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REMOVAL OF PHENOL FROM INDUSTRIAL WASTEWATER EFFLUENT BY USING HYDRODYNAMIC CAVITATIONS

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Abstract- Phenol and phenolic compounds are common organic contaminants in air and wastewater, which are released into the environment from various industrial activities such as petrochemical and pharmaceutical processes. Phenol is classified as hazardous pollutants because of its potentials harm to human health. Thus, the removal of phenolic compounds from wastewater is very much essential. The industrial effluent which is handled contains hazardous chemicals like phenol etc. which make the water toxic and increase its COD by 60000-70000 mg/liter. For the eco-friendly discharge of this effluent, this effluent must be treated and the COD value must be reduced. So, the removal of phenol from effluent is studied by hydrodynamic cavitation. Hydro-dynamic cavitation is a very efficient and convenient method of separation. In which pressure is varied by passing the liquid through a specified geometry of construction such as orifice plate and venturi. This method is preferred over all other methods because it is one of the cheapest energy efficient method and scales up of the method is easy.
Keywords: Phenolic effluent, Chemical oxygen demand (COD), hydro-dynamic cavitation, toxic.

1. INTRODUCTION

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

Since phenol is classified as toxic and most serious pollutant regarding its damage to human health and aquatic life due to its toxicity even at low concentration. Chronic toxic effect of phenol on human health includes vomiting, difficulties in swallowing, liver and kidney damage and other disturbances. Not only on human health, but these industrial wastes are also a critical environmental issue due to their harmful threats to wildlife and aquatic life.

The world health organization recommends the permissible phenolic concentration of 0.001 mg/lit in potable water. The effective removal of organic contaminants from waste effluent is considered as a challenge of increasing interest. Several water treatment techniques such as liquid-liquid extraction, ozonation, adsorption, activated sludge process, chemical oxidation, and hydrodynamic cavitation are used for removal of these pollutants from wastewaters, by non-toxic materials and eco-friendly technologies have been considerable interests.

The phenol in various effluent is often removed by liquid-liquid extraction by using different solvents like MIBK, Acetone, but the process has difficulty in recovery of solvents. The solvents need to be recovered by distillation process which makes the separation process expensive and time-consuming. The other process used to remove phenol from various effluent is by a biological process such as activated sludge process and chemical oxidation processes, these processes have difficulties in its recovery. Adsorption processes using activated carbon, ion exchange process can be used with highly efficient removal however they have the problem of desorption and their continuous operation is difficult.

Among them, the use of hydrodynamic cavitation technique for removal of phenol has significant advantages due to its simple experimental setup and ease of handling. It is also very economical because it does not include any addition of extracting solvents.

Cavitation is the formation and then immediate implosion of cavities in a liquid – i.e. small liquid-free zones ("bubbles") that are the consequence of forces acting upon the liquid. It usually occurs when a liquid is subjected to rapid changes of pressure that cause the formation of cavities where the pressure is relatively low.

Cavitation is a significant cause of wear in some engineering contexts. When entering high-pressure areas, cavitation bubbles that implode on a metal surface cause cyclic stress. This results in surface fatigue of the metal causing a type of wear also called"cavitation"[1], [2].

1.1 Types of cavitation

Cavitation is the phenomenon of sequential formation, growth, and collapse of millions of microscopic vapor bubbles (voids) in the liquid. The collapse or implosion of these cavities creates high localized temperatures roughly of 14000 K and a pressure of about 1000 atm or results into short-lived, localized hot–a spot in cold liquid.

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Thus, cavitation serves as a means of concentrating the diffused fluid energy locally and in very short duration, creating a zone of intense energy dissipation.

The method of energy efficiently producing cavities of the desired quality (a type of dynamic behavior) can be taken as the main criterion in distinguishing among different types of cavitation. The four principal types of cavitation and their causes can be summarized as follows:

1. Acoustic cavitation: In this case, the pressure variations in the liquid are effected using the sound waves, usually ultrasound (16 kHz–100 MHz). The chemical changes taking place due to the cavitation induced by the passage of sound waves are commonly known as sonochemistry.
2. Hydrodynamic cavitation: Cavitation is produced by pressure variations, which is obtained using the geometry of the system creating velocity variation. For example, based on the geometry of the system, the interchange of pressure and kinetic energy can be achieved resulting in the generation of cavities as in the case of flow through the orifice, venturi, etc.
3. Optic cavitation: It is produced by photons of high-intensity light (laser) rupturing the liquid continuum.
4. Particle cavitation: It is produced by the beam of the elementary particles, e.g. a neutron beam rupturing a liquid, as in the case of a bubble chamber.

Out of these four types of cavitation, only acoustic and hydrodynamic cavitation generates desired intensity suitable for chemical or physical processing.

2. LITERATURE SURVEY

The heavily industrial world we live in today continues to generates 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 [3]. 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 [4].

Phenol and phenolic compounds (aromatic compounds) represent a significant group of pollutants present in waste-water resulting from manufacturing of pesticides, herbicides, pharmaceuticals , dyes , etc. [3]. Also, the presence of trace amounts of these compounds has restricted the reuse of water in different industrial applications [4]. The world health organization recommends the permissible phenolic concentration to 0.001 mg/ltr in potable water and regulation by environment protection agency has set a phenol concentration less than 1 mg/ltr in the industrial effluent for safe discharge to surface water [5]. 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 [6] , using a parabolic trough collector (PTC) photo catalysis system [7], and reverse osmosis (RO) has been successfully utilized in several industrial processes [4].

There are other conventional methods that we still employed in the treatment of waste water 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 phase's [7]. The phenol is removed by biological processes such as activated sludge process, chemical oxidation processes these process have difficulties in its recovery [8]. 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 [5], [9].

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 [10]. 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 [11]. Lignite activated coke (LAC) , assisted sludge (AS) process has also been developed and can be used for enhancing biodegradation of phenol [12].

Hydrodynamic cavitation is also one of the best water treatment process. In cavitation the phenomenon of sequential formation growth and collapse of the million of microscopic vapor bubbles in liquid. Hydrodynamic cavitation has been shown to be effective for the production of highly reactive free radicals due to creation of high temperature and pressure and generation of intense turbulence and liquid circulation current[11]. 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].

Going through all the processes used to separate phenol from water, it is observed that hydrodynamic cavitation is one of the best methods for separation process because of having easy experimental setup a well as easy procedure. This method is energy efficiently producing cavities of a desired quality (type of the dynamic behavior) can be taken as the main criterion in distinguishing among different types of cavitation. It is also very economical because it does not include any addition of extracting solvents.

3. PROPOSED METHODOLOGY

Materials

i. Phenolic effluent(sample)
ii. orifice plate
iii. Hydrogen Per-Oxide(H2O2)

Hydrodynamic cavitation can simply be generated by the passing of the liquid through a specified geometry of constriction such as orifice plates, venturi, etc. When the liquid passes through the constriction, the kinetic energy of the liquid is increasing at an expense of the pressure.

Cavitation is generated using an in-house constructed unit term as Hydrocavitator which has a feed vessel tank 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 the feed vessel tank, which is necessary as cavitations result in the production of heat thereby increasing the temperature of the effluent stream.

The present work aims at modeling the magnitude of the pressure pulse generated at the time of the 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, the flow area of the orifice diameter of the hole and also the number of holes, and initial radius of the nuclei.

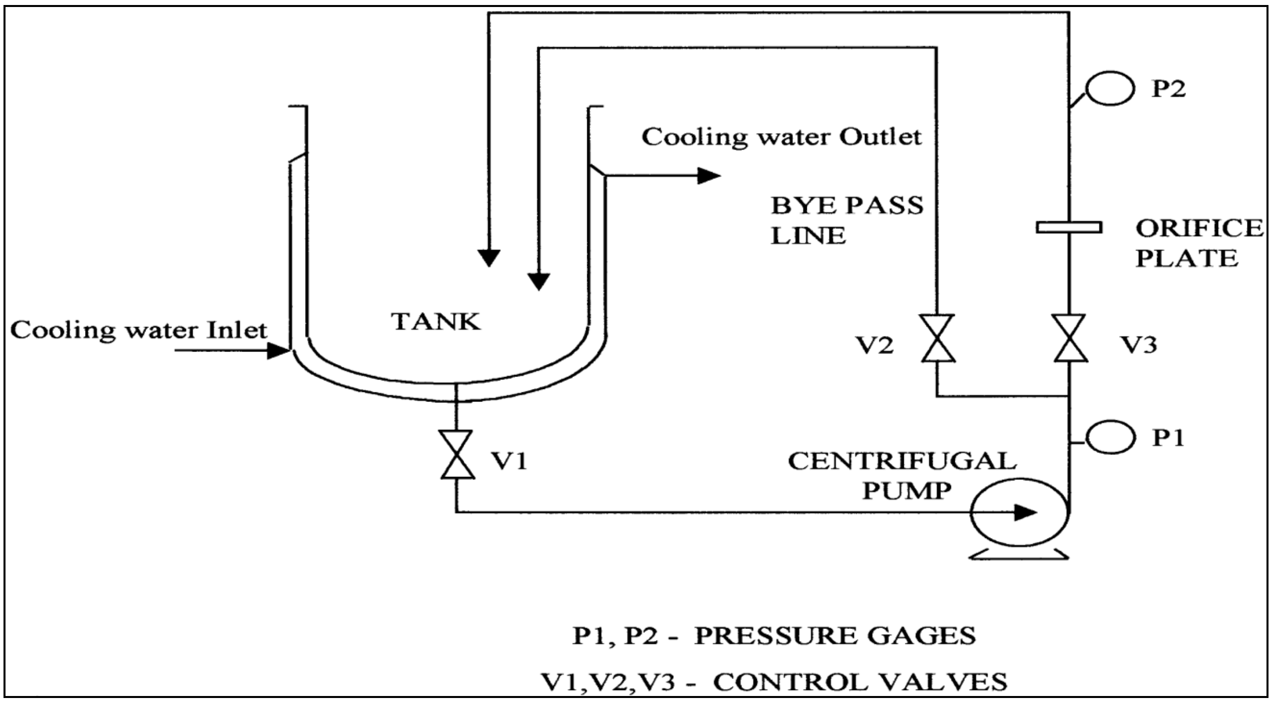

Figure 1.Schematic diagram of set up.

4. EXPERIMENTAL SETUP

The experimental setup is shown in Fig. The setup includes a holding tank of 10-liter volume, a centrifugal pump (2900 rpm, 1.5 kW), control valves (V1, V2, V3), flanges to accommodate the orifice plate, a mainline and a bypass line. The discharge branches into two lines; the mainline and the bypass line. The mainline consists of a flange which houses the orifice plate and a hard glass tube are next to the flange for visual observation.

The bypass line is provided to control the liquid flow through the mainline. Both the mainline and the bypass line terminate well inside the tank below the liquid level in order to avoid any induction of air into the liquid due to the plunging liquid jet.

The control valves (V1, V2, V3,) 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. Plates are made up of stainless steel (SS316). The diameter of each plate is 40 mm. During experimentation, valves V1 and V2 are always kept fully open, while initially bypass valve V3 is kept fully open. ValveV3 was then partially throttled to keep the inlet pressure to a fixed value.

5. RESULT AND DISCUSSIONS

5.1 Effect of changing the concentration of phenol

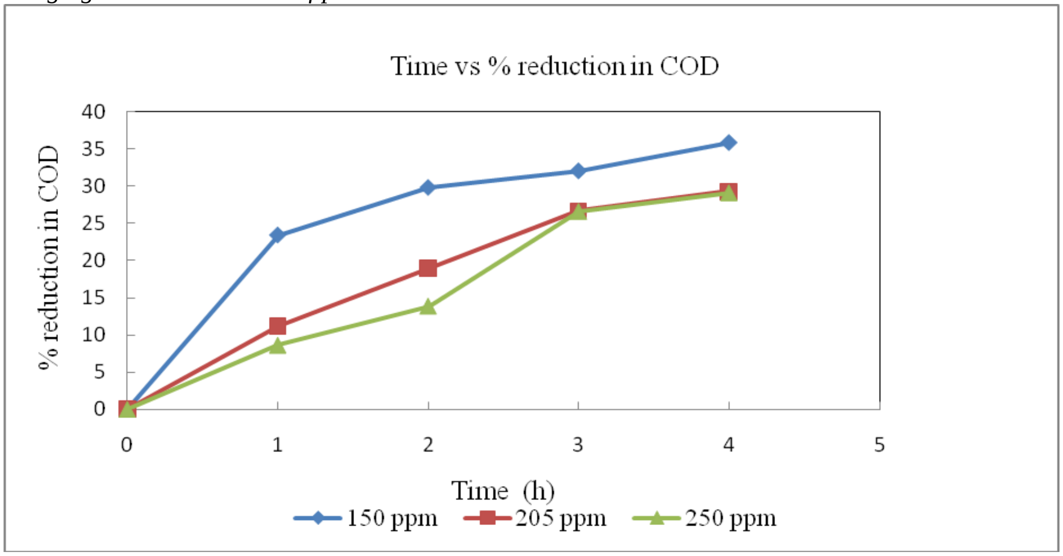

Figure 2.Effect of changing concentration of phenol

i. At 150 ppm

The total reduction in COD after 4 hours at pressure 3 kg/cm2was about 35.8 percent.

ii. At 205 ppm

The total reduction in COD after 4 hours at pressure 3 kg/cm2was about 29.31 percent.

iii. At 250 ppm

The total reduction in COD after 4 hours at pressure 3 kg/cm2 was about 29.1 percent.

Above graphs shows that the process of hydrodynamic cavitation is more beneficial at lower concentration of phenol. But there is not that much significant difference in reduction percentage if we increase the concentration. So it is clear that we can use Hydrodynamic cavitation for degrading the phenol and decreasing the COD value of the effluent.

5.2 Effect of changing pH

Initially the sample was approaching as Neutral solution that is it is having pH of 6.8, and at this pH the reduction was more than 30 percent. But when the pH value of sample is changed the following results where obtained at pressure 3 kg/cm2.

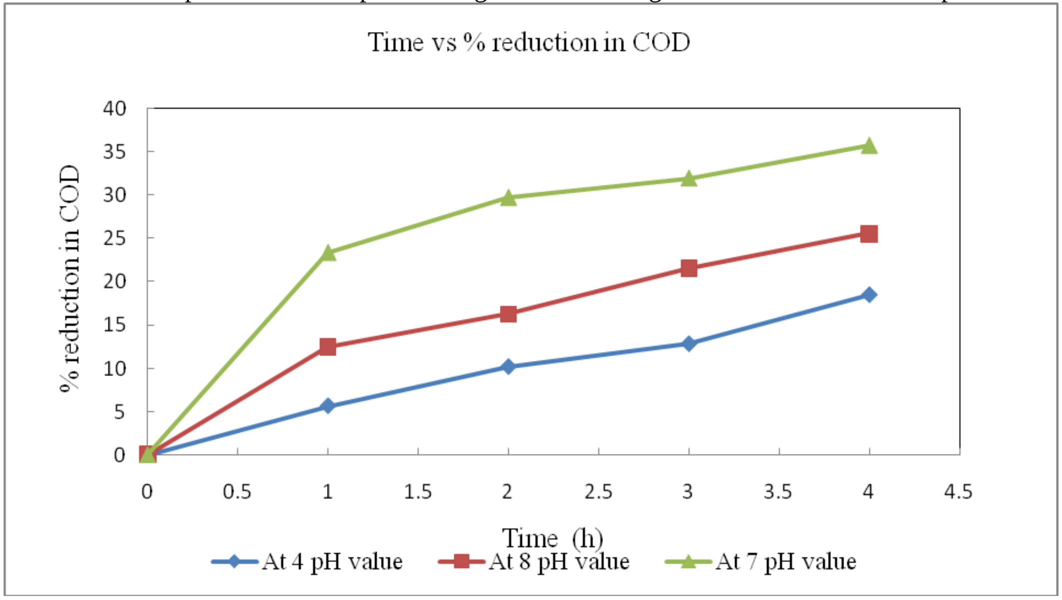

Figure 3.Effect of changing pH of sample

When the sample to be treated is maintained at the pH equals 4. That is H2SO4 is added to make it Acidic the following results are obtained. The total reduction in COD after 4 hours was about 18.56 percent.
When the pH equals 8 that is NaOH is added to make it Basic the following results are obtained. The total reduction in COD after 4 hours was about 25.6 percent.
From above calculations it is very much clear that the reduction in COD is not favorable in both Acidic or Basic medium.

5.3 Effect of adding hydrogen peroxide(H2O2)
The purpose of adding hydrogen peroxide is that when H2O2 is passed through cavitating device it gets degrade and produces OH- ions.
The reactions are as follows

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

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

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

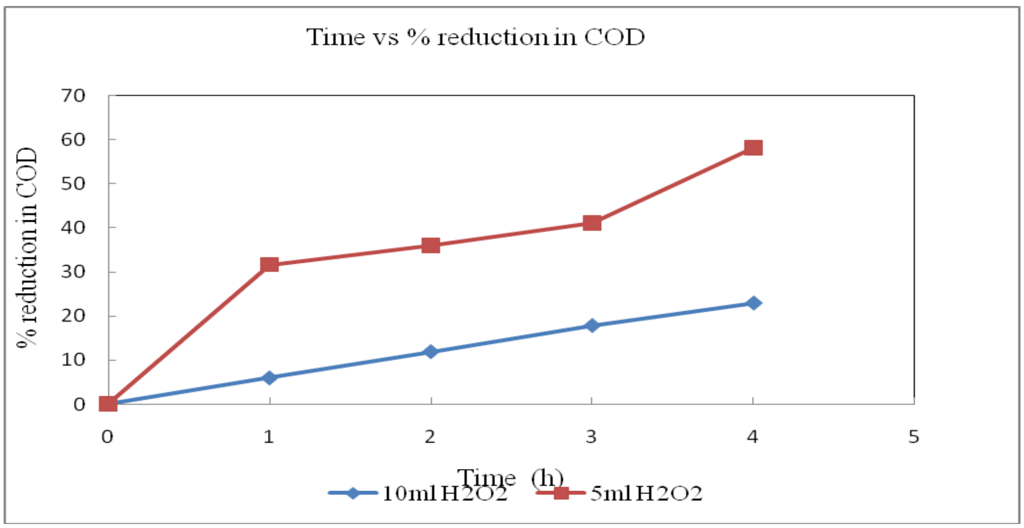

Figure 4.Effect of adding different volumes of H2O2

10 ml H2O2 in 150 ppm solution
The total reduction in COD after 4 hours was about 22.8 percent.
5 ml H2O2 in 150 ppm solution
The total reduction in COD after 4 hours was about 58.11 percent.

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 excess amount the reverse reaction takes place. That is the reaction number 3 mentioned above begins.

6. CONCLUSION

From the above study and calculation it is clearly seen that hydrodynamic cavitation is effective and can be used for treating waste water. 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 is 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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