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NEUTRALIZATION OF ACIDIC CONDENSATE OBTAINED AFTER COMBUSTION OF NATURAL GAS USING THE HYDRODYNAMIC CAVITATION METHOD. FEATURES AND EFFICIENCY OF THE PROCESS

Abstract: *This paper examines the question of the efficiency of neutralization of acidic liquid media by the method of hydrodynamic cavitation. This method was proposed for the neutralization of acidic condensate obtained as a result of the combustion of natural gas at thermal power plants and allows to significantly reduce the acidity of the solution without adding chemical reagents with moderate energy consumption due to the removal of dissolved gases. If we consider acidic condensate, then it contains up to 70 mg/l of* CO_2*, when the solubility of this gas at normal temperature in water reaches 0.47 mg/l. The majority of this gas is present in the form of bubbles with a radius of less than 5 μm. Their removal leads to a change in the balance of carbonic acid in the system, which affects the acidity of the solution. To evaluate the effectiveness of removing soluble gases from a liquid by the method of hydrodynamic cavitation, studies of the effectiveness of degassing of a model substance (*CO_2 *solution in distilled water) were conducted. The rotor-pulsation apparatus was chosen as the cavitation device in the installation. As a result of theoretical studies, the minimum size of the* CO_2 *bubble was determined, that can be removed from the liquid with the applied processing parameters, and the total volume of carbon dioxide removed during processing and the dynamics of changes in the volume of gas during storage over time were determined.*

Keywords: *cavitation, acidic condensate, neutralization*

Introduction

In order to improve the efficiency of thermal power enterprises, deep cooling of fuel combustion products is used, which allows to increase the coefficient of heat utilization of the fuel of the boiler plant from 5% to 12%. However, obtaining acidic condensate and its subsequent utilization is a significant environmental problem. In addition to the environmental hazard, the high acidity of the condensate leads to corrosion of the metal in the contact equipment and, accordingly, to its destruction. There are two solutions to this problem, one of them is the safe disposal of acidic condensate into the sewer, for which it is necessary to ensure its pH level to the values determined by the standards. Another way is to use a neutralized liquid to feed power equipment, if its parameters meet the requirements of the operational documentation of the boiler manufacturer. The acidic environment of the condensate is due to the presence of gases dissolved in it – CO_2, SO_2 and SO_3 – formed during fuel combustion. While sulfur oxides when interacting with water form sulfite and sulfate acids, carbon dioxide is in water in a balance between the dissolved form formed by carbonic acid and in the form of bubbles up to 5 μm in size. Removal of such bubbles leads to a violation of this balance and, accordingly, a change in the acidity of the solution. Most often, chemical methods using chemical reagents are used for effective neutralization of acidic solutions [1]. These methods, along with their effectiveness, have a number of disadvantages, including the high cost of reagents and contamination of the liquid with chemical reaction products.

Recently, methods of physical impact on the environment have become more widespread. In particular, acoustic cavitation technologies in laboratory conditions have demonstrated the effectiveness of the degassing process, which can be applied to neutralize water from carbonic acid. However, such methods were not widely used in production, which is due to high energy consumption and low productivity of acoustic reactors. It is possible to solve a number of these problems and provide a continuous method of processing by using the process of hydrodynamic cavitation. It was on the basis of this process that the Institute of Engineering Thermophysics of the National Academy of Sciences of Ukraine developed technology and equipment for the neutralization of acidic condensate obtained after burning natural gas at thermal power plants.

Problem formulation

Neutralization of acid condensate, which is a by-product of burning natural gas, is associated with the removal of carbon dioxide in the form of bubbles in the liquid. The need for degassing processes in modern industry is widespread and applies to many and very different branches of production, from food to metallurgy [1, 2]. There is a wide range of methods that allow it to be carried out with varying degrees of effectiveness. Modern requirements for degassing technologies, in addition to efficiency, are energy consumption, environmental friendliness, economy, relative simplicity and versatility of equipment, etc. Currently, there are quite a few methods of degassing, which confirms the interest in such processes. Among them are chemical and physical methods, which are given greater preference. Technologies based on the use of hydrodynamic cavitation, which eliminate the disadvantages of acoustic technologies, can be quite promising. The Institute of Engineering Thermophysics of the National Academy of Sciences of Ukraine conducts scientific research aimed at studying the thermo- and hydrodynamic characteristics of this process. As a result, a technology was developed, the principle of which is based on the use of the hydrodynamic cavitation process. It implements the process of neutralization by the cavitation method, where the cavitator is a rotor-pulsation apparatus (RPA). In the technological scheme, a rotor-stator- rotor type apparatus RPA was used, since in the apparatus of this design, the liquid, passing through the channels, undergoes a high-frequency variable sharp increase in pressure, followed by its decrease to negative values due to the instantaneous stretching of the liquid. The task of this study is to establish the influence of the proposed water treatment method on the content of carbon dioxide in the liquid and acidity indicators, which determine its further disposal or use for boilers feeding.

Object, subject, and methods of research

Within the framework of degassing by physical methods, it is necessary to solve the problem of a sharp drop in pressure to values sufficient for the activation and growth of bubbles, the creation of a film flow, as well as the subsequent release of non-condensed gases, which determines the process to be carried out at pressures in the saturation region. In view of the above, a laboratory installation was designed for conducting the liquid decarbonation process.

The research was carried out in laboratory conditions at the installation, the diagram of which is shown in Figure 1. During the neutralization process, the liquid is subjected to multiple hydrodynamic effects due to recirculation in the circuit of the installation. In this installation, the cavitator is the RPA – the main working element of the installation (Fig. 1).

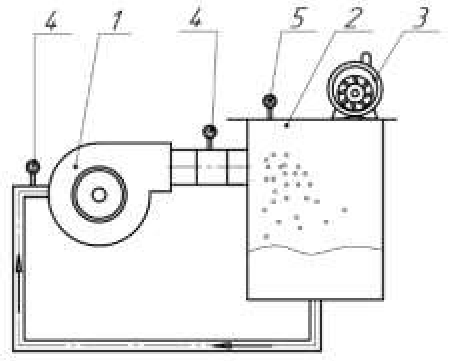

Figure 1. *Laboratory installation for liquid degassing: 1 – RPA, 2 – vacuum chamber, 3 – vacuum pump, 4 – manometer, 5 – vacuum meter*

The RPA is directly connected to the vacuum chamber 2, in which a pressure lower than atmospheric is created with the help of a vacuum pump 3 and the removal of removed gases is ensured. The pressure parameters in the chamber are monitored by vacuum gauge 5. To control pressure in the system, manometers 4 are installed, which display pressure readings at the inlet and outlet of the RPA.

The obtained acidic condensate after burning natural gas at one of the boiler houses in Kyiv was sent to a degassing plant, where it was processed in the recirculation mode to ensure a stable acidity indicator, which was 16 minutes, reaching a stable pH value. Condensate pH sampling and measurement were performed every 2 minutes. The concentration of carbonic acid in selected condensate samples and the efficiency of degassing – the ratio of the removed carbonic acid to its initial content in the solution expressed as a percentage – were calculated from the value of pH. The results of the study of the change in pH in the treatment conditions and calculations of the concentration of carbon dioxide and the efficiency of its removal are shown in Table 1.

Table 1. *Dependence of the pH change on the treatment time in the cavitation degassing installation*

Processing time, min.	**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**
pH	4.04	4.79	4.94	4.96	5.02	5.09	5.19	5.32	5.40
CO_2 concentration, mg/l	1112.1	43.3	21.5	19.7	15.1	11.1	7.2	4.1	2.9
Carbon dioxide removal efficiency, %	–	96.1	98.1	98.2	98.6	99.0	99.4	99.6	99.7

It is known that cavitation has an effect on the change in the pH value of solutions, which is associated with the removal of carbon dioxide, a change in the equilibrium in the solution due to the balance of carbon dioxide contained in the form of bubbles and dissolved carbon dioxide, hydrocarbonate and carbonate ions. Experimental studies confirm this and show that already during the first two minutes of treatment, the concentration of carbonic acid CH_2CO_3 in the liquid significantly decreases. In the following minutes of processing, it further decreases, but it is not significant enough compared to the significant increase in pH in the first minutes of processing, which allows to achieve an efficiency of 96.1%.

Study results and their discussion

For a more detailed understanding of these experimental studies, theoretical studies of the decarbonation process of acidic condensate were conducted. To determine the hydrodynamic parameters of the processing modes, analytical calculations of the pressure change in the RPA were carried out according to the model [3]. As research has shown, pressure pulses during processing in RPA reach negative values, which creates conditions for the occurrence of cavitation (Fig. 2). At the exit from the device, the pressure in the liquid corresponded to the value of 0.11 atm, which is slightly higher than the saturation pressure and is caused by the operation of the vacuum pump.

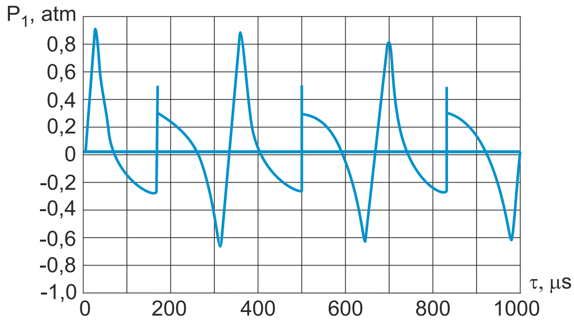

Figure 2. *Change over time in the pressure in the fluid flow at the boundary between the stator and the outer rotor during 3 periods of holes overlap*

The obtained pressure curves formed the basis of the calculations of the dynamics of steam-gas bubbles with a radius of 0.6 μm to 5 μm by solving the equations of the dynamics model of the ensemble of steam-gas bubbles using the modified Rayleigh-Plesset equation. In Figure 3 presents the dependence of the bubble radius change over time. Thus, the negative pressures achieved in the RPA allow the initiation of the growth of bubbles larger than 0.6 μm, which makes it possible to remove the main part of the dissolved gas. The dependences also show that the growth rate of the bubbles depends on their initial radius R, and the intensity of the size change is greater for bubbles with large sizes. This determines the priority removal of larger bubbles, and therefore the main volume of dissolved gases is removed at the beginning of the treatment. This is also confirmed by calculations obtained on the basis of experimental data (Table 1).

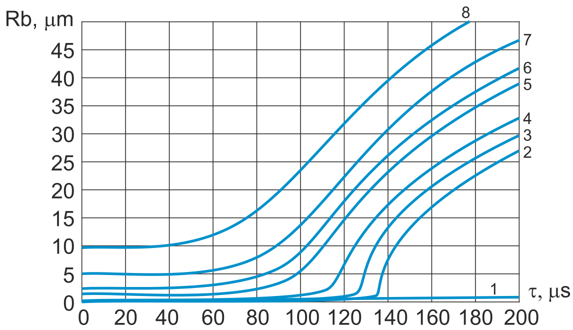

Figure 3. *Change over time in the radius of gas bubbles in the channels of the outer rotor for a monodisperse collection of carbon dioxide bubbles in water at initial radius values: 1 – 0.5 μm, 2 – 0.6 μm, 3 – 1 μm, 4 – 2 μm, 5 – 3 μm, 6 – 4 μm, 7 – 5 μm, 8 – 6 μm*

According to the data [4] of the distribution of the number of bubbles of dissolved carbon dioxide Nb in the liquid, a curve of the specific volume of dissolved gas occupied by the bubbles was constructed depending on their radius (Fig. 4a, b).

The integration of the built curve made it possible to establish the value of the total volume of dissolved gas contained in bubbles up to 5 μm in size and made it possible to calculate the minimum bubble radius that can be removed from the liquid. Previous studies have shown that bubbles are removed as their size decreases. That is, bubbles of the largest sizes will be removed first, since the activation speed of their growth is greater. The results of calculating the sizes of the bubbles removed during processing are shown in Table 2.

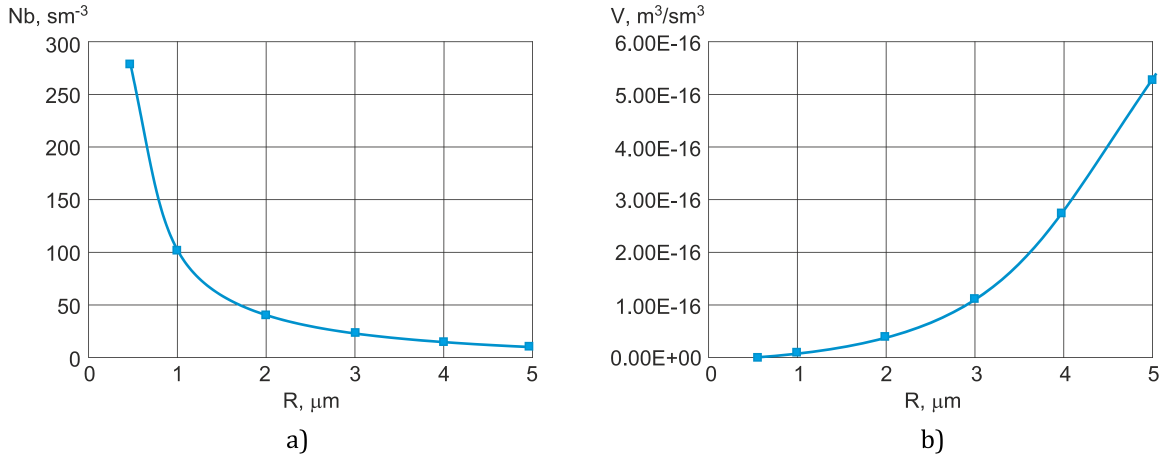

Figure 4. *Distribution of bubbles of dissolved* CO_2 *in the volume of liquid under normal conditions (a), specific volume of dissolved gas occupied by bubbles depending on their radius (b)*

Table 2. *Dependence of the pH change on the processing time in the cavitation degassing installation*

Processing time, min.	2	4	6	8	10	12	14	16
R, µm	2.204	1.851	1.826	1.712	1.585	1.425	1.245	1.147

The calculation showed that in the first two minutes of processing, the largest amount of carbon dioxide contained in bubbles from 5 to 2.204 microns is removed. The next processing time allows you to remove all bubbles up to 1.147 µm in size. Research on the vapor content in the liquid-gas system for this installation is described in works [5].

Conclusion

The application of the proposed technology of cavitation neutralization of acidic condensate allows to significantly reduce the concentration of carbonic acid in the condensate obtained as a result of burning natural gas at thermal power plants. The greatest gas removal is already achieved during short-term processing (within the first 2 minutes). The presence of negative pressures in the RPA enable the growth of bubbles from 0.6 µm. The removal of smaller gas bubbles depends on the operational parameters of the equipment and is associated with the possibility of activating the growth of bubbles of certain sizes. The obtained results showed high efficiency of acid condensate degassing and its neutralization. The development of this technology can consist in tests of various designs of cavitators, in particular, the first studies of the technological scheme of liquid degassing using a Venturi nozzle as the main working body of the technology are given in work [6].

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