Removal of *p*-nitrophenol using hydrodynamic cavitation and Fenton chemistry at pilot scale operation

Amey A. Pradhan, Parag R. Gogate *

Chemical Engineering Department, Institute of Chemical Technology, N.P. Marg, Matunga, Mumbai 400019, India

ARTICLE INFO

ABSTRACT

In the current work removal of *p*-nitrophenol has been investigated using hydrodynamic cavitation, either operated individually or in combination with H_2O_2 and conventional Fenton process. In hydrodynamic cavitation, two different cavitating devices viz. orifice plate and venturi have been used. Effect of different operating parameters such as initial concentration (5 g/l and 10 g/l), inlet pressure (over a range 5.7–42.6 psi) and pH (over a range 2–8) on the extent of removal has been investigated. In conventional Fenton process two loadings of $FeSO_4$, 0.5 g/l and 1 g/l were investigated and three ratios of $FeSO_4$:H_2O_2 viz. 1:5, 1:7.5 and 1:10 were used. Removal observed with venturi was higher than with orifice plate in combination with Fenton chemistry. For 5 g/l initial concentration of *p*-nitrophenol, maximum removal of 63.2% was observed whereas for 10 g/l solution it was 56.2%.

1. Introduction

The impact of industrial wastewaters discharges on the environment and human population can be tragic at times and instances of pollution with potentially adverse impacts in the longer term have continued to occur. New developments in the variety of fields to meet the ever-increasing requirements of human beings have also led to the presence of new compounds in the effluent streams of processing plants, which are not readily degraded by the conventional effluent treatment methods. It is of utmost importance to keep the concentration of chemicals in the effluent stream to a minimum level in order to comply with the environmental laws, which are becoming more stringent these days, hence there is a need to develop treatment schemes based on the use of advanced techniques such as advanced oxidation processes (AOPs), wet air oxidation, supercritical oxidation, etc. either individually or in combination with conventional methods, such that the stringent environmental regulations are met.

AOPs are defined as the processes that generate hydroxyl radicals in sufficient quantities to oxidize majority of the complex chemicals present in the effluent water [1]. Some of the AOPs, which have shown considerable promise for wastewater treatment applications, include cavitation, Fenton chemistry, and photocatalytic oxidation [2–4]. Usually a combination of different AOPs has been found to be more efficient for wastewater treatment [5–10]

as compared to individual oxidation process. Cavitation based AOPs have been widely investigated for wastewater treatment applications but more focus has been on the use of ultrasonically induced cavitation [11–14]. However, it has been observed that use of sonochemical reactors, pose significant problems due to substantially lower energy efficiencies and higher costs of operation. Use of hydrodynamic cavitation reactors, which has been recently looked as an alternative to acoustic cavitation, is an emerging technology and there are not many instances where these reactors have been investigated for wastewater treatment applications. One of the possible reasons for this is that the intensity of cavitation generated in the reactors is lower as compared to the sonochemical reactors. There have been only a few reports where use of hydrodynamic cavitation has been applied for wastewater treatment and with much larger energy efficiency as compared to acoustic cavitation. Sivakumar et al. [15] have studied the applicability of hydrodynamic cavitation reactors for degradation of Rhodamine B samples (a pink coloured dye solution) and reported that hydrodynamic cavitation was indeed more energy efficient compared to acoustic cavitation. Chakinala et al. [16] have reported the use of a combination of hydrodynamic cavitation and advanced Fenton process for treatment of real industrial effluents and it has been observed that the novel combination results in about 60–80% removal of TOC under optimized conditions depending on the type of industrial effluent samples. In the current work, the use of the combination of hydrodynamic cavitation and Fenton chemistry for wastewater treatment applications has been investigated utilizing *p*-nitrophenol as a model pollutant. Nitrophenols pose significant health risks since they are carcinogenic and is also listed on the US

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* Corresponding author. Tel.: +91 22 24145616; fax: +91 22 24145614.
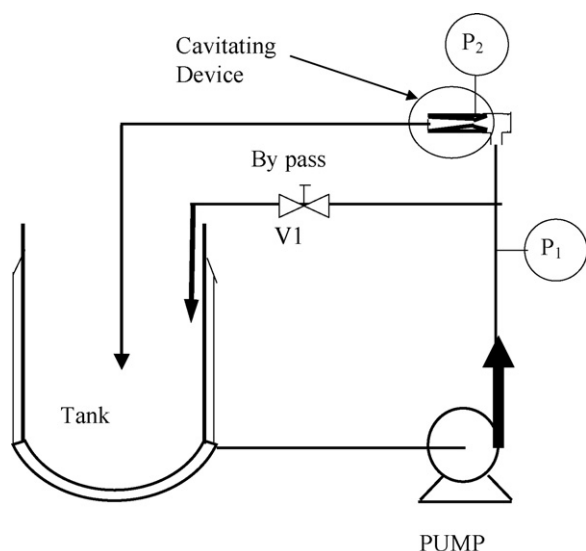*E-mail address:* parag@udct.org (P.R. Gogate).

Fig. 1. Schematic representation of the hydrodynamic cavitation set up.

environmental protection agency's priority pollutants list. Due to this fact, p-nitrophenol has been selected as a model pollutant.

2. Materials and methods

2.1. Materials

p-Nitrophenol was obtained from Loba chemie, India, and was 98% pure. It was diluted to required concentrations using distilled water. Hydrogen peroxide (30%, w/v) and ferrous sulphate heptahydrate (FeSO$_4$·7H$_2$O), all of AR grade were obtained from SD Fine chem, India. Solutions of sulphuric acid (2 M) and sodium hydroxide (2 M) were used for adjustment of pH. All procured chemicals were used as received.

2.2. Experimental setup

Schematic of the experimental setup used for hydrodynamic cavitation has been shown in Fig. 1. The setup essentially consists of a closed loop circuit including a holding tank of capacity 15 l, a centrifugal pump (2900 rpm) of power rating 370 W and a valve. Calorimetric studies were performed and it was observed that the conversion efficiency is 63.7% indicating that actual power dissipa-

tion into the liquid is 235.7 W. All experiments were performed at 7 l of operating capacity based on the pump capacity so as to maintain desired flow rate in the circulation loop and ensure generation of cavitating conditions. The suction side of the pump is connected to the bottom of the tank. The discharge from the pump branches into two lines. The main line consists of a venturi or orifice plate which acts as a cavitating device, located just after the pressure gauge. The cavitation device is made of acrylic. A by-pass line and control valve (V1) is provided to control the liquid flow through the main line. Pressure gauges are provided to measure the inlet pressure and the fully recovered downstream pressure which in most of the cases was equal to 1 atm. During the experiment, the by-pass valve was kept open till the pump reached its maximum speed and is then totally or partially closed to achieve desired pressure in the cavitation chamber.

2.3. Experimental procedure

The holding tank was filled with 7 l of aqueous solution of p-nitrophenol of desired concentration. Pump was started and flow in the by-pass line was controlled to set the required inlet pressure. The reaction was carried out for 90 min and sample was collected after every 15 min. Aim was to maximize the extent of degradation using different combinations of hydrodynamic cavitation and Fenton chemistry and hence a base was considered as 90 min of treatment for comparison purpose. Analysis of the samples was done using chemito-2500 UV–vis spectrophotometer at λ = 401 nm [17,18]. Concentration of p-nitrophenol was calculated by measuring the absorbance of p-nitrophenol with the help of the calibration chart prepared earlier with known concentrations.

The experiments with hydrodynamic cavitation operating individually were performed with venturi and orifice as the cavitating device. Fig. 2 gives the geometrical details of the venturi used in the work. Orifice plate of diameter 25 mm with a single hole of 2 mm diameter was the second cavitating device considered in the work. To examine the effect of inlet pressure on the extent of removal, the inlet pressure was varied from 5.7 psi to 42.6 psi. The resultant flow rate through the system and cavitation number has been given in Table 1 for each operating pressure. The operating temperature was maintained at 30 ± 4 °C (due to unavailability of cooling system, strategy was applied to operate hydrodynamic cavitation setup for a period of 10 min followed a cooling period of 20 min).

Hydrogen peroxide was also used as an additive (over a concentration range of 0.5–5 g/l) as an additional source of hydroxyl radicals to intensify the removal using hydrodynamic cavitation.
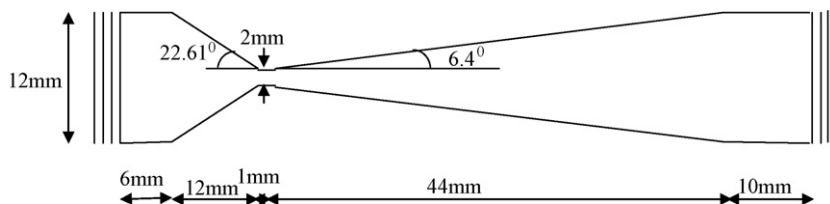

Fig. 2. Geometric specifications of a venturi used as a cavitating device.

Table 1
Cavitation number calculations.

Venturi				Orifice			
Pressure (psi)	Flow rate (l/min)	Velocity (m/s)	Cavitation no.	Pressure (psi)	Flow rate (l/min)	Velocity (m/s)	Cavitation no.
5.7	2.1	10.15	1.57	5.7	1.42	7.54	3.43
19.9	4.77	25.31	0.3	19.9	2.61	13.85	1.01
34.1	6.16	32.69	0.18	34.1	3.67	17.36	0.51
42.6	6.69	35.5	0.15	42.6	4.01	21.28	0.43