Acoustic cavitation Coupled with Advance Oxidation Process for Treatment of Dairy Industry Wastewater

Yogendra D. Thakare¹, Kishor S. Wani²
¹Research Scholar, SSBT’s College of Engineering & Technology, Bambhori, Jalgaon, MS, India
²Professor and Principal, SSBT’s College of Engineering & Technology, Bambhori, Jalgaon, MS, India

ABSTRACT: - This paper investigates the reduction of COD of dairy industry waste water by individual and combined process of acoustic cavitation, H₂O₂, Fenton and Photo Fenton process. All experiments were performed on a laboratory scale setup. The effect various parameters such as sonication power, duty cycle, initial pH, hydrogen peroxide concentrations and Fenton reagents on the reduction of COD of dairy waste water have been assessed. Effective system conditions were found to be sonication power of 800W, duty cycle of 60 %, pH of 3, 200 µL/L of hydrogen peroxide concentration and 78 mg/L of Fenton reagents. The results show that the % of COD reduction of dairy industry waste water after 180 min reaction time follows the decreasing order: Acoustic Cavitation + Photo Fenton Process (88.78 %) > Acoustic Cavitation + Fenton Process (66.22 %) > Acoustic Cavitation + H₂O₂ (40.02 %) > Acoustic Cavitation (13.53 %).


1. INTRODUCTION

Among the food industries, the dairy industry is the most polluting in volume in regards to its large water consumption. Water is used throughout all steps of the dairy industry including cleaning, sanitization, heating, cooling and floor washing and naturally the requirement of water is massive [1]. In the dairy industry, starting, equilibrating, interrupting and stopping any of the processing units generate large volumes of effluent [2]. Dairy wastewater generally does not contain conventional toxic chemicals like those listed under EPA’s Toxic Release Inventory. However, it has high concentration of dissolved organic components like fats, oils and grease, nutrients such as ammonia or minerals and phosphates and therefore require proper attention before disposal[3].

In Advance Oxidation Processes (AOPs) oxidation is based on intermediate reactions in which the hydroxyl radical (HO•) is present. These processes are able to degrade a large number of organic compounds by reduction–oxidation and free-radical reactions to carbon dioxide (CO₂) and water (H₂O). Advanced oxidation
processes (AOP) such as Acoustic cavitation, Fenton and Photo Fenton process are useful for the treatment of high initial concentration of COD [4]. The sonochemical effect is cavitation phenomena based on ultrasound interaction with aqueous liquid medium, when ultrasound passed through the liquid medium cycles of compression and rarefaction are developed. These cycles induce the cavitation bubble which expands and compresses before the collapse at million locations in the reactor. The higher temperature (4000–5000 K) and pressure (1000–50,000 bars) conditions reach inside the bubble cavity before collapsing. These conditions are highly useful for enhancing the rate of chemical processing. During cavitation cycle, reactions are occurring at the three zones: (a) inside the cavity of the bubble, (b) at the interface of gas–liquid, and (c) radicals generated after the collapse of the cavity [5,6]. The application of ultrasound alone is not efficient for the degradation of the target organic pollutant because of the fact that the ultrasound alone requires more time and high amount of energy for an acceptable degradation [7,8].

When applied individually cavitation often gives lower rates of the degradation, but the efficiency of cavitation can be significantly enhanced by combining it with other advanced oxidation processes (AOP) such as Fenton [9,10] and Photo Fenton [11,12]. Combination of acoustic cavitation with other AOPs often leads to an intensification of the degradation of organic pollutants due to the enhanced generation of the hydroxyl radicals [13].

The present work deals with the study of reduction of COD of dairy industry waste water by using Acoustic cavitation and Acoustic cavitation based hybrid techniques such as Acoustic cavitation + Fenton and Acoustic cavitation + Photo Fenton process and also to study the effect of key operating conditions on the reduction of COD of dairy industry waste water.

2. MATERIALS AND METHODS

2.1 Materials

Raw wastewater was collected from local dairy industry, Jalgaon, Maharashtra, India at an interval of 15 days and stored in the refrigerator at 4°C, in order to maintain its characteristics throughout the research.

2.2 Chemicals and reagents

Hydrogen peroxide (30% W/V H₂O₂), Ferrous sulfate heptahydrate (FeSO₄ .7H₂O), Sulfuric acid (H₂SO₄) and Sodium hydroxide (NaOH) etc. of S. D. fine were purchased from the local supplier, Jalgaon, India. All reagents and chemical were used as received from vendors without any purification or further treatment.
2.3. Methods

2.3.1 Characterization of dairy industry waste water

pH, Turbidity, Conductivity, Hardness, COD, BOD, TDS and TSS of dairy industry waste water were determined using APHA, Standard Methods for the Examination of Water and Waste-Water [14].

2.3.2 Cavitation Reactor

The cavitation reactor (Figure 1) used in the present study was an ultrasonic horn manufactured by Johnson Plastosonic Pvt. Ltd., Pune. Ultrasonic processor was operated at a constant frequency of 20 kHz with maximum power 800W. The height of the ultrasonic horn was adjusted using metal stand in such way that the tip of the probe was immersed 2 cm inside the liquid. The source of UV radiations were four UV lamps emitting light of 8 Watt at wavelength 254 nm, manufactured by Phillips Company. UV lamps were placed parallel to the each other at the top of photolytic reactor. UV lamps were cooled with fan incorporated in setup. At the beginning of the treatment, 400 ml of dairy industry waste water taken in a glass beaker was put up on the stand to adjust height of the beaker and then ultrasonic processor and UV light was immediately turned on, that accounted for time = 0; i.e. the start of the reaction. The effect of different process parameters like sonication power (200, 400, 600 and 800 Watts), duty cycle (80%, 60%, 40% and 20%), pH (3, 6.5, and 9), H$_2$O$_2$ loading (50, 100, 150, 200 and 150 µl/L) and Fenton reagent (FeSO$_4$.7H$_2$O at optimum H$_2$O$_2$ concentration) loading (26, 39, 52, 65 and 78 mg/L) were determined at constant operating temperature of 28 ± 3 °C and 20 kHz constant sonication frequency.

![Figure 1. Experimental Setup of Acoustic cavitation](image-url)
2.3.3. Analysis

Required amount of sample dairy industry waste water were taken from the reactors at regular time intervals and analyzed for Chemical Oxygen Demand (COD). It was determined by APHA, Standard Methods for the Examination of Water and Waste-water [14].

3. RESULTS AND DISCUSSION

3.1 Characterization of dairy industry waste water

The main characteristics of the dairy industry effluent used in this work were presented in Table 1.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>pH</td>
<td>6.5</td>
</tr>
<tr>
<td>2</td>
<td>Turbidity</td>
<td>12 NTU</td>
</tr>
<tr>
<td>3</td>
<td>Hardness</td>
<td>640 ppm</td>
</tr>
<tr>
<td>4</td>
<td>COD</td>
<td>900 ± 50 mg/L</td>
</tr>
<tr>
<td>5</td>
<td>BOD</td>
<td>580 mg/L</td>
</tr>
<tr>
<td>6</td>
<td>TDS</td>
<td>1922 mg/L</td>
</tr>
<tr>
<td>7</td>
<td>TSS</td>
<td>651 mg</td>
</tr>
</tbody>
</table>

3.2 Calculation of Percentage of Reduction of COD

The percentage of reduction of COD of dairy industry waste water was calculated according to equation.

\[
\text{% of COD Reduction} = \left( \frac{\text{COD}_0 - \text{COD}_t}{\text{COD}_0} \right) \times 100
\]

COD0: initial COD of the dairy industry waste water (mg/l)
CODt: COD of the dairy industry waste water after time ‘t’ (mg/l)

3.3 Acoustic Cavitation

3.3.1. Effect of sonication power on the reduction of COD of dairy industry waste water

The effect of sonication power on reduction of COD was studied at different operating powers (200, 400, 600 and 800 Watts) with 400 ml of dairy industry waste water, pH 6.5, 60 % duty cycle, at constant operating temperature of 28 ± 3 °C and 20 kHz sonication frequency. Sonication was carried out for 180 minutes. Figure 2 shows the effect of sonication power on reduction of COD of dairy industry waste water at different operating powers (200, 400, 600 and 800W) using acoustic cavitation.
Figure 2. Effect of sonication power on the reduction of COD of dairy industry waste water

It has been observed that the reduction of COD of dairy industry waste water increases with an increase in the operating power. The maximum COD reduction was observed at power dissipation of 800 W whereas minimum COD reduction was observed at power dissipation level of 200 W. The increase in % of COD reduction of dairy industry waste water with increasing power can be due to the enhancement in the number of cavities leading to higher cavitation activity and hence enhanced production of the hydroxyl radicals [15].

Table 2 shows the effect of sonication power on the % of COD reduction of dairy industry waste water using acoustic cavitation. It has been observed that as sonication power is increased from 200 W to 800 W and % of COD reduction of dairy industry waste water increases from 3.15 % to 10.11 %. Thus 800 W sonication power was considered as optimum for further studies.

Table 2. Effect of sonication power on the % of COD reduction of dairy industry waste water

<table>
<thead>
<tr>
<th>Process</th>
<th>Power (Watts)</th>
<th>% of COD Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustic Cavitation</td>
<td>200</td>
<td>3.15</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>5.95</td>
</tr>
<tr>
<td></td>
<td>600</td>
<td>7.50</td>
</tr>
<tr>
<td></td>
<td>800</td>
<td>10.11</td>
</tr>
</tbody>
</table>

3.3.2. Effect of duty cycle on the reduction of COD of dairy industry waste water

The effect of different duty cycles (20%, 40%, 66% and 80%) on the treatment of dairy industry wastewater was investigated by varying ON and OFF time of ultrasonic irradiation. These experiments were conducted for 400 ml dairy industry waste water, sonication power 800 W, constant temperature of 28 ± 3 °C,
constant sonication frequency 20 kHz for 180 minutes of time. Figure 3 shows the effect of duty cycle on reduction of COD of dairy industry waste water.

![Figure 3. Effect of duty cycle on the reduction of COD of dairy industry waste water](image)

Table 3 shows that the % of COD reduction of dairy industry wastewater increased from 3.22% to 11.46% with an increase in duty cycle from 20% to 80%. The increase in % of COD reduction of dairy waste water due to increase in the time of exposure to the sound wave more is attributed to the bubble formation and implosion more is the reduction. But, operating the ultrasonicator for long period of time (ON time) is not recommended due to excessive heating and also it may creates problem to transducers [16,17]. Additionally, only marginal increase of % COD of reduction of dairy waste water was observed at 80% duty cycle and thus accordingly 60% duty cycle was set as optimum duty cycle.

![Table 2. Effect of duty cycle on the % of COD reduction of dairy industry waste water](image)

3.3.3. The effect of pH on the COD reduction of dairy industry waste water

Initial pH is an important parameter influencing the treatment efficiency waste water. In this study, in order to investigate the effects of pH on reduction of COD of dairy industry waste water using acoustic
cavitation, experiments were conducted at different pH values 3, 6.5 and 9. These experiments were conducted for 400 ml dairy industry waste water, sonication power 800 W, 60 % duty cycles, constant temperature of 28 ± 3 °C, constant sonication frequency 20 kHz for 180 minutes of time. Figure 3 shows the effect of pH on the reduction of COD of dairy industry waste water using acoustic cavitation.

![Figure 3. Effect of pH on the reduction of COD of dairy industry waste water](image)

Table 3 shows that the % of COD reduction of dairy industry waste water is very rapid under acidic pH 3, 13.53 % reduction of COD of dairy industry waste water was obtained. At lower pH (acidic), the oxidation capacity of hydroxyl radicals is high and generates the maximum amount of hydroxyl radical to oxidize organic compounds [18]. The value of pH is one of the crucial factors affecting the performance of the Fenton-like process. The activity of Fe(OH)⁺ in Fenton’s and photo- Fenton’s reaction and the decomposition of H₂O₂ in acidic medium was found to be very fast in producing hydroxyl radical (OH*) [19,20]. Thus pH 3 was considered as optimum pH for further studies.

**Table 3. Effect of pH on the % of COD reduction of dairy industry waste water**

<table>
<thead>
<tr>
<th>Process</th>
<th>pH</th>
<th>% of COD Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustic Cavitation</td>
<td>3</td>
<td>13.53</td>
</tr>
<tr>
<td></td>
<td>6.5</td>
<td>10.11</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>12.56</td>
</tr>
</tbody>
</table>
3.4 Acoustic cavitation + H$_2$O$_2$

3.4.1 Effect of H$_2$O$_2$ on the reduction of COD of dairy industry waste water

The amount of H$_2$O$_2$ is considered as one of the most important factors in the Fenton’s and photo-Fenton’s Process. To increase the generation of free radicals, the combination of ultrasound with hydrogen peroxide looks to be a promising option. The concentration of hydrogen peroxide plays a crucial role in deciding the extent of degradation obtained for the combined process. On one side where it acts as a source of free radicals by the dissociation process, also it acts as the scavenger of the generated free radicals, as indicated by the following reaction scheme:

\[
\text{H}_2\text{O}_2 \rightarrow 2\text{OH}^* \\
\text{OH}^* + \text{H}_2\text{O}_2 \rightarrow \text{H}_2\text{O} + \text{O}_2\text{H}^* 
\]

The effect of addition of H$_2$O$_2$(50 to 250μl/L) on the reduction of COD of dairy industry waste water is shown in Figure 4. These experiments were conducted for 400 ml dairy industry waste water, sonication power 800W, 60 % duty cycle, 3 pH, constant temperature of 28 ± 3 °C, constant sonication frequency 20 kHz for 180 minutes of time. In Acoustic cavitation + H$_2$O$_2$ process, the addition of H$_2$O$_2$ from 50 to 200μl/L increases the reduction of COD from 27.40 % to 40.02 % for 180 minutes. Further increase from 200 to 250μl/L, decrease in reduction of COD from 40.02% to 37.53%.

![Figure 4. Effect of H$_2$O$_2$ on the reduction of COD of dairy industry waste water](image-url)

The increase in the reduction of COD is due to the increase in hydroxyl radical concentration by the addition of H$_2$O$_2$. This adverse effect after optimum concentration is due to scavenging effect. On increasing concentration of H$_2$O$_2$ rate of hydroxyl radical also increases but beyond certain concentration some of H$_2$O$_2$ remains in excess. This excess H$_2$O$_2$ recombines with OH$^*$ radicals and form H$_2$O and O$_2$H$^*$ radical that has
low oxidation potential compared to that of OH* radical, which results into decrease in rate of degradation [21,22].

Table 4 shows the effect of H$_2$O$_2$ on % of COD reduction of dairy industry waste water. It has been observed that 13.53% and 2.89% reduction of COD was obtained after 180 min of operation using Acoustic Cavitation and Aeration respectively. Further the COD reduction was significantly increased to 40.02% and 6.11% by applying the combination of Acoustic Cavitation with H$_2$O$_2$ and Aeration with H$_2$O$_2$ respectively.

### Table 4. Effect of H$_2$O$_2$ on the % of COD reduction of dairy industry waste water

<table>
<thead>
<tr>
<th>Process</th>
<th>H$_2$O$_2$ (µl/L)</th>
<th>% of COD Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustic Cavitation</td>
<td>-</td>
<td>13.53</td>
</tr>
<tr>
<td>Aeration</td>
<td>-</td>
<td>2.89</td>
</tr>
<tr>
<td>Aeration + H$_2$O$_2$</td>
<td>200</td>
<td>6.11</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>27.40</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>32.28</td>
</tr>
<tr>
<td>Acoustic Cavitation + H$_2$O$_2$</td>
<td>150</td>
<td>35.63</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>40.02</td>
</tr>
<tr>
<td></td>
<td>250</td>
<td>37.53</td>
</tr>
</tbody>
</table>

### 3.5 Acoustic Cavitation + Fenton Process

#### 3.5.1 Effect of FeSO$_4$.7H$_2$O on the reduction of COD of dairy industry waste water

Fenton process utilizes the reactivity of hydroxyl radicals generated in acidic conditions by iron catalyzed decomposition of hydrogen peroxide for the degradation of organic pollutant. Amount of ferrous ion is one of the main parameters to influence the Fenton process. More hydroxyl radicals are produced with the increase in the concentration of ferrous ions (Fe$^{2+}$) [24]. Effect of FeSO$_4$.7H$_2$O on the reduction of COD of dairy industry waste water has been investigated for various concentration of Ferrous sulfate heptahydrate (FeSO$_4$.7H$_2$O) in the presence of H$_2$O$_2$ (200µl/L) and Acoustic Cavitation (800W).

Figure 5 shows the effect of FeSO$_4$.7H$_2$O on the reduction of COD of dairy industry waste water. These experiments were conducted for 400 ml dairy industry waste water, sonication power 800W, 60% duty cycle, 3 pH, 200µl/L of optimum H$_2$O$_2$ loading, constant temperature of 28 ± 3 °C, constant sonication frequency 20 kHz for 180 minutes of time. It has been observed that the reduction of COD of dairy industry waste water increases with an increase in the loading of FeSO$_4$.7H$_2$O from 26mg/L to 78mg/L under acoustic cavitation with optimum concentration of hydrogen peroxide(200µl/L). The reduction of COD is faster in the early stage of the reaction than in the later stage. Most of the hydrogen peroxide dose was consumed in the early stage of the Fenton reaction. Since ferrousion catalyzes hydrogen peroxide to form hydroxyl radical quickly in the first stage of reaction, more reduction occurs in the early stage of reaction [25]. Fenton reaction can be described using equation,

$$\text{Fe}^{2+} + \text{H}_2\text{O}_2 \rightarrow \text{Fe}^{3+} + \text{OH}^- + \text{OH}^*$$
Resulting Fe$^{3+}$ ions can react with H$_2$O$_2$ to produce the intermediate complex Fe-O$_2$OH$^{2+}$, which can easily get converted into Fe$^{2+}$ and HO$_2^*$ under cavitation.

$$\text{Fe}^{3+} + \text{H}_2\text{O}_2 \rightarrow \text{Fe-O}_2\text{OH}^{2+} + \text{H}^+$$

$$\text{Fe-O}_2\text{OH}^{2+} \rightarrow \text{Fe}^{2+} + \text{HO}_2^*$$

Generated Fe$^{2+}$ ions can again react with H$_2$O$_2$ to generate even more number of hydroxyl radicals. In addition to this, some part of H$_2$O$_2$ directly decomposes to hydroxyl radicals in presence of acoustic cavitation as shown in below,

$$\text{H}_2\text{O}_2 \rightarrow \text{OH}^* + \text{OH}^*$$

Hence, the combination of Acoustic cavitation and Fenton process accelerates the rate of generation of hydroxyl radicals [25-27].

Table 5 shows the effect of FeSO$_4$.7H$_2$O on % of COD reduction of dairy industry waste water. It has been observed that 13.53% and 2.89% reduction of COD obtained after 180 min of operation using Acoustic Cavitation and Aeration respectively which significantly increased to 66.22% and 29.12% by applying the combination of Acoustic Cavitation with Fenton Process and Aeration with Fenton Process respectively.

**Figure 5.** Effect of FeSO$_4$.7H$_2$O on the reduction of COD of dairy industry waste water

**Table 5.** Effect of FeSO$_4$.7H$_2$O on the % of COD reduction of dairy industry waste water

<table>
<thead>
<tr>
<th>Process</th>
<th>FeSO$_4$.7H$_2$O (mg/L)</th>
<th>% of COD Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustic Cavitation</td>
<td>-</td>
<td>13.53</td>
</tr>
<tr>
<td>Aeration</td>
<td>-</td>
<td>2.89</td>
</tr>
<tr>
<td>Aeration +Fenton process</td>
<td>78</td>
<td>29.12</td>
</tr>
</tbody>
</table>
3.6 Acoustic Cavitation + Photo Fenton Process (Sonophotofenton Process)

3.6.1 Effect of FeSO$_4$.7 H$_2$O on the reduction of COD of dairy industry waste water

The reduction of COD of dairy industry waste water was investigated using different concentration of FeSO$_4$.7H$_2$O ranging from 26mg/L to 78mg/L. Four 8 W low-pressure mercury UV lamps (Philips) were used at 254 wavelengths for UV irradiation and ultrasonic processor for cavitation. These experiment conducted for 400 ml dairy industry waste water, sonication power 800W, 60% duty cycle, 3 pH, 200µl/L of optimum H$_2$O$_2$ loading, constant temperature of 28 ± 3 °C, constant sonication frequency 20 kHz for 180 minutes of time.

![Figure 6. Effect of FeSO$_4$.7H$_2$O on the reduction of COD of dairy industry waste water](image)

Figure 6 shows the effect of FeSO$_4$.7H$_2$O on the reduction of COD of dairy industry waste water. It has been observed that the reduction of COD of dairy industry waste water increases with increase in the concentration of FeSO$_4$.7H$_2$O under Acoustic Cavitation + Photo Fenton process with optimum concentration of H$_2$O$_2$ (200µl/L). In Fenton process ferrous salts react with hydrogen peroxide to generate the hydroxyl radicals as follows

$$\text{Fe}^{2+} + \text{H}_2\text{O}_2 \rightarrow \text{Fe}^{3+} + \text{OH}^- + \text{OH}^*$$
The rate of degradation can be considerably increased via photochemical reaction in the photo-Fenton’s process. In this case, the regeneration of catalyst i.e. Fe$^{2+}$ ions, with production of new OH$^*$ radicals from Fe$^{3+}$/Fe(OH)$^{2+}$ by UV irradiation take place [25,26].

$$\text{Fe}^{3+} + \text{H}_2\text{O} \rightarrow \text{Fe(OH)}^{2+} + \text{H}^+$$

$$\text{Fe(OH)}^{2+} + h\nu \rightarrow \text{Fe}^{2+} + \text{OH}^*$$

Also hydrogen peroxide readily decomposes into hydroxyl radicals in the presence of acoustic cavitation and UV lights [27].

$$\text{H}_2\text{O}_2 + \text{US/UV Lights} \rightarrow 2\text{OH}^*$$

Table 6 shows the effect of FeSO$_4$.7H$_2$O on % of COD reduction of dairy industry waste water. It has been observed that 13.53% and 2.89% reduction of COD obtained after 180 min of operation using Acoustic Cavitation and Aeration respectively which significantly increased to 88.78% and 48.89% for the combination of Acoustic Cavitation with Photo Fenton Process and Aeration with Photo Fenton Process.

<table>
<thead>
<tr>
<th>Process</th>
<th>FeSO$_4$.7H$_2$O (mg/L)</th>
<th>% of COD Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustic Cavitation</td>
<td>-</td>
<td>13.53</td>
</tr>
<tr>
<td>Aeration</td>
<td>-</td>
<td>2.89</td>
</tr>
<tr>
<td>Aeration + Photo Fenton process</td>
<td>78</td>
<td>48.89</td>
</tr>
<tr>
<td>Acoustic Cavitation + Photo Fenton process</td>
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<td>74.73</td>
</tr>
<tr>
<td></td>
<td>39</td>
<td>77.42</td>
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<td></td>
<td>52</td>
<td>80.96</td>
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<tr>
<td></td>
<td>65</td>
<td>84.00</td>
</tr>
<tr>
<td></td>
<td>78</td>
<td>88.78</td>
</tr>
</tbody>
</table>

4. CONCLUSIONS

The present study has shown the efficiency of acoustic cavitation for the reduction of COD of dairy industry waste water. Combined methods were found to be more efficient as compared to an individual process. The main conclusions drawn from present study can be summarized as follows:

1. The percentage of reduction of COD of dairy industry waste water was influenced by sonication power, duty cycle and solution pH using acoustic cavitation. Maximum percentage of COD reduction was 10.11% for sonication power of 800W, 11.46% for 80% duty cycle and 13.53% pH 3 respectively.

2. It was observed that acoustic cavitation coupled with H$_2$O$_2$ enhances the percentage of COD reduction of dairy industry waste water, giving 40.02% reduction of COD at an optimum concentration of H$_2$O$_2$ (200µl/L) as compared 13.53% obtained using acoustic cavitation alone.
3. The combination of Fenton process with acoustic cavitation gives 66.22% reduction of COD of dairy industry waste water at optimum concentration of FeSO$_4$.7H$_2$O (78mg/L) as compared 40.02% and 13.53% reduction of COD obtained using acoustic cavitation + H$_2$O$_2$ and acoustic cavitation alone.

4. The combination of acoustic cavitation and Photo Fenton process gives 88.78% maximum reduction of COD of dairy industry waste water at optimum concentration of FeSO$_4$.7H$_2$O (78mg/L) as compared 66.22%, 40.02% and 13.53% reduction of COD for acoustic cavitation + Fenton process, acoustic cavitation + H$_2$O$_2$ and acoustic cavitation alone.

Overall, the obtained results revealed that the combination of Acoustic Cavitation with Photo Fenton process can be a better method to maximum reduction of COD of dairy industry waste water.

5. REFERENCES


