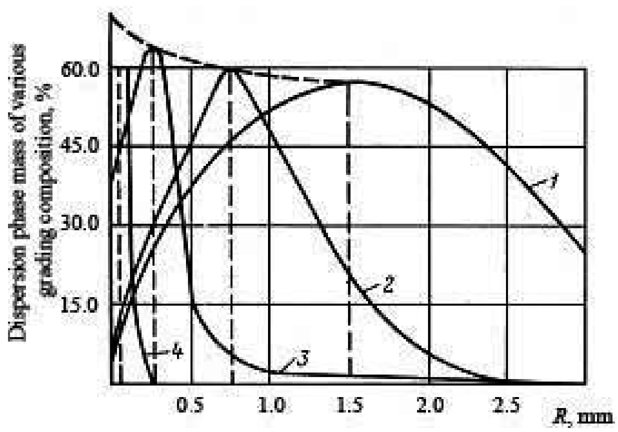

Fig. 4. The particles behavior of the WCS source dispersion phase R at a various degree of grind fineness (by the parameter “efficiency of conversion”): 1 – 15 %; 2 – 30 %; 3 – 45 %; 4 – 90 %

The analysis of the results of liquid fuel hydrodynamic emulsification and the comparison with the results of acoustic effect for binary emulsions (WDF, "water–gasoline") have shown that resistant emulsions of gasoline in water can be easily obtained whereas the reverse emulsions due to intensive coalescence cannot be produced so easily (the water content in such an emulsion with the absence of surface-active substances does not exceed several percent). It is possible to produce a WDF with the water content up to 30-40 % [2].

Recent work indicates that the efficiency of the cavitation emulsification process is essentially affected by the mechanism based on a density distinction of liquids; the highest-quality emulsions are produced when the density of the carrying phase is more than that of dispersion. The use of water-fuel emulsions in internal-combustion engines decreases solid and gaseous (CO, CO_2, NO_x) emissions.

Given in the same section are the descriptions of technological flowcharts and modes for the above mentioned and other processes at their industrial use. Promising fields of using the cavitation technology have been noted and the most important lines of further research have been determined.

In building industry the increase of the cement specific surface directly in the water medium with the help of the cavitation dispersion allows to use more completely the cement potential qualities and to increase the hydration degree and the surface energy of particles. By destroying the weak original aluminate coarse-grained structure it is possible to obtain a fine-grained structure of cement stone which solidity increases by 2-3 times (Fig. 5) as compared with cement mortar preparation in usual mixers.

The mineralogical characteristics of high-content calcium ash produced as a result of burning the Kansk-Achinsk coals enable using it instead of cements in producing building mortars and concretes. The problem of its usage lies in the fact that it contains plenty (up to 20-30 %) of encapsulated quicklime. When using this ash as a cementing agent, the slow slaking causes a resulting slow self-destruction of the material.

With the help of the cavitation technology it is possible to produce a high-quality cementing agent from ash-and-slag waste products at producing building products by slaking the lime contained in slag in the process of treatment; the cavitation treatment of water-ash suspension (WAS) brings about the increase of the suspension samples resistance by 10-15 %.

The influence of multiple-factor effect of cavitation consequences on living organisms is of interest in medicine, microbiology, and biotechnologies. The investigation is concerned with two lines of cell

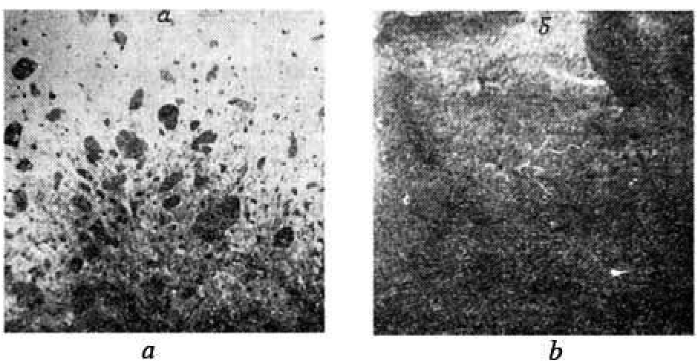

Fig. 5. The cement stone cube structure (W/C = 0,5, cement M300): *a* – without the cavitation treatment (bending resistance R_b = 3,6 MPa, compressive resistance – R_{cm} = 17,3 MPa); *b* – $t_{treatment}$ = 60 s (cavitation relative number χ/α = 0,34, R_b = 9,6 MPa, R_{cm} = 38,1 MPa)

cultures: transplantable L-41 and primary-tripsinized culture of cells of human embryos fibroblasts (HEF). The density of the cell slurry during the time of replanting was 150-200 thousand of cells in one ml for the cell culture L-41 and 300-350 thousand in one ml for HEF. The culturing was performed in matrices with the volume of 230 cm^3. The growth environment consisting of 10 % cattle blood serum and 90 % nutrient medium 199, was replaced in two days.

Medium 199 was a control over both cell cultures and was used for preparing a nutrient medium without machining. Totally there are given 31 passages of transplantable L-41 cell cultures where the medium cavitation treatment was done and 12 passages for the HEF culture. They are enough for obtaining a high (95 %) degree of reliability of the results given in Table 1.

Table 1. The results of cell cultures treatment

Cell cultures type	199 treated medium content, %	Number of passages	Monolayer time formation		
			1-st day	2-nd day	3-d day
L-41	25	31	+	++	+++
	50	31	++	+++	++++
	100	31	+	++	+++
	Control	31	+	++	+++
HEF	25	12	+–	+	++
	50	12	+	++	+++
	100	12	+–	+	++
	Control	12	+–	+	++

Notes: (+–) – cells are sparsely attached to the substrate layer; (+) – cells are densely attached over the whole area; (++) – occurrence of a tender monolayer; (+++) – formation of a solid monolayer; (++++) – the beginning of cells ageing.

With the various content of 199 medium treated in a nutrient solution, the unequal degree of growth intensity of cell cultures L-41 and HEF is observed. The fastest growth is common for both the cell cultures under bringing 50 % 199 treated medium into the growth environment. Both the complete and partial (25 %) replacement of the usual 199 medium by a medium highly saturated with oxygen does not reveal essential distinctions in the growth of cell cultures in comparison with the control.

The analysis of the obtained results allows to draw a conclusion about the effect of 199 treated medium on the of L-41 and HEF cell cultures reproduction (towards acceleration of cell cultures growth). The greatest effect is achieved at 50 % content of such a medium in a nutrient solution. The replacement of 199 medium by the treated medium results in growth impairment connected with free O_2 super saturation, which changes pH of the growth environment towards acidity increase.

Fig. 6 illustrates the results of biochemical treating the previously hydro dynamically activated WCS in producing the «Gumat» biostimulant of growth for flower, vegetable and garden cultures. In comparison with the control

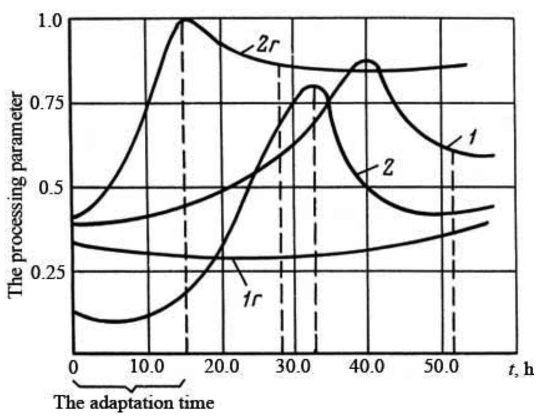

Fig. 6. The kinetics of changes of the WCS processing parameters depending on the time of biochemical treatment without the previous (control) and with the previous cavitation treatment (g): *1*, *1g* – surface tension, $g/cm^2 \cdot 1.7$; *2* – protein concentration, % ·100, HA^{daf} = 63 %; *2g* – the same at HA^{daf} = 94.5 %; HA^{daf} – humic acids output in regard to dehydrated, de-ashed organic mass

cultures the significant decrease of the biochemical treatment time is observed here with simultaneous suppression of WCS viscosity and increased output of humic acids from the organic body of WCS water-soluble part.

The complex hydrodynamic and biochemical treatment of WCS allows to significantly speed up the processing of high-concentrated polydisperse systems. In so doing it is observed: cutting the time of WCS biochemical treatment from 50 down to 25 hours due to the liquidation of coal particles swelling phase and realization of the immediate process of physical and chemical dispersion in the presence of microbiological dispersers (protein complexes in particular); increased output of micro disperse coal fraction by 40 % (from dry substances of the micro disperse fraction) and holmic acids by 34 % (from the organic component of the micro disperse fraction); improvement of processing characteristics of WCS (suppression of the surface tension from 1.1 down to 0.52 g/cm^2, viscosity by 52 %); cutting the time of the maximal formation of the microbiological disperse factor down to 15 h (without the previously hydrodynamic treatment – 40-45 h). This technology is promising in land restoration, e. g. on completion the development of open-pit coal mines.

In this work the cavitation treatment effect in a supercavitation mixer on the colibacillus and aureate staphylococcus presence in potable water has been investigated. The experiments have been carried out with a V-shaped cavitation apparatus (the wedge top angle $\alpha = 20°$) at a temperature of 20-22°C. Varied number of rotor revolutions in the range from 2 up to 10 thousand rev/min and the treatment time τ has been tested. The cavitation number computed for the impeller diameter is χ= 0.56-0.02. The measurements have been taken with the help of light diffusion procedure and an electron microscope. The results of the experiment are presented in Fig. 7. As is obvious, the patterns of concentration change for the colibacillus and staphylococcus are identical as well as quantitative characteristics, so that is, probably, explained by approximately identical characteristics of cells. Young's modulus is equal to ~$5 \cdot 10^8$ and $4 \cdot 10^7$ Pa respectively, and the ultimate stress limit of cells membranes is ~10^5-10^{10} Pa. Taking into account these data and the level of design values under the cavitation effect (P ~ 10,000 atm; $\dot{T} \sim 10^{11}$ K/s; T ~ 2000 K; $P_m \sim 10^8$ Pa), it is possible to make the conclusion about of the force effect sufficiency for the destruction of cell material. These results can be used to develop a technology to destruct microorganisms in foodstuff, potable water, etc.

In agriculture the use of the cavitation-treated water allows to get a crop capacity gain for greenhouse vegetable cultures up to 30 % with simultaneous reduction of plants morbidity (Fig. 8, 9).

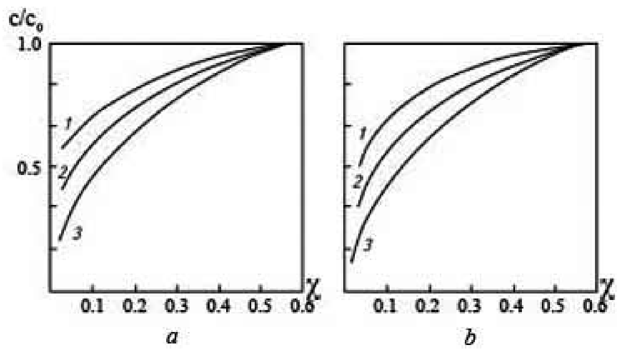

Fig. 7. The dependence of dimensionless c/c_0 concentration on the cavitation number X: *a* – colibacillus; *b* – aureate staphylococcus; *1* – τ = 30 s; *2* – τ = 1 minute; *3* – τ = 3 minutes; c_0 – original concentration

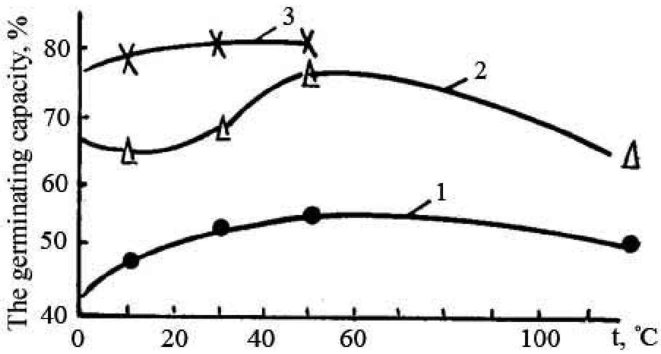

Fig. 8. The seeds germinating capacity: 1 – "Nantes-4" carrots (Δ_{max} = 8.2 %, $HCP_{0.5}$ = 7.7 %); 2 – "kid" tomato (Δ_{max} = 4.7 %, $HCP_{0.5}$ = 5.9 %); 3 – "elite" tomato (Δ_{max} = 11.3 %, $HCP_{0.5}$ = 11 %)

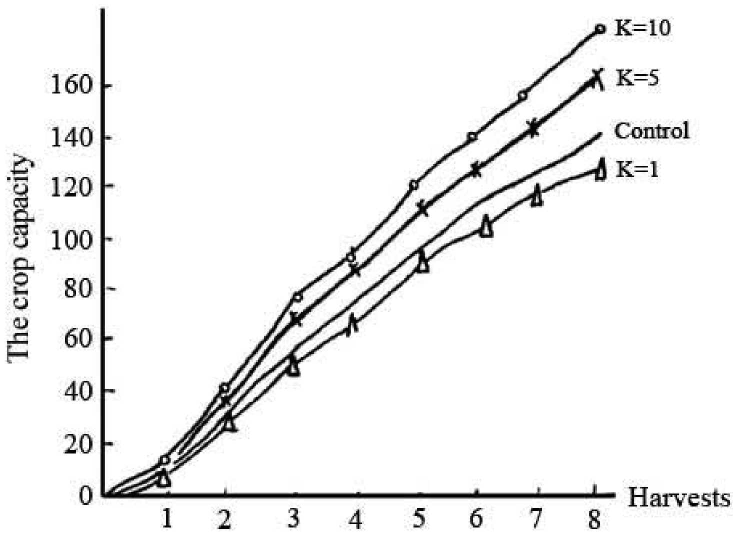

Fig. 9. The results of the experiments with the "September" cucumber: K – frequency rate of treatment

It is obvious that the major factors influencing the produced effect are the increased oxygen content of the treated (activated) water as well as the complex physical and chemical processes occurring under the cavitation effect:

redox reactions that proceed in the water between the dissolved substances and the water splitting products emerging in cavitation bubbles and passing into the solution after their collapse;

reactions between the dissolved gases inside cavitation bubbles;

chain reactions in the solution initiated by the products of splitting in impurities cavitation bubbles;

macromolecules break-down and its initiated polymerization;

water structure change with the production of free hydrogen bonds, etc.

The obtained result is in good agreement with other researchers' experiments, who have applied the given technology with the efficiency of 15-20 % when using the cavitation-treated water as potable water in animal raising and in fish whitebait raising from berries.

In food industry the cavitation treatment makes for increased juice extraction (approximately by 15 %) (wine industry), for cutting the time of preliminary and base liming of beetroot diffusion juices approximately 10 times less (sugar industry), qualitative extraction of nutrients from fruits and plants when producing various food supplements and vitamins, etc. [1].

When producing composite materials the multifactor cavitation effect (mostly the erosion mechanism of destruction and intensive turbulent micromixing) makes for obtaining high-disperse homogenized substrata and mixtures.

Fig. 10 and 11 illustrate the results of dispersing ultra disperse diamond (UDD) in comparison with the traditional ultrasonic treatment (US). There have been used the samples having efficient dispersing sizes before the treatment 170 nanometers.

The effect of US and hydromechanics (HM) treatment are qualitatively and quantitatively identical, however the latter due to a large number of changeable parameters (frequency, effect duration, a wedge angle) allows to provide optimum treatment modes more precisely. The HM-treatment in the

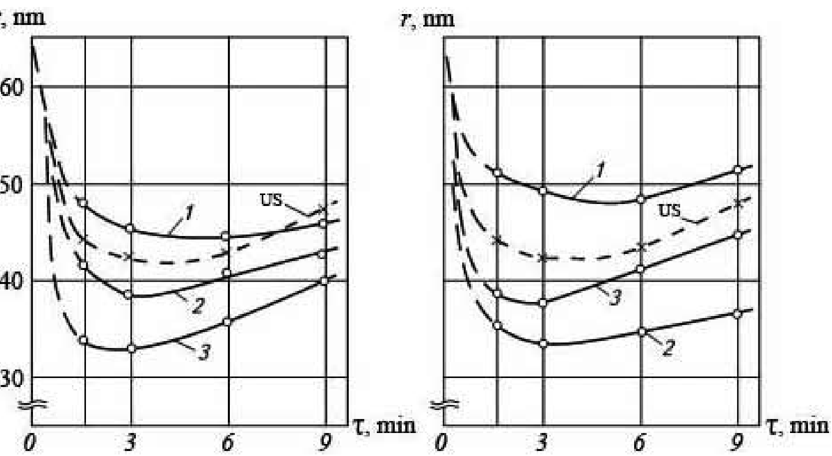

Fig. 10. The dependence of the UDD average radiuses on the time of ultrasonic (US) and hydromechanics (HM) treatment: *a* – wedge angle 20^0; *b* – wedge angle 40^0; rotational speed, rev/min: *1* – 3000; *2* – 4000; *3* – 7500

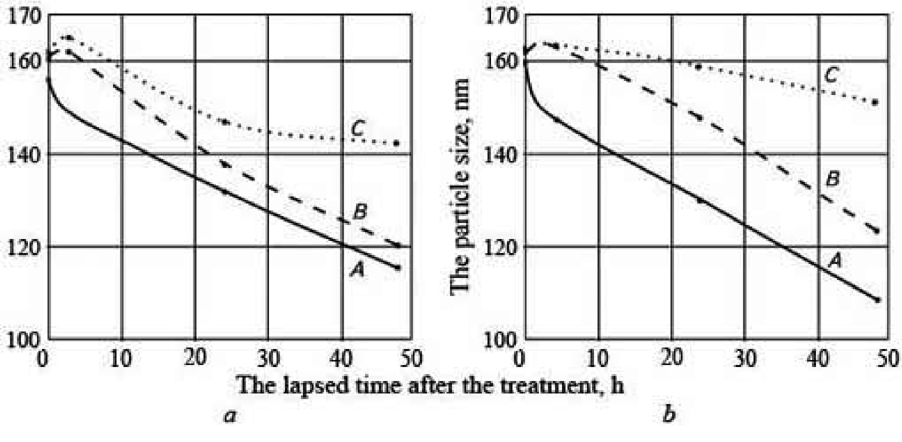

Fig. 11. The dependence of the UDD average radiuses on the sediment time after ultrasonic (a) and HM-treatment (b) at three cuvette levels: a – the top level; b – middle; c – bottom

process does not bring any additional factors into the system, which influence the suspension aggregate resistance. Having regard to cheapness, productivity, and an opportunity to design a continuous process the hydromechanics dispersion procedure is more preferable than US especially in industry.

Ultra disperse diamond mixed with graphite finds application as additives to engine oils and other oils to increase the performance of internal combustion engines, to improve antifriction, antiwear, and antiscore qualities of engine oil. The HM-treatment use is much more efficient in comparison with the traditional.

It is promising to use the cavitation treatment in papermaking where the most important processes determining its qualities (durability, conductivity, etc.), are pulp beating stage and deflocculation. In this manufacture there are specifically introduced some mineral filling agents (talc, kaolin, and others) which need to be ground to about 0.5-1.5 microns and mixed simultaneously whereas it is easily attainable in a supercavitation apparatus.

The use of the cavitation technology in treating corundum content and aluminiferous dusts of alumina process allows to obtain compositions to manufacture polishing pastes and solutions with approximately ten times smaller power costs in comparison with traditional procedures.

References

1. Ivchenko V.M. Cavitation Technology / V.M. Ivchenko, V.A. Kulagin, A.F. Nemchin. – Krasnoyarsk: Krasnoyarsk State University, 1990. 200 pp. (in Russ).
2. Kulagin V.A. Simulating Binary Phase Supercavitation Streams / V.A. Kulagin, A.P. Vilchenko, T. A. Kulagina. – Krasnoyarsk: Krasnoyarsk State Technical University, 2001. 187 pp. (in Russ).
3. Ivchenko V.M. Kinetics of Cavitation Effect on the Elements of Hydraulic Engineering Constructions and the Hydropower Equipment / V.M. Ivchenko, V.A. Kulagin, S.A. Yesikov // News of the All-Union Research Institute of Hydraulic Engineering after B. E. Vedeneyev, 1987. Vol. 200. 43–48 pp.
4. Kulagin V.A. Cavitation Treatment Effect on Humidity-Disperse Characteristics of Water-Fuel-Oil Emulsion / V.A. Kulagin, T.A. Kulagina // Problems of Using the Kansk and Achinsk Coals at Power Generating Plants: Collection of Reports of the All-Russia Scientific and Practical Conference. – M.: PAO EC, 2000. 424–427 pp.