

Application of Hydrodynamic Cavitation to Improve the Biodegradability of Municipal Wastewater

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ABSTRACT

In the present study, the application of hydrodynamic cavitation to improve the biodegradability index of mechanically pre-treated municipal wastewater was examined. The experiments were carried out at the pressure of 3.5, 5, and 7 bar, which was sustained every time in the inlet zone of the cavitation device. As a result, the concentration of soluble chemical and biochemical oxygen demand increased, indicating an effective decomposition and solubilization of complex organic matter. These were accompanied by a visible drop in COD value; in turn, increases in the BOD₅/COD ratio known as biodegradability index were observed.

Keywords: wastewater, hydrodynamic cavitation, biodegradability index, BOD₅/COD ratio

INTRODUCTION

The urban and industrial development is responsible for the production of a large quantity of wastewater and thus increases the load of pollutions (Ibrahim et al., 2020). The municipal wastewater includes human excreta, complex organic substances, nutrients, and pathogenic microorganisms. Wastewater also comprises residues of pharmaceuticals as well as detergents, products of personal care, and disinfectants commonly used for domestic activities (Gogate et al., 2020, Sikosana et al., 2020). Due to stringent wastewater and water quality law regulations, the expanded investigation has been focused on developing the processes that are viable and can efficiently deal with toxic and refractory organic pollutants in wastewater and on improving the existing wastewater treatment technologies. Numerous studies were have been conducted to enhance biodegradability and treat municipal wastewater (Korpe et al., 2019). The conventional and commonly known treatment methods of wastewater are not capable to reach complete transformation of the pollutants to water and carbon dioxide, so the development in wastewater treatment methods and technologies is focused to meet the requirements

of environmental law (Thanekar and Gogate, 2018). Advanced oxidation processes (AOPs) are the technologies that have been effectively applied for the removal of toxic and refractory contaminants, as a result of uncomplicated reactor construction and the exceedingly efficient operation. The AOP includes the formation of highly reactive hydroxyl radicals ($\cdot\text{OH}$) aimed at the decomposition of contaminants (Dular et al., 2016). Hydrodynamic cavitation is the developing technology that has been investigated by researchers for the water and wastewater treatment and its disinfection, dye removal, cell disruption, delignification of fibrous matter, improvement of protein extraction from soybean and extraction of intracellular biomolecules from the yeast and algae compared to the commonly used conventional methods (Prece et al., 2017, Manusco et al. 2019, Burzio et al., 2020, Yan et al., 2020, Waghmare et al., 2019). Hydrodynamic cavitation is an efficient method that reduces the number of chemical reagents which are necessary for the enhanced treatment process. Therefore, hydrodynamic cavitation as a wastewater and water treatment method does not affect the environment (Dular et al., 2016). Hydrodynamic cavitation allows to efficiency formation of hydroxyl radicals which are responsible

for contaminant oxidation. During the cavitation process, local hot spots are generated in which imploding gas bubbles cause sudden pressure and temperature growth in the treated medium. Additionally, volatile organic contaminants can infiltrate into the formed cavities which, imploding with high energy can encourage the oxidation process even more effective. The collapse energy of cavitation bubbles is usually applied to destroy the microorganisms and bacteria structures present in wastewater (Bagal and Gogate, 2014, Gałol et al., 2018). The present study examined the advisability of applying the hydrodynamic cavitation of mechanically pre-treated wastewater to improve its biodegradability.

MATERIALS AND METHODS

Materials

Municipal wastewater treatment plant “Hajdów” (Lublin, Poland) constituted the source of mechanically pre-treatment wastewater. Nine samples, 35 L each, were collected from the wastewater and taken directly to the laboratory to conduct the cavitation experiment in triplicate under three different pressure values (3.5, 5.0, 7.0 bar). Upon delivery, the composition of mechanically pre-treatment municipal wastewater was examined and the results were presented in Table 1.

Experimental set-up

The utilized set-up (closed-loop arrangement) consisted of a centrifugal pump for

Table 1. Characteristics of mechanically pre-treatment municipal wastewater (average values \pm standard deviation)

| Parameter | Unit | Average values \pm standard deviation |
|------------|--------------------|---|
| COD | mg L ⁻¹ | 521.02 \pm 18.3 |
| SCOD | mg L ⁻¹ | 457.75 \pm 15.6 |
| BOD | mg L ⁻¹ | 242.38 \pm 14.2 |
| VFA | mg L ⁻¹ | 135.13 \pm 13.7 |
| Alkalinity | mg L ⁻¹ | 544.67 \pm 23.3 |
| Phenols | mg L ⁻¹ | 2.73 \pm 0.46 |
| pH | --- | 7.41 \pm 0.17 |

pressure generation and a cavitation device that was connected to a circulation tank via pipes. A transparent organic glass tube was installed to enable observing the on-going cavitation; it comprised a steel plate with a conical concentric 3/10 mm orifice (inlet/outlet diameter). The pump was characterized by the following parameters: maximum operating pressure – 16 bar, 1000–3000 rpm, power rating – 2.2 kW; the output was controlled using a thyristor regulator. The cavitated mixture was driven by the pump – from the 30 L circulation tank, to the cavitation device and back. The inner diameter of the connecting pipes amounted to 28.76 mm. The employed set-up consisted of the following devices: a manometer (used for measuring the inlet pressure p_1), control valves, an electromagnetic flow meter (0.05 L min⁻¹ resolution), as well as piezoelectric pressure gauges (Keller PR-33X, resolution of 1 mbar) which were connected to a system for digital data measurement (Fig. 1).

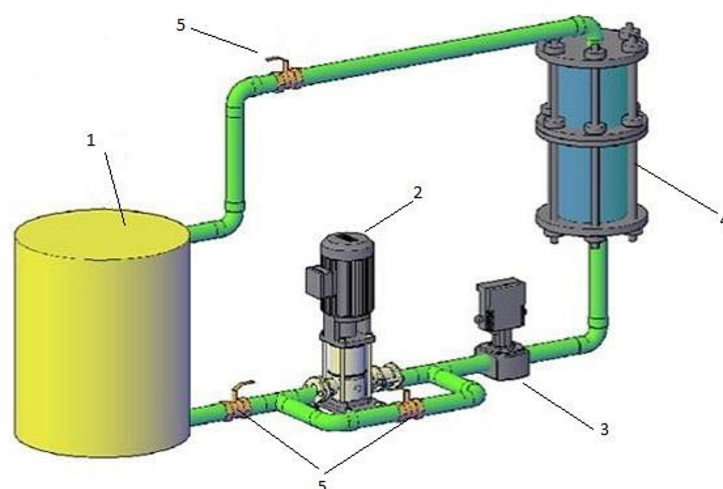


Fig. 1. Scheme of cavitation installation: 1 – circulation tank, 2 – pump, 3 – electromagnetic flow meter, 4 – hydrodynamic cavitation reactor, 5 – valve

The hydrodynamic cavitation experiment was conducted using an experimental set-up found to be optimal by Montusiewicz et al. (2018).

Hydrodynamic cavitation of wastewater was investigated as a method of improving its biodegradability. The process involved 30 recirculation passes through the cavitation zone at an inlet pressure of 3.5, 5, and 7 bar. The pressure was constantly maintained and controlled using the manometer. The operating time was 60 minutes. The analyses were performed after 2, 5, 10, 30, 45, and 60 minutes. The main objective was to ensure that

the biodegradability index is markedly higher than in the case of the uncavitated wastewater.

Composition analysis

The majority of analyses conducted to determine wastewater composition were performed in accordance with the Polish Standard methods for BOD₅ and pH. In turn, a HACH DR 3900 spectrophotometer was used to measure COD, SCOD. An electronic pH meter was used to establish the pH value.

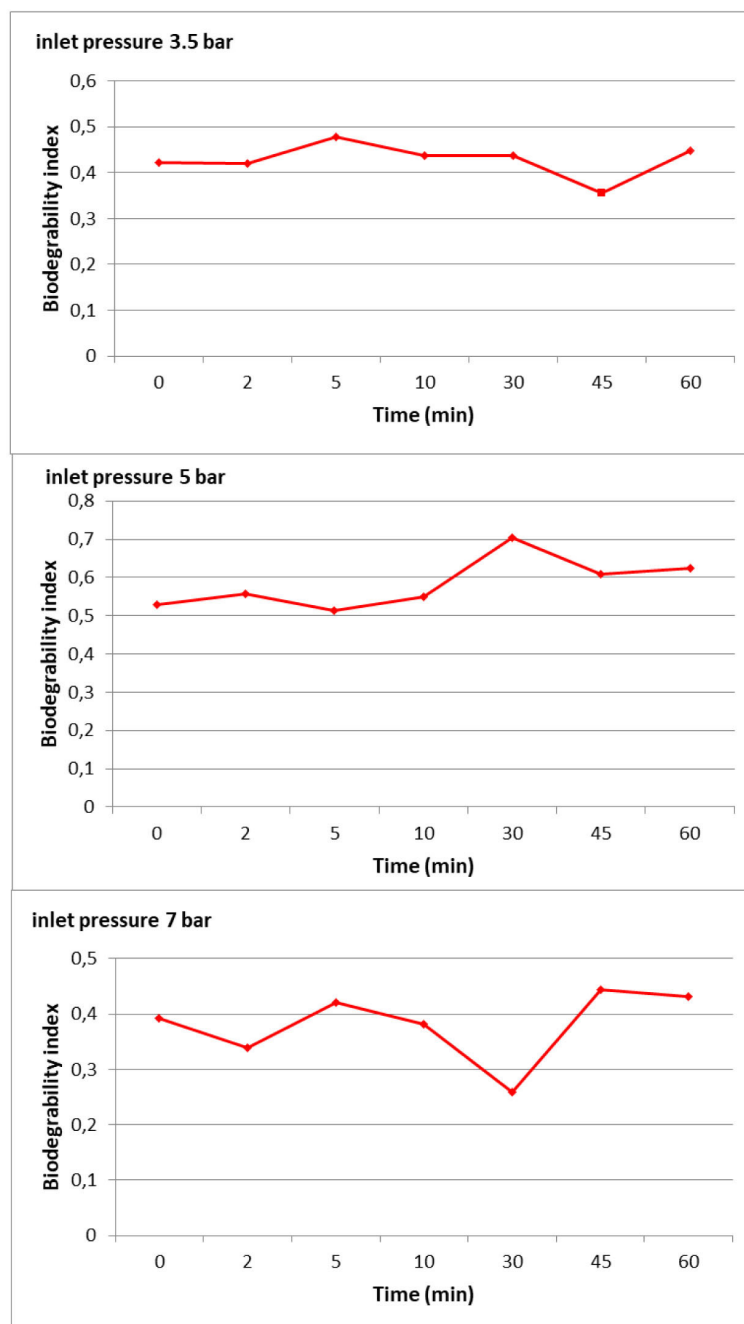


Fig. 2. Changes in BOD₅/COD ratio during the experiment

RESULTS AND DISCUSSION

The results obtained in the present study suggested that cavitation effects varied for the different pressures. The use of hydrodynamic cavitation has contributed to increasing the biodegradability index (BOD_5/COD ratio) of wastewater and may affect the subsequent biological stages of their treatment (Fig. 2).

The use of an inlet pressure of 3.5 bar increased the BI index from 0.42 to 0.48 in the 5th minute of the process, a similar effect was obtained for the pressure of 7 bar (in the 5th minute of cavitation, the 13% increase in the BI index was obtained). The highest value of the BI index increase was observed for a pressure of 5 bar in 30 min of process. The biodegradability ratio increased by 32%, from 0.53 to 0.7. Similar results were obtained by Padoley et al. (2012) for the enhancement of distillery wastewater biodegradability. They observed that higher inlet pressure (13 bar) provided the maximum value of the BOD_5/COD rate. Dhanke et al. (2020) used the hydrodynamic cavitation process to treatment fish processing industry wastewater. They observed a significant increase in the BI index, up to 0.93 in the 120-minute duration of the experiment at an inlet pressure of 8 bar. The same researchers applied the hydrodynamic cavitation to treatment vegetable oil refinery wastewater, the biodegradability index in this study reaches the maximum value of 0.69, and the reduction of

COD was up to 71.8%. These parameters were obtained for an inlet pressure of 8 bar and in 120 min reaction time (Dhanke and Wagh, 2019). Simpson and Ranade (2018) noted that the cavitation effect depends on many factors like the geometry of the cavitation device and operational parameters. According to Bis et al. (2015) the optimal choice to ensure the enhanced biodegradability index of mature leachate is applying for an orifice plate with a 3/10 mm diameter conical concentric hole. Such a construction of the orifice plate was applied also in this study. Wang and Zhang (2009) noted that there are two basic mechanisms for organic matter degradation by hydrodynamic cavitation. One mechanism is that the organic substances decomposed directly by both high temperature and pressure. The other is the oxidization of OH^* radicals formed by cavitation. Applied in this study the orifice plate with one concentric hole promoted the bubble growth, fast recovery of pressure, and higher cavitation intensity (Simpson and Ranade, 2018). The highest increase of BOD_5 from 243 to 379.3 $g\ m^{-3}$, concomitant with a drop of COD (from 596 to 548.5 $g\ m^{-3}$), was observed for an inlet pressure of 5 bar (Fig. 4), and thus the highest value of the biodegradability index of 0.7 (Fig. 2). At 30 minutes of the experiment, the highest increase in SCOD concentration was also observed from 468.7 to 501 $mg\ L^{-1}$.

The increase in BOD_5 value and the decrease in COD for the other considered pressures

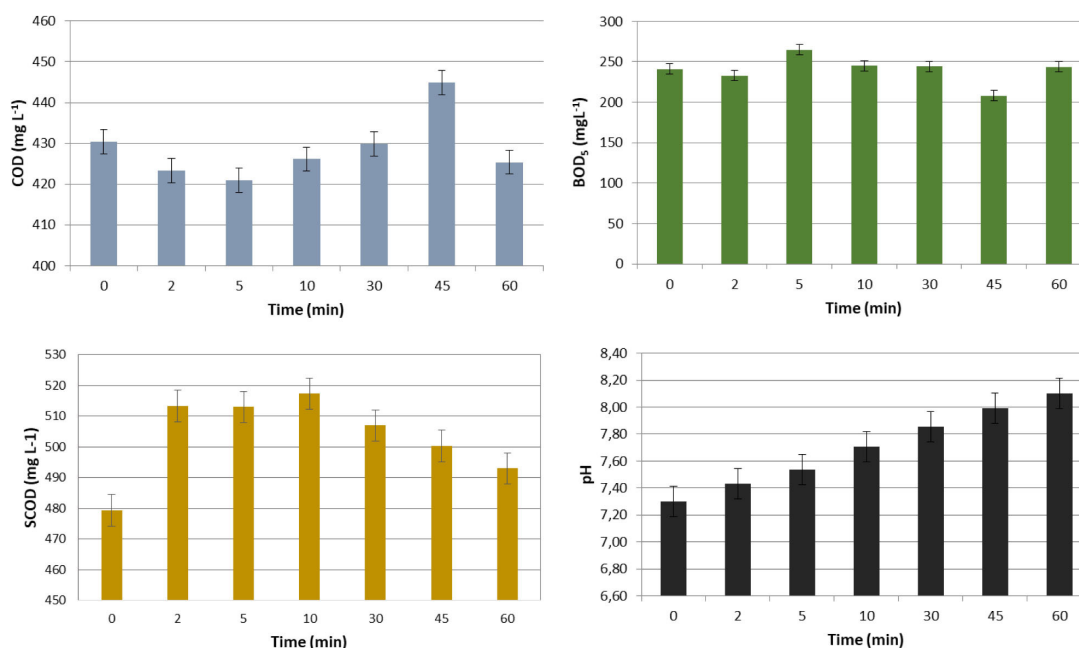


Fig. 3. Changes in COD and BOD_5 , SCOD and pH in time at 3.5 bar inlet pressure (the mean values are given, error bars represent the standard error)

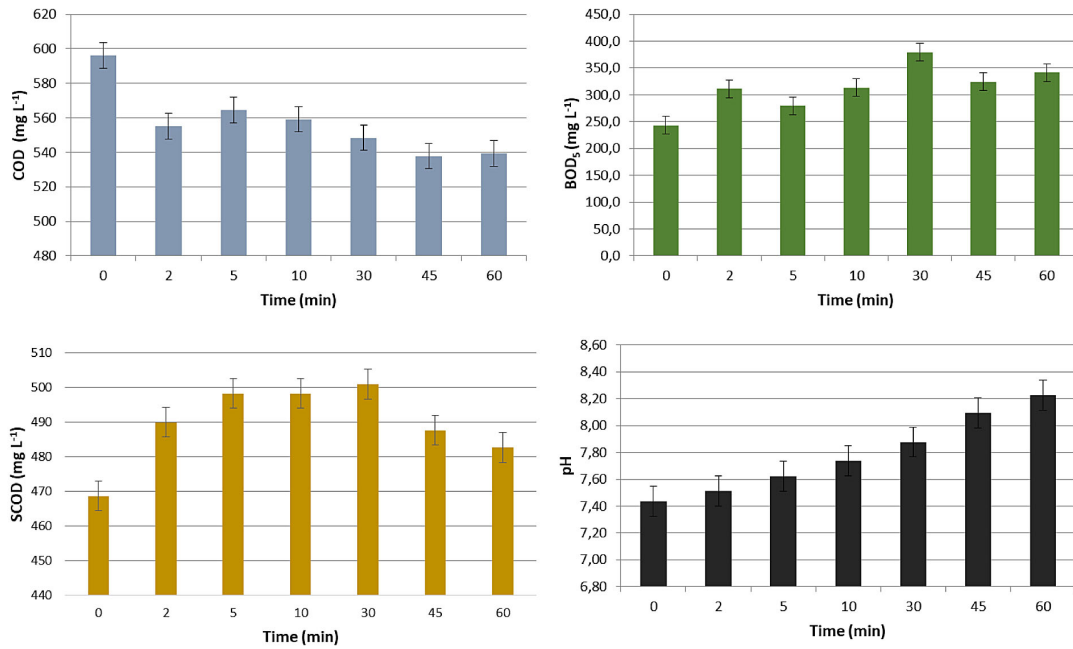


Fig. 4. Changes in COD and BOD₅, SCOD and pH in time at 5 bar inlet pressure (the mean values are given, error bars represent the standard error)

were significantly smaller. At an inlet pressure of 3.5 bar (Fig. 3), the highest value of the biodegradability index of 0.47 was observed in the 5th minute of running the process and slightly exceeded the value of uncavitated wastewater (0.42). Also during the same time of the process, the highest increase in BOD₅ value (from 241 to 264.7 mg L⁻¹) and a decrease in COD value (from 430.4 to 421 mg L⁻¹) were observed. In the case

of SCOD, the highest increase (for about 8%) was observed in the 10th minute of the experiment. At an inlet pressure of 7 bar (Fig. 5), the highest value of the BOD₅/COD ratio (0.44) and a BOD₅ value increase of around 11% was observed in 45 min of the process. Which from an economic point of view is the most unfavorable because the highest inlet pressure and the longest-running time were used. The decomposition of acid groups can

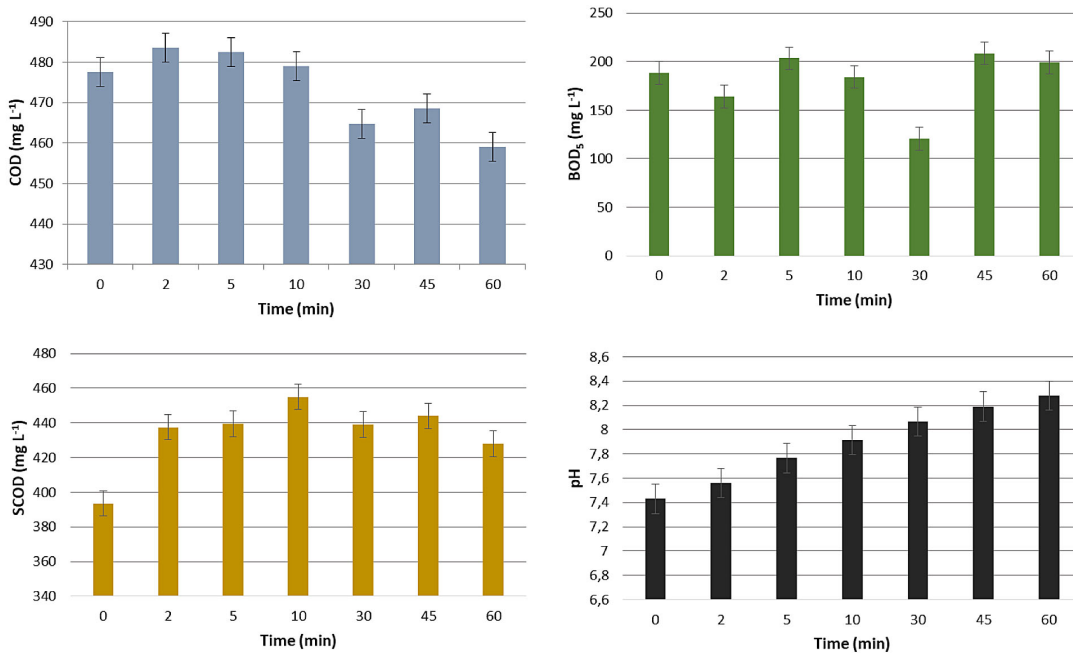


Fig. 5. Changes in COD and BOD₅, SCOD and pH in time at 7 bar inlet pressure (the mean values are given, error bars represent the standard error)

be confirmed by the pH changes through the hydrodynamic cavitation process. The wastewater pH average value was 7.43 and by cavitation, it increased to 8.28. An increase in pH, BOD₅, accompanying with a drop in COD confirmed that the oxidation of the easily biodegradable organic matter, released as the products of the recalcitrant organic compounds degradation, was probably limited due to the presence of antioxidants.

CONCLUSIONS

Hydrodynamic cavitation of mechanically pretreated wastewater ensured a significant increase in both in BOD₅ value and BOD₅/COD ratio making this medium more available for subsequent biological treatment, optimal effects were obtained with an inlet pressure of 5 bar. Moreover, the concentration of soluble organic compounds expressed as SCOD increased, indicating an effective decomposition and solubilization of complex organic matter.

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