Chem. Chem. Technol., 2017,
Vol. 11, No. 4, pp. 475–479

Chemical Technology

VIBROCAVITATION DECONTAMINATION OF BREWING YEAST-CONTAINING WASTEWATER

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https://doi.org/10.23939/chcht11.04.475

Abstract. One of the promising ways to solve the problems of environmental safety is the creation of highly efficient methods of wastewater decontamination and destruction of organic compounds in them. The electromagnetic vibration cavitator was created to treat brewing wastewater. The efficiency of vibrocavitation treatment technology for the food industry was studied. The highest degree of decontamination from biological and organic contaminants was found to be provided by the combined action of vibrocavitation and related processing of gases, nitrogen in particular.

Keywords: cavitation, wastewater, brewing, bacteria, yeast, decontamination, treatment.

1. Introduction

To date wastewater treatment used at food enterprises does not meet modern requirements to ensure the appropriate level and quality of purification. Taking into account the vast geography of agricultural processing enterprises, which are situated in almost all built-up areas, the impact of these enterprises on the environment is quite significant. The breweries contribute to this negative impact as well. Their wastewater, which is essentially contaminated by organic pollutants and yeast plants pollutes the surrounding ponds and groundwater. Therefore, the improvement of existing and development of new treatment technologies is the urgent problem.

Recently the main trend in the development of new treatment methods for agricultural processing enterprises in general and brewing in particular is the development of technologies without chemicals. It means that during decontamination no toxic compounds, as in the case of using chemical reagents, are formed. Lawful requirements for modern decontamination treatment technologies are the following: they must provide not only complete destruction of pathogenic microorganisms, but also the simultaneous degradation of organic contaminants. For that reason nonchemical water treatment methods, including physical methods of water purification and decontamination, are considered to be the safest ones.

A peculiarity of brewing wastewater (BW) is a combination of high levels of organic contaminants with significant (80–90 %) content of yeast component, mainly *Saccharomyces*. Taking this fact into account it may be assumed that the most effective solution for purification of highly concentrated BW is a combination of classical purification methods (mechanical, physical, chemical, biological, *etc*.) with novel physical methods (reverse osmosis, ultrafiltration, microfiltration, electrodialysis, ultrasound, ultraviolet, advanced biological methods, *etc*.) [1-3].

From literary sources we know that one of the effective physical methods of chemical-engineering processes intensification in liquids is a cavitation effect on the processing medium. Powerful energy impact accompanying cavitation in the processed liquid medium creates high stress tension gradients, that lead to destruction of intermolecular bonds in a liquid and formation of cavitation microbubles from available cavitation nuclei. Cavitation microbubbles collapse is accompanied by significant energy liberation in the interphase layer of liquid surrounding the bubble. At the same time an instant storage of energy in the liquid interphase layer initiates occurrence of different effects in the liquid medium. As a result, cavitation in liquids initiates various physical and chemical phenomena; sonoluminescence (liquids glow); chemical effects (sound chemical reactions); solids erosion (surface fracture); dispersion (grinding of solid particles in the liquid), and emulsifying (mixing and homogenizing of liquids which are not mixed) [4-5]. That is why the application of cavitation, including intensification of redox reactions for the organic compounds oxidation and destruction of yeast plants in BW is so promising.

In our previous studies [6] we found that aqueous solutions, including BW, should undergo cavitation treatment at continuous dosage supply of a particular gas to the area of treatment. Gas microbubbles are cavitation nuclei which decrease the interlayer strength of the

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processing environment and reduce fluid breaking strength. Due to this fact, the external energy aimed for keeping cavitation stability will be decreased and more fully used. As a result, the energy level required for cavitation excitation will be reduced and energy consumption for the process will be diminished. However, the beneficial effect of added gas is undeniable yet ambiguous. First of all, this is due to the nature of gas used, its thermodynamic properties, *etc*. Therefore, the choice of the most efficient gas and its dosage favor the increase in efficiency of treatment and decontamination of BW from organic and biological contaminants.

Despite the rather convincing experimental data of scientists and researchers about the cavitation application for the treatment and decontamination of wastewater from food companies, the standard industrial equipment suitable for the effective cavitation treatment of significant amounts of industrial wastewater, including BW, is still not created. Excessive energy consumption and lack of high-performance continuous devices make ultrasonic decontamination noncompetitive.

Therefore, the investigations aimed at creating a high-performance technology and equipment for cavitation treatment of wastewater from various food and processing enterprises, including breweries, remain topical. The investigation results allow not only to reduce the specific (per volume unit of processed liquid) power inputs for treatment operations but also to provide adequate level and quality of water purification.

2. Experimental

2.1. Materials

For the investigations, we used wastewater from JSC "Kumpel Brewery" (Lviv, Ukraine), microorganisms identified in this wastewater, bacteria genera: ***Diplococcus***, ***Sarcina***, ***Bacillus***, ***Pseudomonas***; yeast genus ***Saccharomyces***. Reagents used were: methylene blue, basic fuchsine, safranine, iodine solution, and gentian violet saturated solution. Growth media: meat peptone agar (MPA), wort-agar (WA), immersion oil while microscoping microorganisms (MO) fixed cells. Nitrogen was the investigated gas. Additional substances: sulfuric acid, Mohr's salt, potassium dichromate, *N*-phenylantranyl acid.

2.2. Procedures and Analyses Methods

The studies were conducted in a nitrogen atmosphere at 298 K, atmospheric pressure, within the frequency range of 25–110 Hz under cavitation vibroresonance conditions and without cavitation. Frequency of 37 Hz corresponds to the resonance frequency, so further studies were performed at the frequency of 37 Hz and power of 800 W. The processing time was up to 120 min. Initial values of microbial numbers (MN) of water samples were in the range of $(1–1.2)\cdot10^5$ CFU/cm^3, the content of organic substances was measured in terms of chemical oxygen demand (COD), the initial value of which was $5\cdot10^4$ mgO_2/dm^3.

When determining MO total amount in water we used a universal growth medium – meat peptone agar (MPA: meat water (1 dm^3), peptone (10 g), agar (15 g)).

Cultivation of investigated MO was carried by depth method. MO were grown in an incubator at a constant temperature (310 K for bacteria and 298–303 K for yeast) for 48 h [8].

COD was determined according to the procedure described in [9].

It was investigated that the curves of MN dependence on time and COD are rectified in coordinates ($\ln MN/MN_0 – \tau$) and ($\ln COD/COD_0 – \tau$), respectively, so to describe the kinetics of MO decontamination and destruction of organic compounds under vibrocavitation conditions the kinetic equation of the first order was applied. The effective rate constants of bacteria decontamination and organic compounds destruction, as well as degree of water treatment and decontamination in a nitrogen atmosphere were calculated.

The degree of organic compounds destruction in the water was determined according to the formula:

$$D = 100 - \frac{COD \cdot 100}{COD_0} \quad (1)$$

where COD and COD_0 – current and initial values of COD, respectively, mgO_2/dm^3.

The degree of water decontamination was determined in a similar way, using MN instead of COD.

Vibroresonance cavitation relates to the methods of cavitation hydrodynamic disturbance. It is characterized by organic combination of high intensity of formed cavitation field with considerable capacity of treatment. We have created new design of vibrocavitator, which is simple, energy-efficient and easy to use and maintain. The cavitators were tested at water preparation in aquapark pools, at decontamination from biological and organic contaminants of wastewater from distilleries and milk plants. The results demonstrated the ability of vibroresonance cavitation to provide relatively high degree of decontamination from biological (92–93 %) and organic (94–95 %) pollutants giving the reasons to recommend this progressive method for industrial applications [10].

Vibrocavitation decontamination of brewing yeast-containing wastewater was carried out using vibration electromagnetic cavitator of resonance action developed in Lviv Polytechnic National University [10]. The schematic diagram is depicted in Fig. 1 and the cavitator photo is presented in Fig. 2.

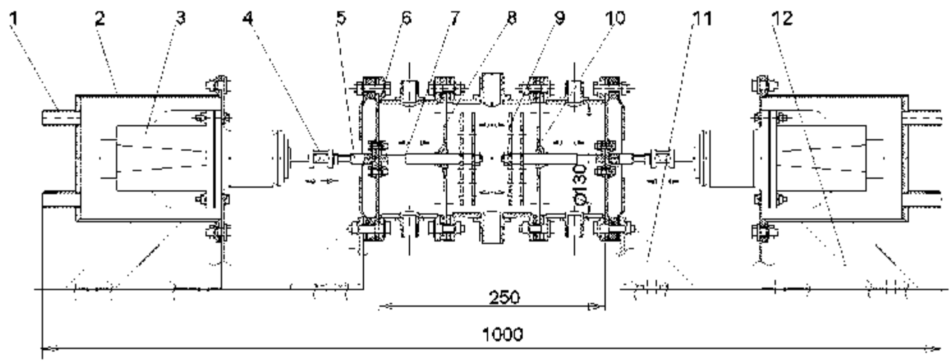

Fig. 1. Schematic diagram of experimental low-frequency electromagnetic vibration cavitator of resonance action for BW treatment: branch pipe (1); casing (2); electromagnetic drive (3); clutch (4); rods (5, 7); elastic membrane (6); divider (8); deck (9); bearing (10) and supports (11, 12)

Fig. 2. Photo of experimental low-frequency electromagnetic vibration cavitator of resonance action for BW treatment

The block-scheme of brewing wastewater treatment process carried out at the experimental low-frequency electromagnetic vibration cavitator of resonance action includes three independent circuits:

- circuit of supply, treatment in cavitator and settling of the processed liquid;
- flow circuit of refrigerating liquid supply to cool the electromagnetic vibrodrive;
- circuit of supply, drainage and purification of effluent gases accompanying cavitation treatment.

BW cavitation treatment at the low-frequency electromagnetic vibration cavitator was carried out as follows. First, the working chamber is filled by the processed liquid and tension is fed on coil blocks of electromagnetic drive with minimum frequency of 15 Hz using AFC-120 frequency controller. Anchors of electromagnetic drive (3) are engaged in counter-phase synchronous straight fluctuations, which are transferred by elastic membrane (6) and rods (5, 7) to the decks which excite the cavitation (9). The decks acquire counter-phase synchronous motion along the geometrical axis of cylindrical working chamber with a frequency which is twice as the frequency of alternating voltage of electromagnetic drive coil blocks. BW is a solution based on water, and the water is known to be not compressed under normal conditions. Thereby, with oscillatory motion of decks (9) the processed liquid is filtered with relatively high rate through conical holes in decks. This maximum rate is proportional to the amplitude and frequency of deck oscillations according to Eq. (2):

$$V = 4A \cdot f \tag{2}$$

where A = 2.0–2.5 mm – amplitude of deck oscillations (9); f – frequency of oscillatory synchronous linear motion of decks equal to doubled oscillation frequency of electromagnetic drive anchors.

With a minimum frequency of coil blocks alternating voltage equal to 15 Hz the frequency of oscillatory synchronous linear motion f is 30 Hz, and the maximum rate at which the processed fluid flows through conical holes in the decks (Eq. 2), is equal to $4 \cdot 2.5 \cdot 10^{-3} \cdot 30 = 0.3$ m/s.

At such rates of motion the processed liquid is actively bubbled in the chamber, but as a rule, at low frequencies the cavitation processes and phenomena in liquids based on water are not excited. The frequency of coil blocks alternating voltage is intensified by frequency regulator AFC-120 on the control panel. The wattmeter on the panel shows power consumption, which is smoothly increasing along with the frequency increase. The rate of the processed liquid passed through the deck holes increases as well. This continues until the rate achieves critical value, regulated by treatment conditions (liquid temperature, pressure, *etc*.), the liquid properties and so-called critical Reynolds number. Under critical flow rate the processed liquid loses its strength and density; the cavitation processes are excited from air and gases microbubbles dissolved in the liquid. The critical rate for BW is within 0.9–1.0 m/s. Moreover, a laminar flow regime turns into turbulent regime. Gas-liquid mixture is self-formed in the liquid; its values of density and viscosity significantly differ from those of liquid flow.

The sharp decrease of processed liquid resistance to linear motion of gas-liquid flow is observed as 25–30 % decrease of power consumed by electromagnets. It is recommended to carry out the treatment at frequencies exceeded lower critical value by 10–15 %. For our experiments the lower range of critical frequencies is within 74–78 Hz. The frequencies of coil blocks alternative voltage 37–39 Hz correspond to the mentioned range.

Experimentally determined upper range of oscillatory frequencies at which cavitation in BW is self-destructed is 110–115 Hz under normal conditions. However, close to the upper range power consumption rapidly grows again, lowering the process efficiency.

After determination of cavitator optimal modes the required frequency range is specified. Then processed liquid and gas (in the case of technological requirements) are supplied to the cavitator working chamber and the BW cavitation treatment begins. The treated liquid is taken away from the working chamber and directed to the appropriate technological equipment for further measurements or to the tank. BW cavitation treatment, depending on the technological requirements, can be carried out under continuous mode or discrete mode in a closed technological cycle.

3. Results and Discussion

As mentioned above, vibroresonance cavitation method for liquids treatment that was created and investigated by us, belongs to the methods of hydrodynamic cavitation excitation. In the electromagnetic vibration cavitators the exciters, *i.e.* solids moving in the flow of processed liquid, are oscillatory decks with through holes. Deck-exciters are provided by low frequency vibration with the frequencies aliquot to the own vibration frequencies of cavitation nuclei. The amplitude-frequency characteristics of deck oscillation modes are determined experimentally using a device specially created for this purpose. Cavitation field is formed in a liquid flow as a result of flow high passing rate (0.9–1.0 m/s) through the holes in the oscillatory decks. In such a case high gradient tensile stresses are formed. Due to these tensions intermolecular bonds in a liquid are weakened and partially destroyed, providing the inception of microbubbles, which are always present in the fluid as cavitation nuclei; the avalanche-like increase of microbubbles amount forms the cavitation field.

According to our previous studies [7], while treating BW from "Kumpel Brewery" under acoustic conditions the effectiveness of nitrogen supply to the reaction zone as an additional source of cavitation nuclei was found. Therefore, in this research under vibrocavitation conditions we bubbled nitrogen. Fig. 3 shows the dependence of COD from vibrocavitation treatment time in the nitrogen medium for BW from "Kumpel". The degree of organic compounds destruction is 96 % (COD is reduced by 1.8 times provided only nitrogen was bubbled).

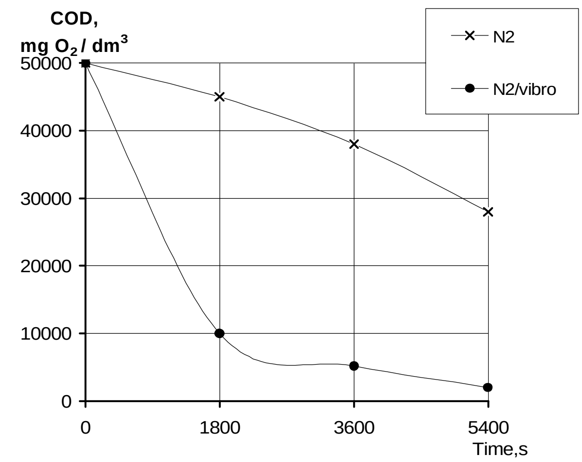

Fig. 3. COD *vs.* vibrocavitation treatment time in the nitrogen medium for BW from "Kumpel"

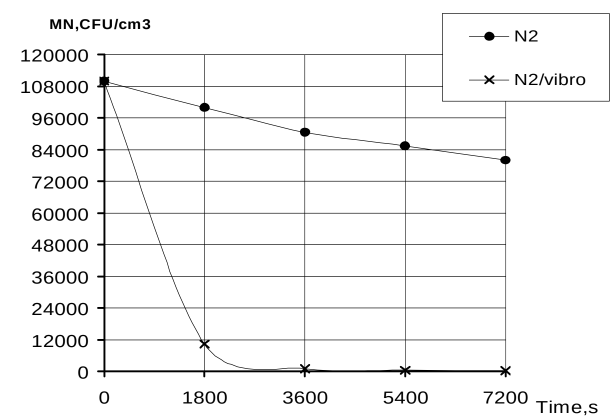

Fig. 4. MN *vs.* vibrocavitation treatment time in the nitrogen medium for BW from "Kumpel"

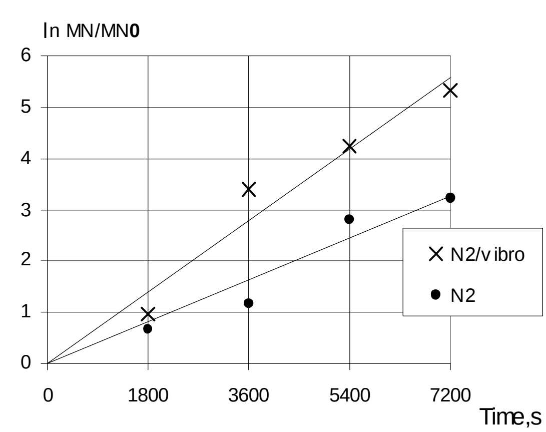

Fig. 5. Semilogarithmic anamorphosis of $\ln MN/MN_0$ depending on time in the nitrogen medium for BW with high content of *Saccharomyces cerevisiae*

The results of microbial number (MN) determination are presented in Fig. 4. The MN decrease is observed in the entire investigation range, but the nitrogen medium as itself does not significantly reduce MN.

Under joint action of vibrocavitation and nitrogen the process of MO destruction, the same as organic contaminants destruction, takes place in the kinetic area and for its description we can apply kinetic equation of the first order (Fig. 5). The effectiveness of this joint action is confirmed by calculated effective rate constants of organic compounds and MO destruction, which are equal to $5.01\cdot10^{-4}$ and $9.55\cdot10^{-4}$ s^{-1}, respectively. If only nitrogen was supplied to the reaction medium, the effective rate constants were lower by order ($4.7\cdot10^{-5}$ and $8.2\cdot10^{-5}$ s^{-1}, respectively). Thus, it is advisable to supply nitrogen during vibrocavitation treatment of BW from "Kumpel".

The joint action of vibrocavitation and nitrogen for organic compounds destruction in BW results in the destruction degree of 96 %. The destruction degree of microorganisms in BW from "Kumpel" was found to be 99.7 % for two hours, though during the first hour the destruction degree was 99 %. The obtained results show satisfactory quality of decontaminated water and allow to halve the treatment time.

4. Conclusions

The effect of vibroresonance cavitation on BW decontamination from organic and biological contaminants, including *Saccharomices cerevisiae* yeast was studied. Electromagnetic vibration cavitator was developed and principle of its operation was described. AFC-120 regulator allows to change technological regimes of vibrocavitation and to set the optimum frequency of BW treatment depending on its composition. Under joint action of vibrocavitation and nitrogen the process of microorganisms and organic contaminants destruction takes place in the kinetic area and kinetic equation of the first order may be used for its description. The use of electromagnetic vibration cavitator for BW treatment allows to achieve the highest destruction degree of organic compounds – 99.7 %, the highest degree of water decontamination – 99 % and to halve the treatment time.

Acknowledgements

This work was conducted within the scientific direction of researches at Lviv Polytechnic National University under state budget item: "Application of vibrocavitation to intensify chemical-technological processes" (registration number 0113U001369).

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Received: November 26, 2016 / Revised: January 29, 2017 / Accepted: April 02, 2017

ВІБРОКАВІТАЦІЙНЕ ЗНЕЗАРАЖЕННЯ ДРІЖДЖОВИХ СТОКІВ ПИВОВАРІННЯ

Анотація. *Показано, що одним із перспективних напрямів вирішення проблем екологічної безпеки довкілля є створення високоефективних методів знезараження стічних вод та руйнування наявних в них органічних сполук. Запропоновано конструкцію та описано принцип роботи створеного для очищення стічних вод пивоваріння електромагнітного вібраційного кавітатора, досліджено ефективну технологію віброкавітаційного очищення стоків харчових виробництв. Встановлено, що при очищенні дріжджових стоків пивоваріння найвищі ступені знезараження від біологічних і органічних забруднень забезпечуються спільною дією віброкавітації та відповідних процесів оброблення газів, зокрема азоту.*

Ключові слова: *кавітація, стічні води, пивоваріння, мікроорганізми, дріжджі, знезараження, очищення.*