16th International Conference on Environmental Science and Technology
Rhodes, Greece, 4 to 7 September 2019

Wastewater treatment processes utilizing hydrodynamic cavitation

Innocenzi V.*, Prisciandaro M., Veglio' F.

DIIIE- University of L'Aquila, Via Giovanni Gronchi 18 - Zona industriale di Pile, 67100 L'Aquila, Italy

*corresponding author: Valentina Innocenzi e-mail: valentina.innocenzi1@univaq.it

Abstract
In the present work, the potentiality of the hydrodynamic cavitation (HC) for the degradation of organic pollutants from industrial effluents has been studied. Cavitation is a phenomenon of formation, growth, collapse of microbubbles or cavities, in a few milli- to microseconds and releases large magnitude of energy in a short span of time. The main chemical effects of HC are the generation of highly reactive free radicals in the aqueous environment; it is possible to exploit these radicals for the intensification of chemical processes such as degradation of the water pollutants. HC represents an innovative advanced oxidation processes that can replace or be combined with the traditional oxidation processes. Lab experiments have been performed to remove pollutants as dyes (methyl orange) that can be present in textile effluents. In order to investigate the potentiality of HC, the effect of several operative conditions was investigated, as the presence of additivities (hydrogen peroxide and titanium oxides), contaminant concentration and cavitation device (venturi tube and orifice plate). The experiments showed the positive effect of hybrid treatment on pollutant degradation.
Keywords: Hydrodynamic cavitation; Wastewater treatment; Advanced oxidation processes Dyes; Venturi tube, orifice plate

1. Introduction

Industrial wastewater coming from the textile industry contains a series of toxic compounds, as for example dyes. These residual solutions cannot be discharged in the sewer without any processing, cause significant damage to the environment as eutrophication and problems to the aquatic environment. Usually, physical and chemical processes (flocculation, flotation, membrane filtration, ion-exchange, coagulation precipitation, ozonation and adsorption using also activated carbon) combined with biological ones are used to treat dye wastewaters. These treatments present good removal efficiency but in some cases the degradation of dye appears very difficult for the presence of some types of colour pigments. An alternative to the traditional processes is represented by the advanced oxidation processes (AOPs) as Fenton's treatment, photocatalytic oxidation, sonolysis and hydrodynamic cavitation (HC). In the latter process, Venturi tubes or orifice plates are used to produce radical $OH^{\cdot}$: as the aqueous solution passes through the holes, it causes a substantial pressure reduction that generates bubble cavities. In some cavities (called hot -spots) local drastic conditions could be reached, 100 MPa of pressure and 5000 K of temperature. These conditions cause the collapse of the bubbles and the production of $OH^{\cdot}$ due to the decomposing water vapor and non-condensable gases inside the bubbles [Sivakumar et al., 2002]. In the present work, the degradation of dyes (such as methyl orange) has been investigated by using hydrodynamic cavitation. Two different experimental devices were used: Venturi tube and an orifice plate. The effect of some parameters such as dye, hydrogen peroxide and TiO_2 concentration as a function of time was studied to define the best configuration and the optimal experimental conditions, from those studied, for dye decolorization.

2. Materials and Methods

2.1. Materials

Methyl orange dye was used to perform hydrodynamic cavitation tests. The solutions of dyes were prepared using distilled water for all the experiments. Sodium hydroxide (Fluka Chemika, >97%) and sulphuric acid (CARLO ERBA, 96%) were used for adjusting of the pH solution. Hydrogen peroxide (30% v/v, Carlo Erba) and titanium oxide (Sigma Aldirich, >97%).

2.2 Experimental procedure

The equipment systems used in the lab experiments is constituted by a reactor with a recycling line. During the experimental tests, it has been studied the efficiency of two types of cavitation devices: Venturi tubes (Fig.1) and orifice plate (Fig.2).

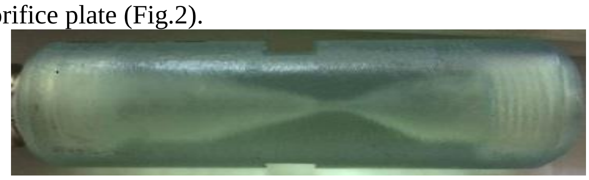

Figure 1. Venturi tube used for the experimental tests

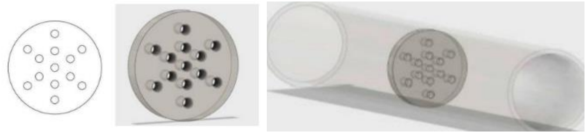

Figure 2. Orifice plate used for the experimental tests

The maximum diameter of the Venturi (Fig. 1) was 12 mm as piping diameter, while the minimum was 2 mm. The divergence angle value is 5.74° [Innocenzi et al., 2018]. The orifice plate has a diameter of 12 mm, with 13 orifices with a diameter of 1 mm each as shown in Fig. 2. The degradation of methyl orange (MO) by using hydrodynamic cavitation was performed at 4 bar and pH equal to 2 (Innocenzi et al., 2018). The synergistic effect of HC combined with additvities (0.005%v/v H_2O_2 and 0.1 g/L TiO_2) was investigated. In a first series of experiments, the concentration of methyl orange was 5 ppm; after that it has been performed another series of test in which it has been studied the effect of dye concentration on degradation yields. The solutions were circulated in the plant for 60 min as required by the experiments. The temperature was maintained constant ($T = 20$ °C) by cold water that crosses in the jacketed system of the reactor. The samples were collected at regular intervals of 10 min and the analysed to quantify the extent of MO degradation.

2.3 Analytical procedure

The collected samples were analysed using UV-Spectrophotometer (Cary 1E, UV Visible spectrophotometer Varian) in order to observe a change in the absorbance of methyl orange with time at a specific wavelength (λ), that depended on pH value. The concentration of dye was then calculated by the calibration curves. The decolourization efficiency was determined according to Eq. (1), [46]:

$$(1)\quad Degradation\ yield = \frac{[MO]i-[MO]t}{[MO]i} * 100$$

Where [MO]t and [MO]o were the concentration of methyl orange at a generic time (t) and at the initial time.

3. Results and Discussions

The results of the first series of experiments are shown in Fig. 3. In the absence of additivities, the maximum degradation of dye was 31.57%, and it has been evident the positive effect of hydrogen peroxide and titanium dioxide. The degradation yields were near to 50% by combining HC/H_2O_2 and HC/TiO_2. The maximum efficiency of the process was achieved in the experiment performed by combining HC at 4 bar, TiO_2 and H_2O_2; in this case the efficiency was more than 70%.

In a second series of experiments, it has been studied the effect of dye concentration on HC process (Table 1) and cavitation device (Table 2). It is possible to observe that increasing the dye concentration, the efficiency of HC by using venturi tube decreased, showing that the capacity of the lab apparatus was not sufficient to degrade MO if the concentration exceeded 5 ppm. Moreover, Venturi tube was more efficient than orifice plate, probably because the maximum pressure achieved with plate was near to 1 bar.

Table 1. Effect of dye concentration on HC process (experimental conditions: Venturi device, 4 bar, 20°C, 60 min)

Dye Concentration	Dye degradation yields [%]
5 ppm	31.57
10 ppm	8.98
15 ppm	5.62
20 ppm	5.55
25 ppm	4.50
25 ppm + 0.1 g/L TiO_2	4.29

Table 2. Effect of cavitation device on HC process (experimental conditions: 5 ppm of MO, 20°C, 60 min)

Experimental conditions	Dye degradation yields [%]
Venturi tube, HC at 4 bar	31.57
Orifice plate, HC at 1.2 bar	12.86
Orifice plate, HC at 1.2 bar + 0.1 g/L TiO_2	25.06

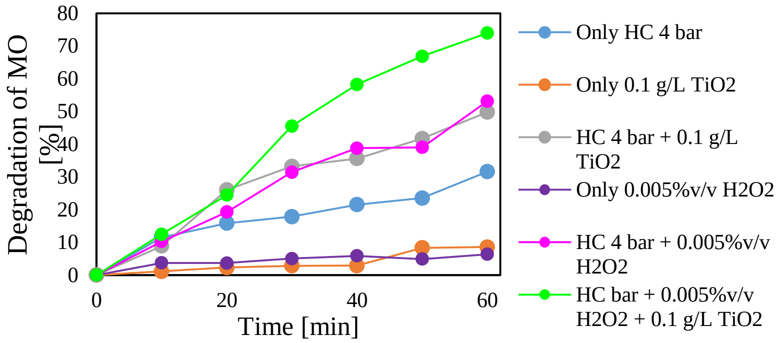

Figure 3. Degradation yield [%] of dye in various experimental conditions (initial concentration of MO = 5 ppm)

4. Conclusions

The results obtained in this research activity showed that hydrodynamic cavitation could be used for the treatment of dye solution. The maximum efficiency was near 32% by using a Venturi tube at operating pressure of 4 bar. The presence of additivities as titanium dioxide and hydrogen peroxide could increase the performance of the degradation process.

References

V. Innocenzi, M. Prisciandaro, F. Tortora, F. Vegliò, Optimization of hydrodynamic cavitation process of azo dye reduction in the presence of metal ions, *J. Environ. Chem. Eng* **6 (6),** 2018, 6787-6796.

M. Sivakumar, A.B. Pandit, Wastewater treatment: a novel energy efficient hydrodynamic cavitational technique, *Ultrason. Sonochem*. **9** (2002) 123-131.