Removal of Naphthalene from Wastewater Using Hydrodynamic Cavitation

Z. Askarniya, M. T. Sadeghi*, S. Baradaran
Department of Chemical Engineering, Iran University of Science and Technology (IUST), Tehran, Iran
Sadeghi@iust.ac.ir

Abstract
Naphthalene is a polycyclic aromatic hydrocarbon that has mutagenic and carcinogenic effects on humans and aquatics. It can be harmful and is considered as a pollutant of environment. In this work, degradation of naphthalene was investigated by the use of hydrodynamic cavitation (HC) for the first time. A maximum degradation of 90% with the Pseudo-first order rate constants of $3.85 \times 10^{-2}$ min$^{-1}$ was achieved for the degradation of 25 mg L$^{-1}$ naphthalene using the method in the Pinlet of 6 bar, the temperature of 35±2°C and the natural pH. The yield efficiency of $1.6 \times 10^{-3}$ mg kJ$^{-1}$ was achieved in this investigation.

Keywords: Hydrodynamic Cavitation (HC); Wastewater Treatment; Naphthalene

Introduction
Water pollution is one of the main universal concerns nowadays. The release of industrial wastewater in the environment without treatment is extremely dangerous for aquatics and humans because of the toxicity and the other harmful properties of the synthetic substances utilized in various industries [1]. Poly aromatic hydrocarbons are known as organic pollutant which cause serious health problems because of their toxicity and carcinogenic property. These compounds are used in various industries such as manufacturing pesticide and dyes and therefore exist in the effluents of these industries [2]. Naphthalene is one of the simplest Poly aromatic hydrocarbons which is found in the effluent of coke making industry [3]. Problems created by Polycyclic Aromatic Hydrocarbons demonstrate the necessity of finding and developing efficient procedures in order to remove them from wastewater. In recent years, hydrodynamic cavitation has been considered to be a promising process for the treatment of industrial effluents [4]. The degradation of pollutants occurs based on the generation of free radicals by the use of HC. As wastewater flows through the throttle of a cavitation device such as an orifice, an increase in velocity leads to a decrease in pressure [5]. When the pressure reaches the below of the fluid vapor pressure, cavitation happens and bubbles are produced. Subsequently, in the downstream of the flow, the pressure increases and the bubbles collapse [6]. The collapse of the bubbles releases a lot of energy in forms of high local temperature (5000 K) and pressure (1000 atm), which can lead to the
pyrolysis of water molecules and consequently, the generation of hydroxyl radicals [7]. The efficacy of the process extremely depends on the type of pollutant in this method and therefore the case study of pollutants is necessary [8, 9]. In the current work, the degradation of naphthalene has been studied using hydrodynamic cavitation. The kinetic and yield efficiency of the process have also been investigated. It is the first time that the degradation of this compound has been studied by HC process.

Experimental
Naphthalene (molecular formula: C_{10}H_{8}, molecular weight: 128.1705 g mol\(^{-1}\)) was purchased from Samchun (Korea) and commercial grade acetone (molecular formula: C_{3}H_{6}O, molecular weight: 58.08 g mol\(^{-1}\)) was utilized. The schematic representation of the experimental set-up employed is observed in Fig.1.

![Figure 1. The schematic representation of the experimental set-up](image)

A storage tank, a centrifugal pump (power rating: 4 kW), a hydrodynamic cavitation reactor equipped with an orifice plate, two pressure gauges and 4 flow control valves are the essentials of this set-up. The characteristics of the orifice utilized in this work has been addressed in Table 1. The discharge side of the pump is divided into a main line and a bypass line. The main line consists of a reactor which is equipped with an orifice plate. A cooling coil installed in the storage tank is utilized in order to adjust the temperature. All the experiment was carried out with the naphthalene concentration of 25 mg L\(^{-1}\). The stock solution of naphthalene was provided by dissolving specific amount of naphthalene in the mixture of water and acetone. The pressure of the main line was adjusted using the flow control valve on the bypass line. The temperature was kept constant by the use of the cooling coil installed in the storage tank.
The 11th International Chemical Engineering Congress & Exhibition (IChEC 2020)
Fouman, Iran, 15-17 April, 2020

<table>
<thead>
<tr>
<th>Table 1. Characteristics of the orifice used as cavitating device.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>Pipe diameter (mm)</td>
</tr>
<tr>
<td>Hole Diameter (mm)</td>
</tr>
<tr>
<td>Flow Area (mm²)</td>
</tr>
<tr>
<td>Flow perimeter (mm)</td>
</tr>
<tr>
<td>Hole diameter to pipe (β)</td>
</tr>
<tr>
<td>Flow area to pipe cross sectional flow area (β₀)</td>
</tr>
<tr>
<td>Total perimeter of holes to the total flow area of the plate mm⁻¹ (α)</td>
</tr>
</tbody>
</table>

The concentration measurement was done using UV-vis spectrophotometry at the wavelength of 275 nm.

Result and discussion
Hydroxyl radical is a strong oxidant with the high oxidation potential of 2.8 V, which can diffuse among the bulk of fluid and cause pollutant molecules to degrade [10]. This free radical can be produced by the pyrolysis of water molecules using cavitation condition according to Eq. (1) [11].

\[ \text{H}_2\text{O} \rightarrow \text{H}^\circ + \text{HO}^\circ \] (1)

The results of the experiment are given in Fig. 2.

![Fig. 2. Degradation of naphthalene (at pressure of 6 bar and temperature of 35±2°C).](image)

At constant temperature of 35±2 °C and the pressure of 6 bar, 90% of degradation has been achieved using HC within 60 min. The obtained result can be an indication of generation of hydroxyl radicals through the dissociation of water molecules by hydrodynamic cavitation. Result of the kinetic study based on assuming pseudo-first order rate constant is seen in Fig. 3.
The first order rate constant of $3.85 \times 10^{-2}$ min$^{-1}$ has been achieved using this process.

![Fig. 3. Kinetics of degradation of naphthalene (at pressure of 6 bar and temperature of 35±2°C).](image)

The yield efficiency of processes is calculated in order to determine the pump energy required for the degradation of specific amount of pollutants according to the following Eq. 2 [11]:

$$
\eta = \frac{\Delta C}{E_{\text{pump}}}
$$

(2)

Where $\Delta C$ is the amount of degradation in a determined time in mg and $E_{\text{pump}}$ is the pump energy which is consumed in the same time in kJ ($E_{\text{pump}} = \text{pump power (kW)} \times \text{time (second)}$).

![Fig. 4. Yield efficiency of degradation of naphthalene (at pressure of 6 bar and temperature of 35±2°C)](image)

Fig. 4 shows the results of the yield efficiency calculated for the degradation of naphthalene. The yield efficiency achieved using hydrodynamic cavitation has been $1.6 \times 10^{-3}$ mg kJ$^{-1}$ in 60 min.

**Conclusion**

This survey has demonstrated that the degradation of naphthalene can be achieved effectively
by the use of HC. 90% of the degradation of naphthalene with the first-order rate constant of $3.85 \times 10^{-2}$ min$^{-1}$ has been obtained by the use of this process. The yield efficiency of $1.6 \times 10^{-3}$ mg kJ$^{-1}$ was achieved in 60 min.

References


