

# Aeration Supported Process Intensification of Waste Water for Degradation of Benzene in an Orifice Type Hydrodynamic Cavitation System

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Isolated and aerated benzene degradation in the wastewater using orifice plates as the cavitating devices for the hydrodynamic cavitation (HC) reactor was investigated. Initially, calorimetric tests were used to measure the energy efficiency of the HC reactor run at various inlet pressures. At an inlet pressure of 3.0 bar, the maximum energy efficiency of 55.8 % was achieved. In both isothermal and adiabatic treatment conditions, the treatment procedures were compared, and the degree of deterioration in comparison with the isothermal condition was observed in the adiabatic condition. The study related to understanding the impact of inlet pressure has revealed that the maximum degradation of 99.7 % was obtained at 3 bar pressure using the HC's individual activity under adiabatic conditions in 90 min of treatment. The combination of HC and air at different airflow rates were investigated with the best results for maximum benzene depletion at an airflow rate of 65 mL/s. A novel approach to cavitation was also illustrated in terms of the level of degradation, energy demand and operating costs for a small fraction of the overall processing time. The resonant radius from cavitation bubbles aggregates was also calculated based on the strength of the cavitation in both distilled water and aqueous benzene. Overall, important advantages for degradation of benzene along with an understanding of cavitation effects have been shown by HC in combination with air.

## 1. Introduction

The unsuitable discharging of industrial organic waste is responsible for environmental damage. In most industrial wastewater streams from the manufacture of petrochemicals, plastics, resin, rubber, textiles, pharmaceutical products and the tanning industry, aromatic compounds such as ethylbenzene and p-nitrophenol are major pollutants (Thanekar et al., 2021). Benzene is a commonly utilised aromatic hydrocarbon in the production of plastics, resins, synthetic fibres, dyes, detergents, cosmetics and industrial solvents, among the many aromatic compounds. In the case of benzene, industry exposure and auto exhaust are around 20 % of overall exposure, and additional environmental exposure is due to tobacco smoke, a byproduct of tobacco combustion. Due to its remarkable chemical stability, benzene has a high ability to linger in the environment. The harmful component benzene has several detrimental impacts on your health, such as blood-forming organ cancer, skin irritation, redness, and immune system flaws that increase infections. In view of the high probabilities and dangerous effects, an effective strategy to completely eliminate benzene is required. Benzene must be removed in order to save ecological deterioration (Ramteke and Gogate, 2015). The present work on the treatment of wastewater contaminated with benzene based on previous studies on successful treatment of different aromatic chemicals considers a sophisticated technology known as hydrodynamic cavitation (HC) (Goel et al., 2004). It's called HC because the liquid is forced into an obstruction (throttling valve) orifice plate (venturi) to create cavities (Ghayal et al., 2013). Liquid velocity increases as it travels through a constriction, while pressure decreases. The water flashes when it is under pressure at the throat of mechanical constriction, causing a large number of cavities that collapse when the pressure is restored downstream of the constriction. Hot patches are created, highly reactive free radicals are released, surface cleaning and/or erosion is increased, along with local transport rates (heat, mass, and momentum)

(Gole et al., 2013). In HC, cavitation formation is based on local pressure changes and kinetic energy in the fluid due to geometry such as pulleys, venturi or apertures. The highest temperatures and pressure of roughly between 1,000 -5,000 atm are produced during cavitation (Bokhari et al., 2016). The hot springs generated together with high turbulence can exacerbate pollutant oxidation (Bokhari et al., 2017). An analysis of literature has recently been offered to show that HC has not been used for benzene degradation in wastewater, which emphasises the originality of existing work. Aerobic-anaerobic degradation, TiO based photocatalysis, nanocomposite extraction and cavitation are all processes reported in the literature (Thanekar et al., 2021). Braeutigam et al. (2009) investigated degradation by hydrogenating cavitation at the upstream pressure of 25 psi with an orifice sheet as a cavitating device in benzene, toluene, naphthalene and xylene (Btex) in an aqueous solution. The significantly lower degradation of benzene was reported to be just 19 % and toluene 21 % in 4 h. Wu et al. (2004) studied the degradation in aqueous solution, by means of a 40 W ultrasound reactor, of various cyclic hydrocarbons such as benzene, 1,3-cyclohexadiene, 1,4-cyclohexadiene, cyclohexene, cyclohexane and methycyclopentane.

In comparison to other cyclical hydrocarbons, it has been reported that benzene degradation was modest ( $0.025 \text{ min}^{-1}$ ). Ramteke et al. (2015) investigated ultrasound therapy of water-containing BTXs. The combination treatment technique of ultrasound and Fenton process with fixed loading of  $\text{Fe}^{2+}$  and  $\text{H}_2\text{O}_2$  were used to significantly improve benzene degradation (current values as 93.4 %) and the COD reduction (actual value at 88.6 %). The biodegradability index was also found to have grown from 0.17 to 0.39 in 40 min of therapy utilising the US/Fenton approach. Goel et al. (2004) explored benzene degradation with an ultrasonic reactor. They reported a consistent  $0.0147 \text{ min}^{-1}$  benzene degradation rate for treatment utilising a 20 kHz US bath and 200 ppm  $\text{H}_2\text{O}_2$  combination. For the degradation of an aromatic molecule at two different frequencies of 20 kHz, Weavers et al. (1998) examined the combinations of sonolysis and ozonolysis. The rates for nitrobenzene achieved for the combination of sonolysis and ozonolysis were reported to be greater and synergistic at a lower frequency of 20 kHz.

While literary analysis shows cavity reactors' effectiveness to degrade benzene, extensive research employing HC in combination with air was not documented, and just one study was performed on benzene degradation utilising HC alone (based on a cavitation device) for the treatment of benzene. In view of this, the current work has concentrated on achieving effective benzene degradation by the combination of HC (dust-based) and air treatment under adiabatic and isothermal circumstances.

## 2. Materials and methods

### 2.1 Materials

Kinetic Chemical Malaysia provided the benzene of 99.9 % purity. Distilled water was acquired fresh from the laboratory distillation machine for creating several solutions in the current experiment. The benzene concentration in the solution was tested at regular time intervals with a UV-visible spectrophotometer (Specord 40 M). Fixed sample quantity and absorption measurement at the wavelength of 254 nm was used for every analysis. First of all, a standard calibration curve was created with known benzene content, and a measured absorbance was used to determine the unknown sample concentration. Repetitive experiments in the present work at least twice checked the reproductivity of the results. The inaccuracies noticed were  $\pm 2\%$  of the values presented. Simile repeatability with errors in  $\pm 1\%$  of the stated average has also been confirmed for absorbance values acquired from the spectrophotometer.

### 2.2 Cavitation reactor setup

Chemical benzene degradation reaction was conducted in a 50 L double jacket hydrodynamic cavitation (HC) reactor consisting of borosilicate glass. A double diaphragm pump was used to control the system's upstream pressure and circulate the reaction mixture in a narrow loop across the orifice plate (Chuah et al., 2017). The double diaphragm pump is the main energy control system for a whole HC pilot plant. There were two lines of the downstream part of the pump. Valves at the mainline and circumference were controlled by the upstream pressure and fluid flow through a hole plate. Figure 1 shows the HC pilot reactor scheme setup. The mass flow rates were between 3 - 9 L/min at the main and bypass lines, with the inlet pressure adjusted to 1 - 3.5 bar (Chuah et al., 2015a). The entire pilot plant has pressure gauges and flowmeters. HC heat is dispersed by heating oil, which is around the area of the two jacket glasses (Chuah et al., 2016). For a period of time, the digital temperature controller kept the desired temperature. A detailed description of orifice plates would be found in previously published work (Chuah et al., 2015b).

The 0.0093 M benzene solution was made with distilled water and was placed in a feed container. A total volume of reaction as 25 L and treatment as 100 min were maintained. In the beginning, the solution was removed for 20 min to keep the solution temperature around  $25^\circ\text{C}$  (ambient condition). Control valves have been used to alter the in feed pressure. The various trials under adiabatic and isothermal settings were

conducted. The temperature was nearly constant, i.e. in the event of isothermal operation, temperature fluctuation was not greater than 0.5 °C.

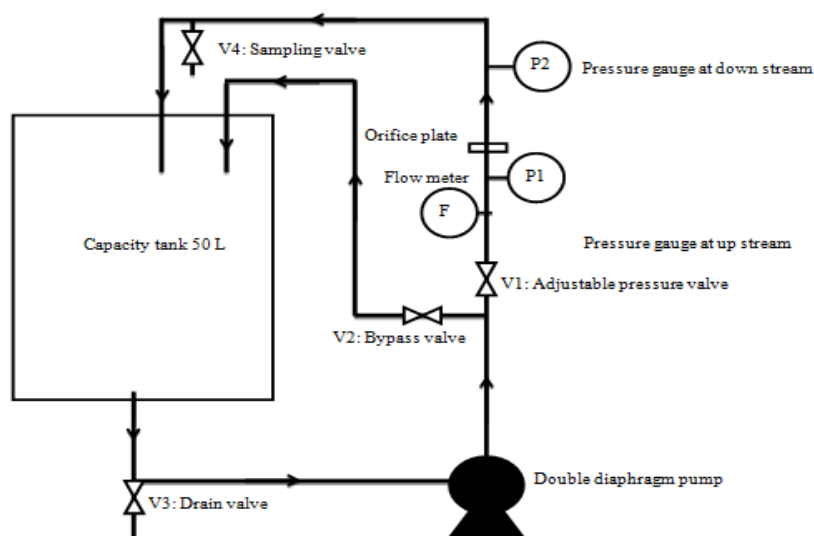


Figure 1: Benzene degradation reaction in a cavitation reactor

### 3. Results and discussion

#### 3.1 Effect of upstream pressure on benzene degradation

The control valves were adjusted for the effect of pressure on the extent of benzene degradation, and experiments were conducted at varied inlet pressures ranging between 1.0 and 3.5 bar. Figure 2 shows the data obtained, and the degradation rate of benzene was first favoured but then dropped above the maximum pressure value of 3.0 bar. The trend seen is ascribed to the reduction in cavitation intensity due to cavity-cloud development, over and above the optimum inlet value (in this case, 3.0 bar). It should also be noted that the increase in temperature was not beyond 45 °C even throughout the adiabatic process, which suggests that not a lot of benzene loss will occur in the surrounding area. No fragrance was also observed during the operation to certify that no fumes were released into the area.

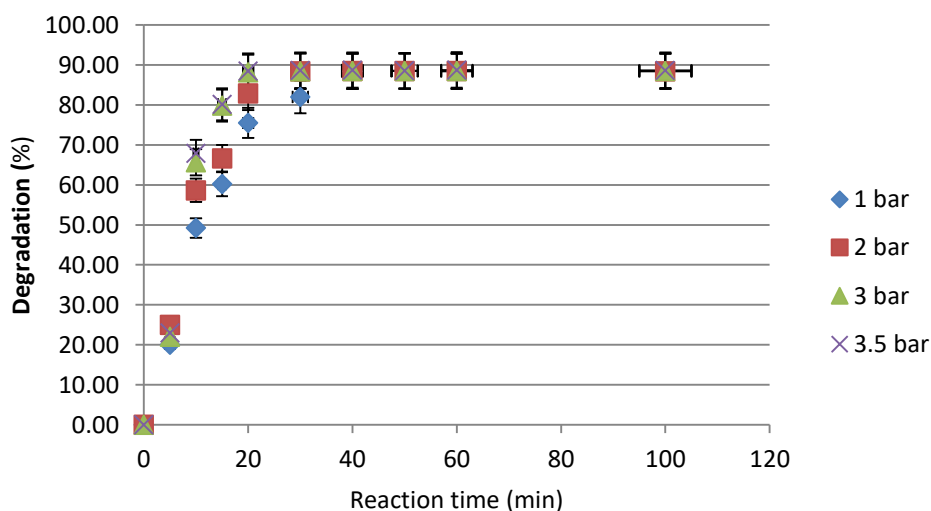


Figure 2: Upstream pressure effect on benzene degradation (adiabatic process)

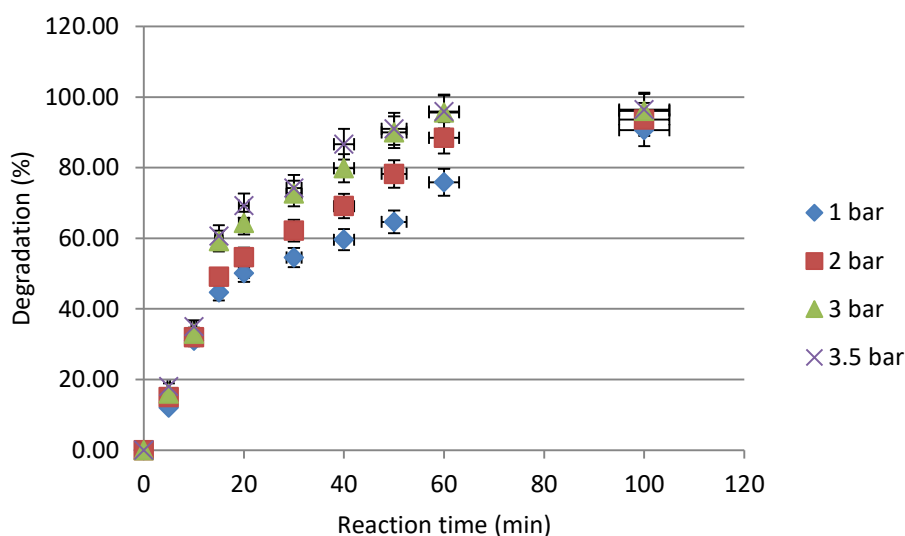


Figure 3: Upstream pressure effect on benzene degradation (isothermal process)

Many literature pieces of research have shown that the pollutant type and the reactor setup are optimally dependent. For the degradation of methomyl by the combination of HC and H<sub>2</sub>O<sub>2</sub>, Raut-Jadhav et al. (2013) reported an optimal value of 5 bar. HC coupled with improved Fenton processes were used in the decolourisation of methyl orange. The greatest decolouration was 31.57 %, with an ideal value of 4 bar, while the extent of the colourisation dropped beyond the ideal pressure (5 bar) to 21.58 %. The decolourisation of dyes present in textile wastewater utilising an HC jet loop system was explored by Badmus et al. (2020). The highest decolouration, as 69.37 %, was reported at best input pressure 4 bar, while the input pressure was increased further to 5 bar, and the decolouration was significantly lower as 9.3 %. The HC reactor operated utilising varied geometric limitations was used to study the degradation of orange G dye by Saharan et al. (2013). The ideal entrance pressure was reported to be three bars for slit venturi, while the best value was 5 bar for circular venturi and orifice plate. A complete examination of the intake pressure effect as it is specific to geometric restriction and the type of pollutant has been validated in the literature analysis and results reported in the present study. At varying intake pressures from 1.0 to 3.5 bar, a series of tests were also done in isothermal circumstances in Figure 3. For the degradation of benzene, Figure 4 show the results. The 99 % degradation was obtained at 3.0 bar pressure, which dropped to 74.6 % 3.5 bar pressure.

### 3.2 Degradation of benzene with the aeration process

Air intake by the compressor at varied flow rates from 60 to 135 mL/min with the fluid pressure of 3.5 bar was examined by inserting air into the feed tank as depicts in Figure 4. The patterns for degradation at various airflow rates are shown in Figure 4 and Figure 5. From the results obtained, there is an increase in the degradation with an airflow rate increase from 50 mL/min to 60 mL/min, but a further increase to 100 mL/min decrease the degradation level. At airflow rates of 70 mL/min within 90 min from treatment, the maximal degradation of benzene was 75 % at the rate of 0.029 min<sup>-1</sup> is observed as shown in Figure 5. The deterioration was reduced to only 55 % with the same inlet pressure. Initially, the effects observed, i.e. below the optimum flow rate, can be attributed to the radical OH production that ultimately promotes the degradation of benzene by gas species that occur in air, such as nitrogen, oxygen, and other gases. The presence of air also offers a larger cavitation intensity in extra nuclei that further contributes to pollutant degradation. In addition to optimal airflow, too many cavity occurrences contribute to lower cavitation intensities due to coiled collapse, resulting in decreased deterioration. Although the deterioration was only relatively high in HC in the best pressure of 3.0 bar (99.2 %) compared to that achieved in HC combination with air, certain intermediates were identified, lowering the mineralisation level. However, HC and air combined did not lead to the intermediate formation, meaning that the amount of mineralisation was higher than merely the operation of HC. After injecting 60 mL/h at 3.5 bar, HC with air degraded by 84.6 % under isothermal conditions but 88.9 % under anaerobic conditions at the same input pressure and airflow rate. Under the isothermal conditions, the 90 % degradation level was obtained at an intake pressure of 3 bar when the air was introduced at a flow rate

of 80 mL/s. Due to a rise in temperature, the presence of air (oxygen) also adds to the oxidation of benzene when under adiabatic circumstances.

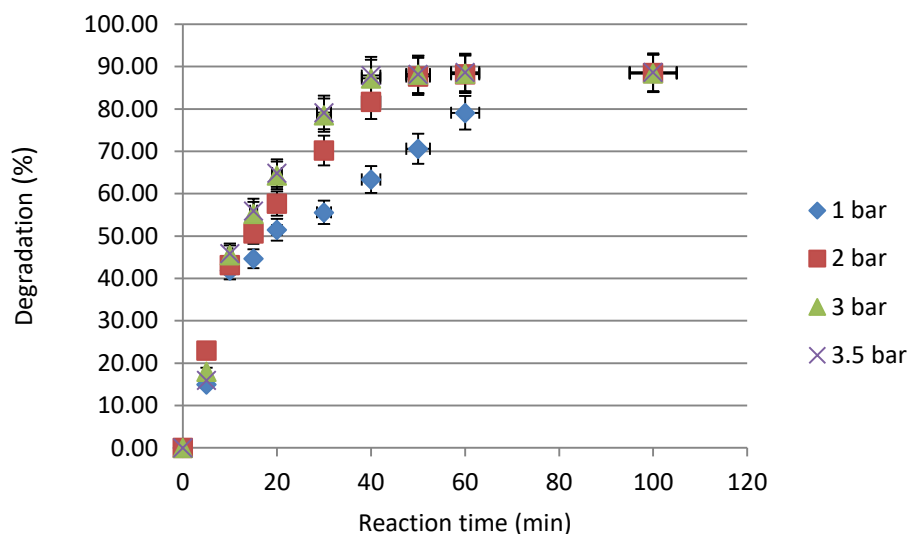


Figure 4: Upstream pressure effect on benzene degradation (with air)

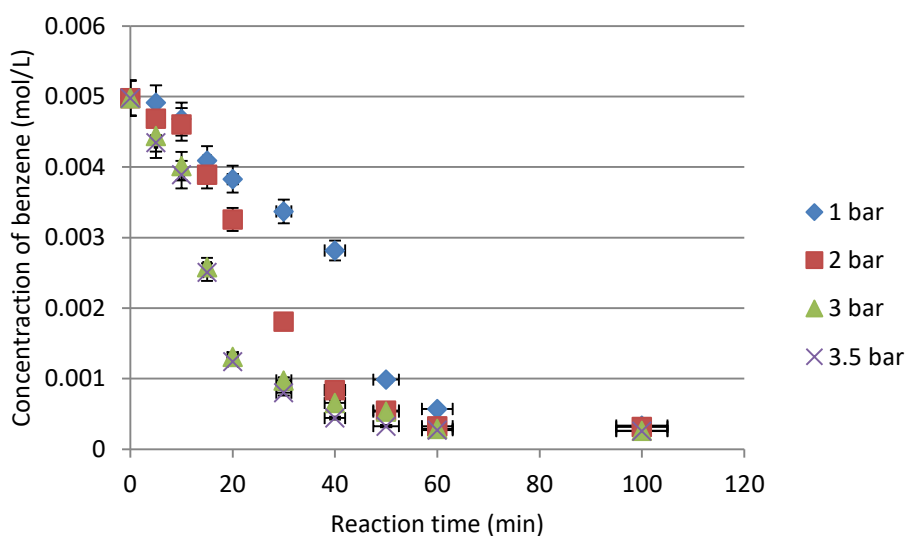


Figure 5: Benzene concentration with respect to time at variable upstream pressure

#### 4. Conclusions

The current investigation has clearly demonstrated the efficacy of HC with the combination treatment of HC with air for benzene degradation. Initially, calorimetric HC reactor effectiveness experiments at various input pressures showed maximum energy efficiency at the inlet pressure of 3.0 bar. Nevertheless, the maximum deterioration of 99.8% by adiabatic HC at 3.0 bar was attained, confirming that too much energy was not a smart choice. This study has the limitation of utilisation of elevated upstream pressure. The high inlet pressure cause the cavitation chocking, which has been lead towards lower benzene degradation. The degradation of benzene under adiabatic and isothermal circumstances by HC with air was shown in an intensified approach, while the effectiveness depended on the operating pressure. Compared with the degradation achieved in isothermal settings, the adiabatic condition was likewise advantageous in the increased degradation, and the efficacy was pressurised again.

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