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Removal of Phenol from Industrial Wastewater Effluent by Using Advanced Oxidation Process

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ABSTRACT: Water pollution has become a major problem due to large amount of industrial effluent discharged into the water body coming from many chemical processing industries such as textile, pharmaceutical, pesticides & petrochemical. This effluent contains large amount of organic hydrocarbon such as textile dyes, aromatic compounds, chlorinated hydrocarbon, & phenolic compounds.

Phenol and phenolic compounds are common organic contaminants in air and wastewater, which are released into environment from various industrial activities such as petrochemical and pharmaceutical processes. Phenol is considered as one of the most serious organic pollutants regarding it damages to human health and aquatic life even at low concentration. So, removal of these pollutants from wastewaters using non-toxic materials and eco-friendly advanced oxidation processes such as hydrodynamic cavitation has been considerable interest.

KEYWORDS*:* Phenol, phenolic compounds, advanced oxidation process, hydrodynamic cavitation.

I. INTRODUCTION

The heavily industrial world we live in today continues to generate large volume of wastewater containing industrial effluent sewage and other harmful by-products, which are disposed into rivers and oceans. At the same time the need of potable water continues to increase at worrying rate due to increase in population and associated demand. The urgent need to treat and reuse water has never been greater in modern world [11]. Among the regulated compounds, phenols are listed in the US Environmental Protection Agency (EPA)\ priority list of pollutants and, related to dangerous substances discharged into aquatic environments.

Phenol and phenolic compounds (aromatic compounds) represent a significant group of pollutants present in wastewater resulting from manufacturing of pesticides, herbicides, pharmaceuticals, dyes, etc. [11]. Also, the presence of trace amounts of these compounds has restricted the reuse of water in different industrial applications. The world health organization recommends the permissible phenolic concentration to 0.001 mg/lt. in potable water and regulation by environment protection agency has set a phenol concentration less than 1 mg/lt. in the industrial effluent for safe discharge to surface water [15]. Different methods have been proposed to eliminate phenolic compounds from polluted water including chemical oxidation, chemical coagulation, extraction with solvent membrane technology, adsorption and ion exchange, using a parabolic trough collector (PTC) photo catalysis system, and reverse osmosis (RO) has been successfully utilized in several industrial processes [3].

There are other conventional methods that we still employed in the treatment of wastewater based on different processes such as chemical, physical, mechanical, and biological method. Some of these technologies (such as adsorption and filtration) many concentrate the pollutants by transferring them to other phases [18]. The phenol is removed by biological processes such as activated sludge process, chemical oxidation processes this process have

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difficulties in its recovery. Among removal methods adsorption technique for the removal of phenol has significant advantages such as high efficiency, low cost, easy handling, and flexibility in design. Adsorption processes using activated carbon, ion-exchange processes, and solid extraction processes, have also been tried with highly efficient removal, however, they have problems of desorption, and their continuous operation is difficult [15].

In recent years, advanced oxidation process (AOP's) in which highly reactive radicals are generated have been increasingly applied for degradation of various classes of organic compounds. Advance oxidation process are based on formation of highly reactive hydroxyl radical species which act as an oxidant for the mineralization of target compounds present in aqueous solution. Lignite activated coke (LAC), assisted sludge (AS) process has also been developed and can be used for enhancing biodegradation of phenol [1].

Hydrodynamic cavitation is also one of the best water treatment processes. In cavitation the phenomenon of sequential formation growth and collapse of the millions of microscopic vapour bubbles in liquid. Hydrodynamic cavitation has been shown to be effective to produce highly reactive free radicals due to creation of high temperature and pressure and generation of intense turbulence and liquid circulation current. Few other techniques is based on extraction principles and experimental results, an extracting solvent was selected in consideration of phenol removal, solvent recovery and COD removal for the coal-gasification wastewater. The extraction process conditions were studied, and a flow sheet for phenol removal was proposed. An on-site trial-plant of 2 t/h wastewater was set up for testing and industrial verification. The results of the on-site trials showed that more than 93% of the phenols and 80% of COD in the wastewater were removed. The operating cost of the proposed process was approximately balanced by the economic return of the recovered phenols [13].

II. LITERATURE REVIEW

Hydrodynamic cavitation (HC) is a process where cavities form and collapse within a liquid flow, induced by pressure variations through geometric constrictions such as orifice plates, venturi tubes, or throttling valves. Moholkar [1] explained that the principle behind HC reactors is based on the Bernoulli equation, where changes in kinetic energy led to pressure drops, causing cavitation when local pressure falls below the vapor pressure of the liquid. These cavities collapse violently, generating intense turbulence and high energy, influencing various chemical and biological processes.

Arrojo et al. [2] explored HC's potential for bacterial disinfection, finding that mechanical disruption, rather than chemical oxidation, played a dominant role in E. coli cell disruption during cavitation. Montusiewicz et al. [3] demonstrated HC's ability to enhance the biodegradability of brewery spent grains (BSG), with improvements in the BOD/COD ratio and solubilization of carbohydrates, showing HC's potential in wastewater treatment.

Gogate [4] reviewed acoustic cavitation, where ultrasound generates pressure oscillations leading to cavitation bubbles that produce both physical and chemical effects, such as free radicals and intense turbulence. Similarly, Ozonek [5] and Gogate & Pandit [6] highlighted the role of cavitation in creating high-temperature and pressure conditions that enhance chemical reactions.

Combining HC with advanced oxidation processes (AOPs) has shown significant improvements in the degradation of organic pollutants. For example, Gogate and Patil [7] combined HC with Fenton's reagent to degrade triazophos, achieving 83.12% degradation under optimized conditions. Litwinienko et al. [8] confirmed the bactericidal activity of HC, noting its effectiveness in eliminating microorganisms through shockwaves and hydrogen peroxide generation.

HC's efficiency was further studied by Sivakumar and Pandit [9], who compared HC with acoustic cavitation for dye degradation, finding HC to be more energy efficient. Kalmuck and Chahine [10] observed similar results in the degradation of p-nitrophenol, where HC outperformed ultrasonic systems in terms of degradation rate.

Several studies have focused on the combination of HC with other methods to enhance treatment efficiency. For example, Bagel and Gogate [12] combined HC with Fenton and advanced Fenton processes to achieve near-complete

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degradation of 2,4-dinitrophenol. Similarly, Raut-Jadhav et al. [14] investigated the use of HC combined with H2O2 and ozone for treating pesticide effluent, reporting significant reductions in COD and TOC.

Saxena et al. [16] found that HC combined with alum coagulation improved mineralization and biodegradability in tannery waste effluent. Thanekar et al. [17] demonstrated that HC, when paired with ozone, significantly enhanced the degradation of dichlorvos, improving treatment efficiency compared to HC alone.

In conclusion, HC has proven to be a highly effective method for treating various types of wastewaters, particularly when combined with other processes such as AOPs, coagulation, and ozone. The studies reviewed highlight its potential in industrial applications, particularly for organic pollutant degradation, disinfection, and improving biodegradability in wastewater treatment.

III. METHODOLOGY OF PROPOSED SURVEY

Hydrodynamic cavitation is generated using an in-house constructed unit term a Hydrocavitator which has a feed vessel tank with maximum capacity of 10L and operates in re-circulation mode. Effluent from the feed tank is pumped using the pump and passes through an orifice unit and finally back to the feed tank. An external ice bath is used to control the temperature in feed vessel tank, which is necessary as cavitations results in production of heat thereby increasing the temperature of the effluent stream.

The present work aims at modelling the magnitude of the pressure pulse generated at the time of collapse of the cavity. The collapse pressure will be dependent on the number of operating and geometrical conditions existing in the reactor, such as the inlet pressure, flow area of the orifice diameter of the hole and the number of holes, and initial radius of the nuclei.

The experimental setup is shown in Fig. The setup includes a holding tank of 10 litter volume, a centrifugal pump (2900 rpm, 1.5 kW,), control valve (V), flanges to accommodate the orifice plate and a mainline. The mainline consists of a flange which houses the orifice plate, and a hard glass tube is next to the flange for visual observation.
Mainline terminate well inside the tank below the liquid level to avoid any induction of air into the liquid due to the plunging liquid jet.

The control valves are provided at appropriate places to control the flow rate through the mainline. The inside diameter of the delivery line of the centrifugal pump is 38 mm. Hydrodynamic cavitation reactor setup.

Multiple-hole orifice plates are considered in the present study. Two plates of different geometries have been used to study the cavitational effect of hydrodynamic cavitation. All the plates are made up of stainless steel (SS316). During experimentation, valves V1 and V2 are always kept fully open.

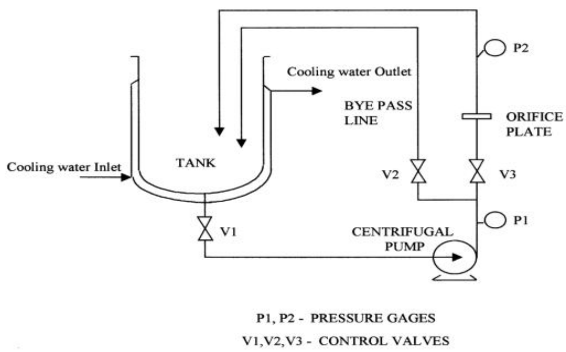

Figure 1. Schematic Diagram of Set up

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1. Effect of Cavitating Device Geometry

a. Plate 1

Size – 1.5 mm multiple holes
No. of Holes – 17
β ratio - 0.061
Initial COD = 968 mg/lit
Results –

Inlet Pressure Bar	Outlet Pressure Bar	Flow Rate Lit/Sec	Orifice Velocity m/sec	Cavitational Number Cv	After COD Mg/Lit	% Reduction in COD
2	0.1	0.172	5.74	0.280165148	816	15.7
3	0.65	0.22	7.4	1.713771984	744	23.1
4	0.59	0.285	9.52	0.933631371	560	42.1
5	0.8	0.33	11.1	0.948973922	392	59.5
6	0.9	0.454	15.15	0.576447591	440	54.5
7	1.1	0.53	17.83	0.512967467	496	48.8

Table 1. Results for Plate 1

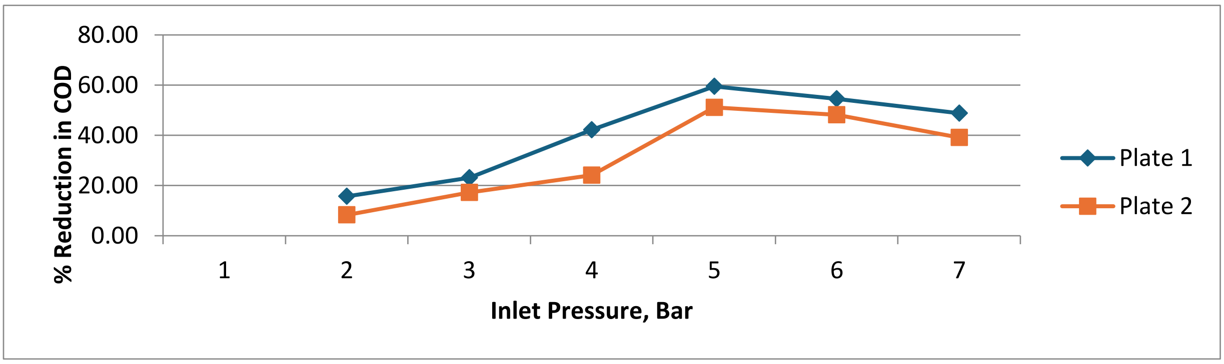
b. Plate 2

Size – 2 mm
No. of Holes – 1
β ratio - 0.006
Initial COD = 1064 mg/lit
Results-

Inlet Pressure Bar	Outlet Pressure Bar	Flow Rate Lit/Sec	Orifice Velocity m/sec	Cavitational Number Cv	After COD Mg/Lit	% Reduction in COD
2	0.6	0.172	5.74	2.614874715	976	8.27
3	0.65	0.22	7.4	1.713771984	880	17.29
4	0.6	0.285	9.52	0.950606487	808	24.06
5	0.8	0.33	11.1	0.948973922	520	51.13
6	0.9	0.454	15.15	0.576447591	552	48.12
7	1.1	0.53	17.83	0.512967467	648	39.10

Table 2. Results for Plate 2

Graph 1. Inlet Pressure v/s % Reduction in COD



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From above calculations it is found that plate 1 with multiple holes with small diameter yielded maximum efficiency as compared to other plate. The reason behind this is enhanced cavitational activity occurred due to more shear force witnessed by liquid generating large number of small cavities and its subsequent collapse.

2. Effect of PH

a. 4 pH solution (150 ppm) (Pressure = 3 kg/cm2, Temperature = 30 ˚C)

Result-

Time	Burette Reading (ml)	COD mg/lit	% Reduction in COD
0	8.2	1056	
1	9.7	996	5.68
2	10.9	948	10.23
3	11.6	920	12.88
4	13.1	860	18.56

Table 3. Results for 4 pH Solution

b. 6.8 pH solution (150 ppm) (Pressure = 3 kg/cm2, Temperature = 30 ˚C)

Result-

Time	Burette Reading (ml)	COD mg/lit	% Reduction in COD
0	8.3	940	
1	13.8	720	23.4
2	15.3	660	29.78
3	15.8	640	32
4	16.7	603	35.8

Table 4. Results for 6.8 pH Solution

c. 8 pH solution (150 ppm) (Pressure = 3 kg/cm2, Temperature = 30 ˚C)

Result-

Time	Burette Reading (ml)	COD mg/lit	% Reduction in COD
0	13.8	1016	
1	14.9	888	12.5984252
2	15.8	851	16.24015748
3	16.5	797	21.55511811
4	17.1	756	25.59055118

Table 5. Results for 8 pH Solution

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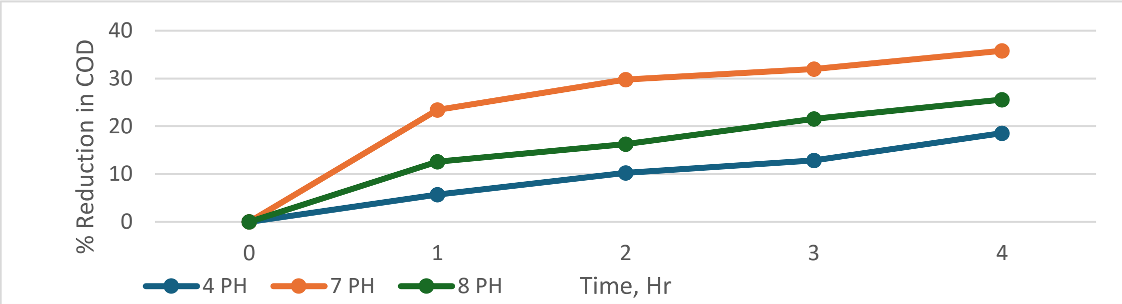

Graph 2. pH v/s % Reduction in COD

When the sample to be treated is maintained at the 4 pH. The total reduction in COD after 4 hours was about 18.56%. When the sample to be treated is maintained at the 8 pH. The total reduction in COD after 4 hours was about 25.6%. But at neutral pH the % reduction in COD was maximum i.e. 35.8%. It is very much clear that the reduction in COD is not favourable in both acidic and basic medium.

3. Effect of adding Hydrogen Peroxide (H_2O_2)

The purpose of adding hydrogen peroxide is that when it passed through cavitating device it gets degrade and produce OH- ions.

$$H_2O_2 \xrightarrow{\text{Cavitation}} 2OH \quad (1)$$

$$OH + OH \longrightarrow H_2O_2 \quad (2)$$

$$OH + H_2O \longrightarrow H_2O^{O} + H_2O \quad (3)$$

a. 10 ml H2O2 in 150 ppm solution (Pressure = 3 kg / cm2, Temperature = 30˚C)

Result-

Time	Burette Reading (ml)	COD mg/lit	% Reduction in COD
0	14.2	944	
1	14.9	888	5.93
2	15.6	832	11.86
3	16.3	776	17.80
4	16.9	728	22.88

Table 6. Results for 10 ml H_2O_2 Solution

b. 5 ml H2O2 in 150 ppm solution (Pressure = 3 kg / cm2, Temperature = 30˚C)

Result-

Time	Burette Reading (ml)	COD mg/lit	% Reduction in COD
0	12.8	936	
1	16.6	640	31.62
2	17	600	35.90
3	17.6	552	41.03
4	19.6	392	58.12

Table 7. Results for 5 ml H_2O_2 Solution

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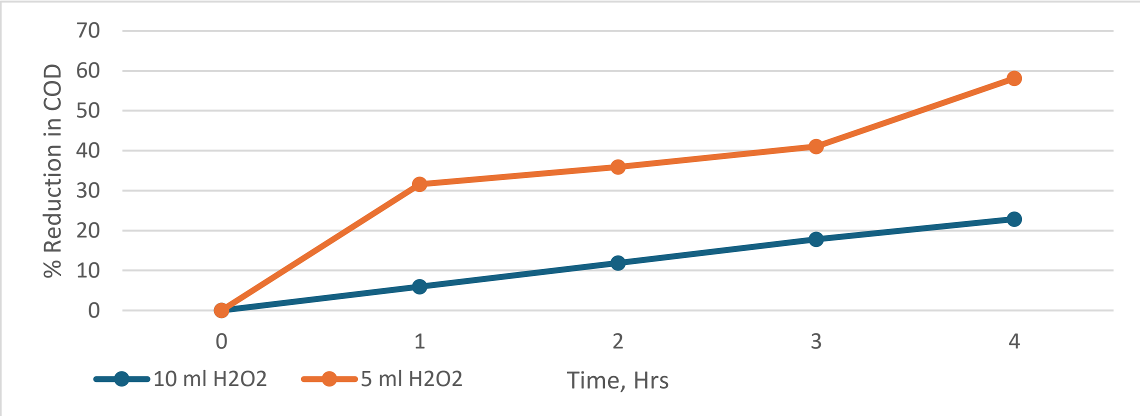
Graph 3. Time v/s % Reduction in COD



From above calculation it is clear that the addition of hydrogen peroxide increases the reduction of COD value. But when the hydrogen peroxide is used in the excess amount the reverse reaction takes place.

IV. CONCLUSION AND FUTURE WORK

From the above study and calculation, it is clearly seen that hydrodynamic cavitation is effective and can be used for treating wastewater. The efficiency of the hydrodynamic cavitation found to be dependent on the geometry of the cavitating device and operating parameters (inlet pressure). It is observed that a continuous reduction in COD is taking place as time increases. It has been observed that as pressure is increased the cavitation increases and COD decreases. It is also observed that the reduction in COD is more when pH is kept neutral. Also, when hydrogen peroxide is added we obtained better reduction.

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