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## PROSPECTS FOR THE USE OF CAVITATION MECHANISMS IN ORDER TO REDUCE THE CONSUMPTION OF NATURAL WATER IN MUNICIPAL ENERGY

**Abstract:** *The paper discusses the existing methods of neutralizing condensate among which the most effective method of hydrodynamic cavitation is determined. To implement the effects of hydrodynamic cavitation, it is proposed to use the way of discrete – pulsed energy input, which allows neutralization by degassing condensate of natural gas combustion products.*

*Based on the created universal mathematical models of the dynamics of single steam-gas bubbles and the ensemble of bubble dynamics, numerical modeling of the growth of steam-gas bubbles in condensate was carried out. Within the framework of the mathematical model of the dynamics of the ensemble of bubbles, an analytical study of the evolution of the unit of steam-gas bubbles to achieve a critical value of the gas content in them was carried out.*

*It has been experimentally proven, the effectiveness of the proposed method, in particular, has been established that the main amount of carbonic acid from both flue gas condensate and model liquid is removed within two minutes of processing. The obtained data prove that an increase in the pH of the treated condensate corresponds to the pH of distillate, which indicates the complete removal of carbonic acid. The implementation of the proposed method of neutralizing condensate will create conditions for improving the environment. This is achieved by reducing the amount of effluent and rational use of water resources by reducing the need for natural water.*

**Keywords:** *cavitation, acidic condensate, neutralization*

### Introduction

Condensate formed during the combustion of natural gas in boilers equipped with a system of deep utilization of the heat of flue gases at municipal energy enterprises is not reused. As a rule, after chemical neutralization, it enters the wastewater of enterprises. Neutralization of condensate is necessary due to the low pH value, which is due to the high content of carbonic acid (approximately 70 mg/l of carbon dioxide). For this purpose, methods of neutralization with chemical reagents and neutralization using mass transfer processes are used. The disadvantage of chemical neutralization is a significant contamination of neutralized condensate with neutralization reaction products and the impossibility of its further reuse. Common mass exchange processes (decarbonization, thermal and vacuum deaeration) are not used to neutralize condensate due to high energy costs or due to insufficient carbon dioxide extraction. Given that from 1 MW of thermal power of the boiler unit, as a rule, up to 140 l/h of condensate is formed, this leads to the formation of a significant amount of it, so it is advisable to consider the possibility of reusing condensate in order to reduce natural water consumption and wastewater emissions.

## Analysis of existing research

Analysis of many sources, including work [1-3] showed that the neutralization of acidic condensate with chemical reagents can be implemented in equipment using a solid reagent, by liquid neutralization, as well as using reagents based on neutralizing amines.

The principle of equipment operation based on the use of solid reagent involves passing acid condensate through a layer of neutralizing reagent. The use of such equipment does not imply the regulation and control of stable values of the hydrogen indicator. It is advisable to use it for boilers with a capacity of up to 1000 kW. The principle of operation of the liquid neutralization equipment involves the addition of a dosed amount of liquid reagent to the acidic condensate. The use of automated dosing and control systems makes it possible to obtain a stable final value of the pH indicator, as well as the possibility of its regulation. Such equipment is economically feasible for boilers with a capacity of more than 1000 kW. The use of special chemicals based on neutralizing amines to adjust the hydrogen index of water is economically impractical due to their too high cost.

Neutralization of acidic condensate using mass exchange processes can be carried out on absorbent-type devices. Their work is based on the extraction of dissolved carbon dioxide as a result of contact with air. Its course is due to a significant number of interdependent factors that can change over a wide range. For example, as indicated in the article [4] the solubility of carbon dioxide in water depends on its temperature, which changes during the decarbonization process. The method is one of the most complex mass transfer processes in the preparation of water in the heat and power industry. Existing decarbonizers are divided into two groups – countercurrent and direct-flow.

The countercurrent decarbonizer is a nozzle apparatus with air supply by a fan from the bottom. Decarbonizers of this design have been used for more than 50 years and are obsolete as evidenced by the article data [5]. The disadvantage of devices of this type is their impressive dimensions, high cost, complexity in maintenance and repair, as well as the need for individual design.

Among direct – flow decarbonizers, ejection devices and direct – flow spray heat and mass transfer device are common. The use of water – jet ejectors is limited due to the low values of the permissible initial concentration of carbon dioxide (up to 20 mg/kg). Direct-flow ejections heat and mass transfer devices can have an ejection coefficient of about 1000, however, the productivity can be from units to hundreds of m<sup>3</sup>/h·m. Common disadvantages of devices of this type are large dimensions and weight, and therefore they have not found wide application.

Among modern alternative methods, it is worth noting acoustic, in which high-frequency ultrasonic generators are used. Their effectiveness lies in the fact that they ensure the fastest possible removal of free gas from the liquid, which is contained in gas bubbles. The degassing of the liquid occurs due to the fact that a significant part of the dissolved gas under the influence of ultrasonic vibrations passes into the bubbles, which subsequently exit the liquid through the phase separation surface. Their advantage lies in the possibility of degassing almost any liquid. However, now these methods are not widely used due to significant specific energy costs.

In recent years, more and more attention has been paid to the possibilities and advantages of using hydrodynamic cavitation in various fields. Numerous studies and implementation of the obtained results in various fields of production have shown that hydrodynamic cavitation should be considered as a significant alternative to acoustic cavitation in the direction of increasing productivity and reducing specific energy consumption.

## Problem formulation

Taking into account the previous experience of scientific work and the shortcomings and complexities of existing equipment, the authors proposed a new alternative method of reagent – free neutralization of condensate. The research carried out within the framework of the project "Improving the efficiency of technology for reducing nitrogen oxide emissions by recirculating flue gases in boiler installations of municipal and industrial energy" (Agreement No. 904 of 04.01.22).

It is method based on the use of physical effects on the treated environment and avoids the addition of chemical reagents, characterized by low specific energy and material costs. The proposed method was initiated on the basis of fundamental research within the framework of the scientific direction of discrete – pulse energy input (DPEI) into dispersed systems and is covered in the work [6]. It includes the use of mechanisms such as high – frequency hydrodynamic vibrations, accompanied by high circumferential speed and shear stresses, as well as cavitation phenomena and transient phase transitions. Removal of carbonic acid from condensate in this way will avoid chemical neutralization and obtain practically degassed desalinated water. Then it can be used to prepare water to power the boilers, bypassing the stage of water softening, as well as for other technological needs.

To accomplish this task, it is necessary:

- to carry out previous modeling of the process of growth of gas-steam bubbles in condensate;
- to experimentally establish the regularity of the influence of cavitation mechanisms on the pH of condensate and investigate its stability over time.

## Materials and methods

To carry out numerical modeling, universal mathematical models of the dynamics of single gas-vapor bubbles and the dynamics of the bubble ensemble created earlier at our institute were used. The models are built on a system of differential equations and describe the transfer of heat and mass through the interphase surface "liquid – steam" within the framework of molecular-kinetic theory. To calculate the dynamics of steam-gas bubbles, it is necessary to present in an analytical form an equation that adequately describes the nature of the change in external pressure due to which bubbles grow or compress. This is an equation specific to each individual problem and is a basic equation.

To carry out the experimental part of the research, acidic condensate from a boiler house in city Kyiv («Vynohradar» district) and a model liquid were used – a solution of carbon dioxide in distilled water with a pH close in size to condensate. The experiments were carried out on a laboratory stand, which consists of two main working units of a rotary – pulsation apparatus (RPA) of a special design and a thermal vacuum processing unit. The method of experimentation assumed that the processed sample of liquid with a volume of 30 liters was processed in a closed circuit in recirculation mode for 10 minutes in the absence of supply and delivery of the treated fluid. Samples were selected every minute throughout the processing cycle (10 minutes) to determine the optimal time. Sampling was carried out through a special pipe at the outlet of the tank of the thermal vacuum treatment unit.

The pH value was measured using the EZODO PCT – 407 device according to the standard methodology described in the operating rules. Simultaneously with the pH, the temperature of the condensate and model liquid was controlled. Measurements were carried out before processing, every minute for 10 minutes of processing and 7 hours after processing.

The selected samples were stored in a non-sealed polypropylene disposable container without direct sunlight.

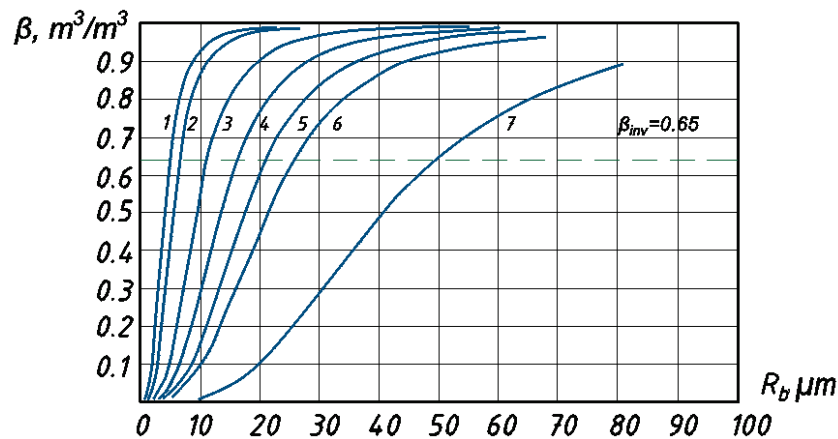
## Results and Discussions

On the basis of universal mathematical models of dynamics of single gas-vapor bubbles created earlier in our institute and dynamics ensemble of the bubble, numerical modeling of the growth of gas-vapor bubbles in condensate was carried out. Within the framework of the mathematical model dynamics of the ensemble of bubble, an analytical study of the evolution of a totality of steam-gas bubbles until a critical value of the gas content in them is reached.

Figure 1 shows the change in the size of the gas content depending on the radius of the growing bubbles in the monodispersed ensemble.

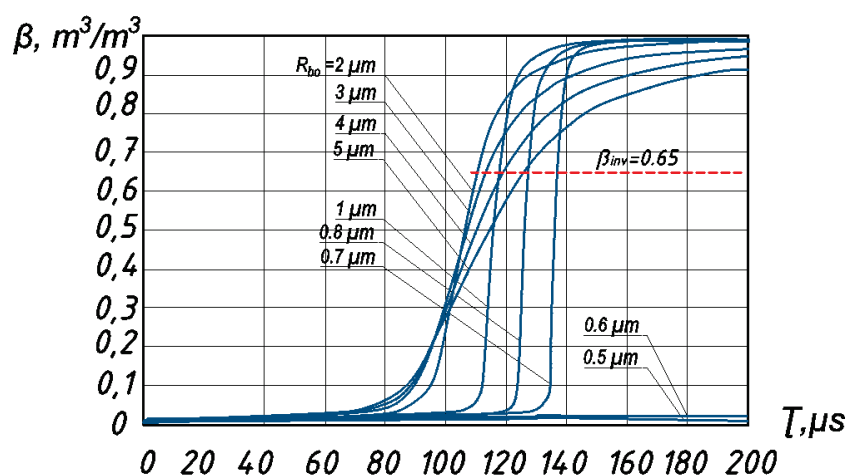
Monodispersed aggregates of bubbles with seven values of the initial radius in the range from 0.7 microns to 10 microns at an initial concentration of carbon dioxide of 70 mg/l and a liquid

temperature of 25°C were investigated. The dotted line shows the value of the critical gas content (the ratio of the volume of the gas phase to the volume of the liquid)  $\beta_{inv} = 0.65$  at which the inversion of the flow structure occurs (the transition from the liquid-bubble structure to the gas-droplet). The figure shows that for all values of the initial radius, the radius of the bubbles increase by about five times when the critical gas content is reached. That is, the volume of the bubble phase increases by more than two orders of magnitude. Those sections of curves 1-7 that are above the dotted line do not correspond to the real state, because bubbles no longer exist in this area due to inversion of phase.



**FIGURE 1.** The dependence of the gas content of a monodisperse totality bubbles of carbon dioxide in water on their current radius at different values of the initial radius: 1 – 0.7 microns; 2 – 1 microns; 3 – 2 microns; 4 – 3 microns; 5 – 4 microns; 6 – 5 microns; 7 – 10 microns

Figure 2 shows the results of calculating the dependence of the gas content on the growth time of bubbles for nine monodispersed bubble ensembles with initial radii in the range from 0.5 microns to 5 microns at an initial concentration of carbon dioxide of 70 mg/l and a liquid temperature of 25°C. As can be seen from the figure, small bubbles with an initial radius of up to 0.6 microns do not grow at all during this mode of operation of the installation. It is characteristic that bubbles of all initial sizes from 0.7 to 5 microns reach a critical value of gas content in almost the same period of time (115÷140 μs) from the moment the external pressure drops. It is characteristic that the increase in gas content in the totality of bubbles with relatively large bubbles with an initial radius of more than 2 microns occurs slowly. While for, a totality of small bubbles with an initial radius of up to 1 micron, the gas content increases almost instantly.



**FIGURE 2.** Change over time of the radius of the value of the gas content of the monodispersed totality of carbon dioxide bubbles in water at different values of the initial radius

These results provide useful information for further research on this problem.

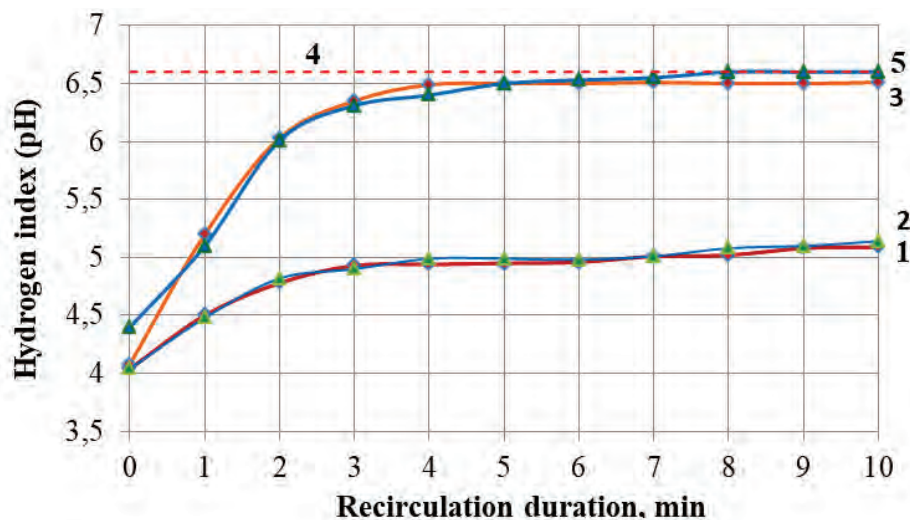
As the above research results have shown, small bubbles with an initial radius of up to 0.6 microns cannot grow at all even with large pressure drops initiated during condensate processing in the proposed way. Also, this method of processing cannot lead to further grinding of microbubbles. However, when a liquid-bubble flow passes through the channels of RPA inside the apparatus, a number of powerful mechanisms are initiated, as a result of which there is a strong dynamic effect on the fluid: flow of very high stresses and shear rates (about  $2.5 \cdot 10^5 \text{ c}^{-1}$ ), periodic high-frequency pressure changes and abnormally high changes in accelerations both in direction and in magnitude, short-term micro vortices, etc. Due to the total action of these factors – high-frequency braking and acceleration of fluid, eddy formation, intensive mixing, etc., the collision of bubbles, their coagulation and the formation of larger bubbles or bubble totality are possible. Then large bubbles form already during the passage of condensate through the RPA channels.

The calculations also showed that the rate of desorption of carbon dioxide from the surface of condensate droplets during their stay at the stage of gas extraction is very small compared to the rate of release of undissolved free carbon dioxide from condensate. This is the advantage and perspective of the proposed method of neutralization.

To confirm the obtained results of numerical modeling of the process of carbon dioxide extraction from a liquid, experimental studies of changes in the pH value of condensate of natural gas combustion products were carried out.

The results of studies on the treatment of acidic condensate in the proposed way confirmed the assumption of the possibility of reducing the acidity of condensate. For comparison, model fluid was also subjected to processing.

Figure 3 shows the results of the dependence of the pH of condensate (curve 1), model fluid (curve 2) on the duration of processing and after 7 hours of holding of the treated condensate (curve 3) and model fluid (curve 5). Lines 4 correspond to the pH of degassed distilled water – 6.6 (according to DSTU ISO 3696 2003). That is, the values to which you need to seek when neutralizing condensate.



**FIGURE 3.** Dependence of the change in the pH of condensate on the duration of processing: 1 – condensate; 2 – model fluid; 3 – condensate after 7 hours of exposure; 4 – degassed distilled water; 5 – model fluid after 7 hours of exposure

The major amount of carbon dioxide is removed within 2 minutes of treatment. After 4 minutes of processing, the pH remains constant, which indicates that further processing is impractical. It was revealed that after processing the condensate is in an unstable state and its pH continues to increase, which is explained by the course of the process of liquid relaxation. After 7 hours of exposure, the pH of the condensate stabilizes at a value of 6.5, which corresponds to the almost complete absence of carbon dioxide in it.



The obtained results of the pH of condensate indicate that after processing we obtain neutralized condensate, which by physicochemical parameters is similar to desalinated water with a low content of dissolved carbonic acid.

The measurement of the change in condensate and model fluid temperature during its processing due to the dissipative release of heat was approximately 1.8°C/min, and for the working cycle 1.5±2 minutes and was insignificant. However, an increase in temperature should have a positive effect on the rate of removal of carbon dioxide from the liquid. Therefore, it is advisable to supply condensate for processing immediately after the economizer.

## Conclusion

The traditional and newest methods of neutralizing condensate, their advantages and disadvantages are briefly considered. It was established that the use of mechanisms of DPEI is promising for neutralization and degassing of condensate of natural gas combustion products.

Based on the created universal mathematical models of the dynamics of single steam-gas bubbles and the ensemble of bubble dynamics, numerical modeling of the growth of steam-gas bubbles in condensate was carried out. Within the framework of the mathematical model of the dynamics of the ensemble of bubbles, an analytical study of the evolution of the unit of steam-gas bubbles to achieve a critical value of the gas content in them was carried out.

Experimentally of way determined that the main amount of carbonic acid from the condensate of flue gases and model fluid is removed within two minutes of processing. The obtained pH values of condensate after neutralization are close to the values of distilled water at which carbonic acid is practically absent. The use of the proposed method of neutralizing condensate will create conditions for improving the environment by reducing the amount of effluent (chemically contaminated neutralized condensate and waste from water softening plants) and rational use of water resources by reducing the need for natural water.

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