THE INCREASE IN THE YIELD OF VEGETABLES IN GREENHOUSES USING SUPERCAVITATION TREATMENT OF IRRIGATION WATER

УВЕЛИЧЕНИЕ УРОЖАЙНОСТИ ОВОЩЕЙ В ТЕПЛИЦАХ С ИСПОЛЬЗОВАНИЕМ СУПЕРКАВИТАЦИОННОЙ ОБРАБОТКИ ПОЛИВНОЙ ВОДЫ

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Abstract: *The use of hydrodynamic and thermophysical effects of cavitation (cavitational technology) 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. There are given 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. 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. 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.*

***KEYWORDS**: CAVITATION, HIGH-VELOCITY HYDRODYNAMICS, POLYPHASE FLOWS, SUPERCAVITATION, THE INCREASE IN THE YIELD.*

1 Introduction

As bodies move in a dropping liquid at high speeds (about 30 m/s and higher) and pressure in the liquid reaches the pressure of its saturated vapors at the designed temperature, the phenomenon of cavitation appears. By the classification adopted in 1955 at a symposium in London [1], the mechanism of development of cavitation is treated as the inertial development of bubbles (vaporous cavitation) or as the diffusion of a dissolved gas in the cavitation core (gaseous cavitation) from a flowing fluid or from cracks on a body's surface (the Kornfeld–Suvorov hypothesis [2, 3]).

At present, basic and applied problems of research in cavitation within the modern objects of the technosphere are priorities for ensuring their safety. The hydrodynamics of cavitating flows, distinguished by the presence of gas–vapor inclusions (separate bubbles, bubble clusters and clouds, and supercavitation pockets), has a number of peculiarities that significantly hinder its study, simulation, and, ultimately, control. This is especially important for high-velocity flows. The motion paths of particles can mismatch the flow lines of the carrying medium; here the development of instabilities on the boundaries of the phase interface has a significant influence in gas–vapor inclusions. Shock-wave propagation has distinctive features in a polyphase medium. Studies on the dynamics of processes that occur near the surface of a body in the conditions of cavitation are extremely important.

The current state of the methods of numerical simulation of cavitation processes does not make it possible to ensure fully the acceptable level of their description even when using the most advanced models and supercomputers. This is due to the extreme complexity, immensity, and diversity of physical processes that take place during cavitation. Therefore, one of the main vectors to improve the efficacy of research into cavitation flows is the design and development of experimental equipment and technologies for model and field studies, taking into account the scale effect. Information about thermodynamic properties and phase equilibria in multicomponent systems is, as a rule, limited [4, 5].

Currently a trend has developed to unite state-of heart mathematical tools and computational technologies to solve practical problems in various industries. It is important that most continuous production flows are accompanied by heat–mass exchange processes in conditions of complex hydrodynamic phenomena, for example, supercavitation [5]. However, it is rather difficult to consider and study the above processes simultaneously. Basically, theoretical and applied problems are considered from different points of view separately, taking little account of how some processes affect others. Uniting the effects of the heat exchange, mass transfer, and hydrodynamics of interacting media into a single computational process based on large-scale physical simulation is one of the most important problems of high-velocity hydrodynamics.

Computational technologies based on state-of theart mathematical methods are becoming the main tool for the development of fundamentally new technologies and engineering systems. Mathematical modeling is an integral part of unique physical experiments and forecasts. On the other hand, the development of methods of mathematical description should, of course, be accompanied by a broad set of verifying experiments, performed on process units of various scales. This evolutionary process may result in scientifically substantiated methods of calculation of the main technological and design parameters (geometrical, hydrothermodynamic, and cavitational) when designing reliable and highly efficient technological apparatuses in industries in which the processes of heat and mass exchange and hydrodynamics of interacting currents play an important role [4–6].

2 Scientific problems of high-velocity hydrodynamics

In 1971, at the opening of the IUTAM International Symposium (Leningrad), Academician L.I. Sedov noted, "…a cardinal solution to high-speed motion of bodies in water is associated with solving hydrodynamic problems implementing fundamentally new schemes of flow around bodies and using new propulsion systems" [7, p. 9]. This thesis has retained its relevance to this day. The problem of water resistance and the problem of new and more powerful thrust-engine systems are closely interrelated and, regardless of the heat medium (chemical or atomic), are, basically, problems of high-velocity hydromechanics. The realm of problems associated with the flow of biphasic media (in this case, supercavitating flows) is extremely broad and includes studies on the flow of systems such as "fluid–fluid", "fluid–solid," and "fluid–gas" [7–11]. Many aspects of these problems are covered by numerous publications, the topicality of theoretical and experimental studies on biphasic systems increasing with the creation of samples of new equipment and armaments. Fundamental knowledge of specific propagation of disturbances in biphasic media (for example, in vapor–gas–fluid flows) of different flow structures (regimes) is necessary to analyze the safety and efficacy of the corresponding systems.

Of interest are processes of exciting cavitation by pulses of negative pressure and of the propagation of these pulses in gas–fluid heterogeneous media. The technological importance of study of biphasic gas–fluid flow is great. However, despite the large number of works dedicated to this topic, designers still have no reliable calculation method or recommendations for designing special-purpose equipment. In the near future, it will be almost impossible to obtain a satisfactory theoretical model that would take into account all aspects of the flow of biphasic systems in which the surface of the interface between phases might have a very complex form. Significant success can be reached in the modeling of such flows if a certain degree of limitation is introduced into the description of the flow structure and the geometrical shape of the interface surface; in other words, the notion of flow behavior or flow regime should be introduced. The theory of advanced cavitating flows is especially necessary for the study of the motion of finite bodies when 3-D cavities appear. The methods of conformal mapping, which are traditionally used to analyze flat flows, prove to be inapplicable to spatial flows.

Interestingly, despite proofs that the uniqueness of solutions to specifically set Helmholtz–Brillouin problems exists, there is not a single precise analytical solution for spatial flows. The hybrid method of E. Trefftz and the asymptotic formulas of P. Garabedian are of a particular nature and are applicable only to the simplest bodies and their motions. Consequently, fundamental studies on spatial cavities and methods of their calculation for bodies of sufficiently arbitrary shapes are necessary. The development of a linearized theory of supercavitating flows for thin elongated bodies will be of great practical importance.

Trends in scientific and technological development anticipate new promising apparatuses and devices that move in water and other fluids at high velocities. This requirement should be accompanied by in-depth study of the most complex thermophysical and hydrodynamic phenomena, as a rule, in biphasic flows. The creation of an experimental technology for model and field studies, which develop the ideas contained in [3–5, 12–18], remains topical.

The use of hydrodynamic and thermo physical effects of cavitation (cavitation technology) [3] 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. In that work there are given 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.

3 Conclusion

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 is explained by the presence besides diffusion mechanism (due to a high degree of compressing the steam-to-gas contents of a cavitation micro bubble), also the kinetic mechanism of saturation of water with the oxygen resulting in a noticeable non-equilibrium of its dissolution process.

Fig. 1 shows the increase of the oxygen equilibrium concentration in the medium of inert gases and nitrogen having effect on the intensity and nature of the oxygenation process kinetics. The nature of oxygenation change in the nitrogen medium is caused 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 [5].

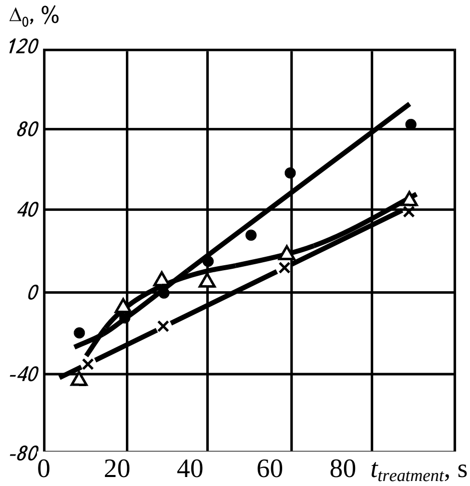

Fig. 1: The dependence $d_0 = f(t_{treatment})$ for the unsettled tap water: o – Ar; d – N_2; x – He; Under the initial O_2 concentration 40 %

In Fig. 2 is shown 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.

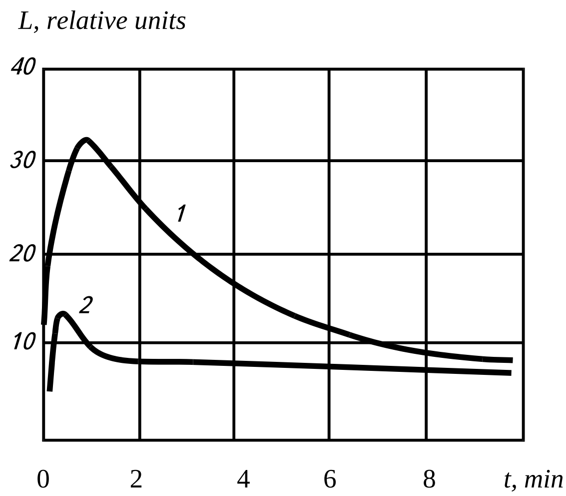

Fig. 2: *The kinetic curves of chemiluminescence's intensity in the redistill ate (C_0 = 100 %): 1 – redistill ate treatment in free air, $t_{treatment}$ = 60 s; 2 – raw redistill ate*

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 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

$$\mathrm{Ar}^*\left(\mathrm{He}^*\right)+\mathrm{H_2O}\rightarrow\mathrm{H_2O}^*+\mathrm{Ar}(\mathrm{He})$$
$$\mathrm{Ar}^+\left(\mathrm{He}^+\right)+\mathrm{H_2O}\rightarrow\mathrm{H_2O}^++\mathrm{Ar}(\mathrm{He}).$$

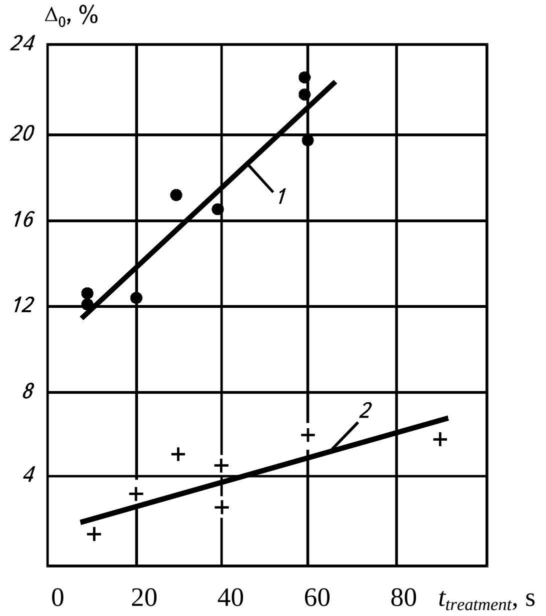

Fig. 3: *The dependence $d_0 = f(t_{treatment})$ in free air (C_0 = 100 %): 1 – redistillate, pH_0 = 5,4; 2 – the unsettled tap water, pH_0 = 7,0*

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.

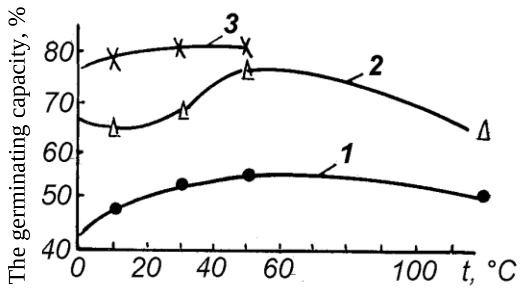

Fig. 4: *The seeds germinating capacity: 1 – "Nantes-4" carrots (d_{max} = 8.2 %, $HCP_{0.5}$ = 7.7 %); 2 – "kid" tomato (d_{max} = 4.7 %, $HCP_{0.5}$ = 5.9 %); 3 – "elite" tomato (d_{max} = 11.3 %, $HCP_{0.5}$ = 11 %)*

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 (Figs. 4, 5). 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 [19, 20]:

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;

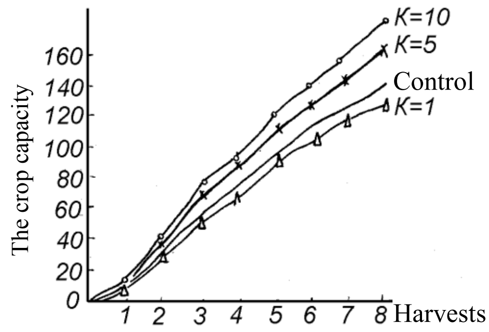

Fig. 5*: The results of the experiments with the "September" cucumber: K – frequency rate of treatment*

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. [5].

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