Textile Wastewater Treatment using Advanced Oxidation Process (AOP)

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Abstract. Wastewater from printing and dyeing industries is often colorful, contains reactive dye residues and chemicals, and requires proper treatment before being released into the environment. The treatment of textile wastes with biotechnology through the general use of high inorganic and organic concentrations is difficult for further process. Therefore, many industries make use of the advanced oxidation process (AOP) because of its ability to eliminate non-degradable organic components and avoid residual deposits removal. A new design of synthetic waste treatment was developed by installing the AOP on the existing wastewater treatment process (WWTP). However, the textile industry faces significant environmental problems because of its vast water consumption. This makes the resulting wastewater from their activities characterized by intense color, a large number of suspended solids, very unpredictable pH and high COD concentrations. Therefore, there is a need to implement some control measures in the future in order to minimize these waste problems. Experiments show that the pollutants can be physically removed by using the AOP process and COD decrease 51.7 % from 16.167 mg/L into 8.364 mg/L.

Keywords—textile, waste, paint and sludge, treatment, AOP

1. Introduction

1.1. Background of the study

Textile industry is a leading industry in most countries such as China, Singapore, England, Bangladesh, Italy, Turkey, Indonesia and many more other countries in the world. Unfortunately, during production activities, several hazards that potentially damage the environment arise as a result of waste produced. Textile wastewater is characterized by the high content of dyes, salt, high COD of additives, suspended solids (SS) and fluctuating pH values. C. Sahunin, et al. explained that the textile industry consumes around 21-377 m³ of water per tons of textile produced, thus generating a large amount of wastewater from various stages of dyeing and refining processes (1). In agreement with this, S. Eswaramoorthi K. Dhanapal revealed that treating wastewater is a severe problem for several reasons including high total dissolved solids (TDS) from wastewater, Cu, Zn, etc.; types of organic dyes which cannot be broken down by waste bacteria; and the presence of dissolved silica free of chlorine (2). One of the major environmental concerns is the removal of dyes from textile waste because it has been reported that only 87% of its content can be decomposed (3).

The primary reason color could be seen in the textile industry waste is because of the use of large amounts of dyes during the dyeing process of textile manufacturing (4). Yonar et al. explained that
inefficient dyeing methods often produce significant coloring residues in the final hydrolysed or irregular dye effluent (5). Even though the production of waste has been minimized, the remaining wastes must be processed into several forms before being discharged into the river or sea. The reduction has significant effects because it helps to reduce operating costs, the risk of responsibility and the requirement for waste treatment. It also helps to improve the efficiency of the production process as well as the protection of health and the environment.

There are several textile wastewater treatment methods, including electro-oxidation, bio-treatment, photochemistry and membrane processes. The use of nano-filtration has been observed to be less energy intensive compared to reverse osmosis and, as a result of this, it is mostly used in processing several industrial wastes (6).

Currently, AOP has a particular advantage over conventional alternative treatments because of its ability to eliminate non-degradable organic components and avoid residual deposits removal. It is based on the high oxidation strength of free radicals, notably hydroxyl, and highly reactive oxidations (7). This paper presents the implementation of AOP in treating textile wastes. For this purpose, a new design of synthetic waste treatment was developed by installing the AOP on the existing plant. AOP was developed by combining ozone and ultraviolet in order to safely dispose of processed liquid waste and meet the environmental quality standard requirements set by the Ministry of Environment.

The X corporate is currently using and operating a WWTP in combination with chemical and biological methods. The plant is also equipped with sludge treatment facilities, including belt press and incinerator. The textile wastes are processed from massive accumulated sludge waste chemically, especially through PAC coagulant used in paint removal, and biologically through sewage sludge from the active basin residual.

The production process of X corporate is quite diverse and tailored based on the needs of consumers in terms of fabric type and desired color. As a result, compound liquid waste is produced. Therefore, a large amount of PAC coagulants is needed in order to remove the dyes contained in the waste making the organization produce 5m$^3$ sludge residual daily.

1.2. Purpose of the study

The purpose of this study was to overcome pollutants from liquid wastes of X corporate containing organic and inorganic compounds that have the potential of becoming toxic to the environment using AOP system. Some text.

2. Materials and Methods

2.1. Materials

AOP system with a processing capacity of 1 m$^3$/day, COD influent 5,000 mg/L, a process pressure of 1 atm, process temperature at 20-40 °C, the power consumption of 1 kWh, and voltage source of 220 Volts 1 Phase 50 Hz was used for field trials.

The AOP unit divided into five parts which have specification and function, as seen in Table 1.

| No | Part             | Specification                                      | Function                           |
|----|------------------|----------------------------------------------------|------------------------------------|
| 1  | Inlet pump set   | Multi-stage/Centrifugal/Submersible 1 piece with a capacity of 40 L/minute, head 15 m, and power at 220V, 1 phase, 50Hz | drive the waste for the treatment process |
| No | Part                     | Specification                                               | Function                                                                 |
|----|--------------------------|-------------------------------------------------------------|--------------------------------------------------------------------------|
| 2  | oxidizing section        | Fiberglass material, capacity of 8 SCFH                     | decompose chemical compounds and kill microorganisms in the waste       |
| 3  | oxidation chamber        | SS material, 1000 L capacity and atmospheric pressure       | absorbing micropollutants which have not been deposited in the previous process |
| 4  | filtration tank room     | SS material, 500 L capacity, and atmospheric pressure       | absorbing micropollutants which have not been deposited in the previous process |
| 5  | pH adjusted tank         | SS material, 500 L capacity                                | controlling pH                                                          |

2.2. Methods

The hazardous waste treatment activities ranged from regulatory restrictions to savings in chemical recycling costs. Most organizations make use of waste treatment industries in order to achieve environmental security. Unfortunately, there is no specific processing method suitable for all types of waste treatment or which can be applied universally. Therefore, wastewater treatment can be conducted through several physical, chemical and biological processes depending on the pollution load.

The method used in this research was ozone/UV (O₃/UV) because the photolysis of ozone in water with UV radiation in the range of 200 to 280 nm might cause hydrogen peroxide. However, the hydroxyl radicals produced by hydrogen peroxide under UV radiation and/or ozone can be seen in the following equation:

\[
O_3 + hv + H_2O \rightarrow H_2O_2 + O_2 \quad (1)
\]

\[
H_2O_2 + hv \rightarrow 2(OH) \quad (2)
\]

\[
2O_3 + H_2O \rightarrow 2(OH) + 3O_2 \quad (3)
\]

From low-pressure mercury vapor lamps, all types of UV light sources can be used for this process. As a result of the fact that the O₂/UV does not have the same limits as the H₂O₂/UV process, low-pressure UV mercury vapor is the most commonly used source of radiation for this process. It is, however, important to state that many variables such as pH, temperature, entry, turbidity, UV intensity, spectral properties of light and types of pollutants affect the system efficiency.

Ozonation is a phenomenon of simultaneous mass transfer while ozone is a well-known potent oxidizing agent widely used for the treatment of water and wastewater, theoretically and practically. It has high efficiency at high pH values such that at a high pH (> 11.0), it reacts almost indiscriminately with everything that is in the organic and inorganic compounds of the reaction. It also reacts with wastewater compounds in two different ways, direct and indirect radical chain reactions. They are simultaneously continuous; therefore, their reaction kinetics are dependent on the characteristic of the treated wastewater.

Simplified ozone reaction mechanism at high pH is as shown below:

\[
3O_3 + H_2O \rightarrow 2(OH) + 4O_2 \quad (4)
\]

Ozon (O₃) is an allotrope of oxygen (O₂)
Textile dyeing and industrial finishing are one of the main contributors to the quantity and chemical composition of wastes disposed. Like many other industrial wastes, textile industry waste varies significantly in quantity and composition (8). It contains organic and inorganic chemicals such as equipment, carriers, surfactants, precipitates, rating agents, etc. This is the reason it is mostly characterized by high COD (400-3000 mg/L), BOD5 (200-2000 mg/L), total solids (1,000 to 10,000 mg/L), suspended solids (100-1000 mg/L, TKN) (~ 10-100 mg/L), total phosphorus (~ 5-70 mg/L), conductivity (1,000-15,000 Ms/cm) and pH (~ 5-10 usually basic). Another important problem of waste from the textile industry is the color (9). Without proper processing, the color of the discarded dye can remain in the environment for a long time, and this has become a major challenge due to strict environmental regulations.

In order to eliminate discarded dye remain in the environment using AOP, it is necessary to have a processing flow chart for textile waste. The treatment is often conducted with a single aerobic sludge or the combination of chemical coagulation and flocculation of sludge. However, aerobic biological treatments have been observed only have the ability to remove paint from the textile waste while the chemical coagulation and flocculation are also not effective in removing reactive dyes. Therefore, dyes and chemicals used in the textile industry have severe inhibitory effects on aquatic ecosystems and visible water pollution (9).

It is, however, important to point out that there are other alternative methods of eliminating textile waste pollution and they include various combinations of physical, chemical and biological treatments and color removal methods. Moreover, they cannot be applied effectively to all dyes and also not cost effective. Therefore, the use of AOP reduces non-biodegradable organic wastes in textile dyeing (10). This ability can be established on the report that ozonation is very effective in removing paint, COD, and toxicity from textile waste.

The main advantage of ozonation is that there is no chemicals addition needed to water or wastewater. As a consequence, it is possible to apply ozonation in textile waste without adjusting pH and adding chemicals. However, the process has several disadvantages, such as inefficient production capacity of the corona destroyer generator (CCD) (2-4%). This can be minimized by using an efficient ozone generator such as the electrochemical ozone generator.

The oxidation process of hydroxyl radicals has shown that toxic organic compounds in wastewater can be destroyed because of the radicals’ high oxidation potential and several production possibilities. They can be made by combining ozone with ultraviolet light; ozone, hydrogen peroxide with ultraviolet light; hydrogen peroxide with iron or iron ions and by photocatalysis which involves combining semiconductors with UV radiation and oxygen molecules. The schematic diagram of the textile waste treatment flow rate with AOP and CA is shown in Fig. 1(11).

**Figure 1.** The flow of textile waste treatment with AOP and CA.

The basic concept of the system created is the AOP, with ozone and ultraviolet as the main component, which is further combined with activated charcoal in the last stage to produce a phylophone. The process of AOP produces a potent but relatively non-selective hydroxyl radical in sufficient quantities and is used to oxidize waste chemicals (12). This is possible because hydroxyl radical (OH) has the highest oxidation potential after fluorine (potential oxidation, E0: 2.8 eV compared to normal hydrogen electrode (NHE) while the most potent oxidant, fluorine has E0: 3.06 V (11) and cannot be used for wastewater treatment due to its high toxicity). For this reason, hydroxyl radicals including AOP have attracted the attention of several scientists and technology developers. The understanding of ozone oxidation has led to the expansion of its applications in drinking water and wastewater treatment industries.
The waste treatment was divided into primary, secondary and tertiary processing as represented by the AOP prototype system and activated carbon in the image. The main purpose of the secondary processing is to remove more BOD than the simple sedimentation and also to save a lot of oil and phenol. During further processing, dissolved organic compounds, colloids, and colors in wastewater are removed or reduced and organic matter stabilized.

3. Experiment Results and Discussion

The first step included the observation of the equipment requirements and field conditions in order to obtain the proposed field trial design as shown in Fig. 2(13).

![Figure 2. The layout of field trial design.](image)

The next has to do with the installation of the AOP unit prototype in stages as shown in Fig. 3. It started with the trial preparation at X corporate then followed by the research stage I (model A) conducted through activated sludge ozonation method, stage II (model B) through the use of medium-color Ex-Jet Dyeing T/R with Ozone method and UV, stage III (model C) using Ex desizing scouring non color with the Ozone method, stage IV (model D) with spunpolly Ozone and UV method, stage V (model E) treated sludge from coagulation with Ozone method, stage VI (model F) with C26 (Finish Resin) with Ozone and UV methods, and stage VII (model G) conducted with T/R solid color discharge by the Ozone method. These can be seen in the WWTP Field Experiment Design Layout in Fig. 2 and field tests in Fig. 3(13). AOP prototype system with active carbon.

![Figure 3. Field trial at X Corporate.](image)
In the field trial, the prototype unit of liquid waste treatment, including ozone and UV was partially operated according to the request of X corporate and coagulation and filtration were not used. As shown in Fig. 4, wastewater stored in the re-circulated container by pumping through the AOP (ozone and UV) process for less is returned to the original reservoir. The circulation was conducted for 1 hour for each sample tested. As stated in Table II, the trial was conducted on seven types of liquid waste produced by the corporate and the experiments and analysis were conducted during the trial process.

Table 2. Results of field trials

| No | Sample                                      | pH | COD   | SS    | Color  |
|----|--------------------------------------------|----|-------|-------|--------|
| 1  | Activated sludge                           | 7  | 15,693| 9,225 | heavy  |
|    | After process (homogenous)                  | 7  | 15,504| 5,100 |        |
|    | After process (sediment)                    | 7  | 7,956 | 687   |        |
| 2  | ex jet dyeing medium color T / R (ozone + UV) | 7.9| 2,346 | 162.5 | heavy  |
|    | after the process of 10 minutes PAC was deposited | 5.6| 476   | 8     | light  |
|    | After process (30 minutes)                  | 6.9| 5,916 |       |        |
|    | After process (60 minutes)                  | 7.2| 5,022 |       |        |
| 3  | Ex Desizing non-color scouring (ozone)      | 7.1| 28,254| 162.5 | moderate |
|    | After process (60 minutes)                  | 7  | 23,511|       |        |
| 4  | Spunpoly (weight reduction) (Ozone + UV)    | 8.6| 16,167| 75    | light  |
|    | After process                               | 7  | 8,364 | 87.5  | light  |
| 5  | Mud from coagulation                        | 5.9| 7,089 | 9,075 | heavy  |
|    | After process                               | 5.7| 7,293 | 8,850 | heavy  |
| 6  | C 26 (Resin finish) (Ozone + UV)            | 6.1| 28,458| 1,600 | light  |
|    | After process                               | 5.2| 28,050| 1,237 | light  |
| 7  | Concentrated color waste                    | 7.9| 1,224 | 62.5  | heavy  |
|    | After process (homogenous)                  | 7.2| 1,648 | 46    | decreased |
|    | After process (sediment)                    | 7.2| 1,360 | 50    | light  |

The results showed that the maximum capacity for the activated sludge (ozone) samples was 5 m$^3$/day. This shows that the sludge is decreasing the maximum capacity for weight reduces (ozone + UV) (ozone) at 110 m$^3$/day as well as the CSB. It was also found that the maximum capacity for ozone concentrated color samples was 350 m$^3$/day which helped in reducing the color.

The result also showed that the activated sludge was well processed with AOP. This can be seen from the decrease in COD and SS that occurs after the process (Table II). Fig. 4 also shows that the pollutants contained in the activated sludge can be removed.

While liquid waste is produced in the APS process, it is possible to reduce the COD content. It was observed in this research, there was a significant decrease of 51.73% from its original value from 16.167 mg/L to 8.364 mg/L after the process. This value is slightly higher than stated by Balasubramaniam et al. which is said that COD reduction usually not exceeding 50% (14). Reduction value can be made continuous through the increment of the ozone dose in the operation process.
In the seventh experiment, a test was conducted to remove the paint in the liquid waste and a significant color reduction was observed as shown in Fig. 5. This shows that AOP is also very suitable for removing colors contained in the liquid waste. However, this is not accompanied by a decrease in COD. Further research is needed to find out the exact cause of the phenomenon that occurs.

Experiment result also shows that the degradation of chemical compounds must be accompanied by a decrease in COD in correlation with the decrease in sludge content and color. This can be associated with the final result of the color reduction test after one hour of processing through the AOP prototype unit as shown in Fig. 6.

To get the expected results, a processing capacity of up to 20 m$^3$/day, COD 25,000 mg/L (coloring), 1 atm printing process, process temperature at 20-40 °C, 5 kWh power consumption, 220 volts 1 phase voltage source 50 Hz are required for all pH values.

From the test results and through the calculation of the required requirements, the specifications needed to make the design of textile wastewater treatment can be divided into two parts, civil parts, and the AOP units. In the Civil Division, the AOP and control room are further divided into two parts. The AOP room functions as a storage area for the AOP units with dimensions of 4m x 3m x 4m while the control room serves as a storage area for the oxidation unit.
As the literature clearly showed, ozonation is very effective in removing paint, COD, and toxicity from textile waste. However, it also important to understand its limitations before it is applied in any other industry.

\( \text{O}_3/\text{UV} \) is the most effective method in changing dye colors when compared to the use of UV oxidation or ozonation only. Although ozone can be used to increase organic degradation through its hydroxyl radical, UV-light also has a strong ability to absorb dyes and in producing minimal amounts of free radicals (\( \text{HO}^• \)) required to degrade dyes. Therefore, the same color removal efficiency can be expected from both \( \text{O}_3 \) and \( \text{O}_3/\text{UV} \).

4. Conclusion
To optimize the processing and possible reuse of textile industry waste, the flow must always be considered separately. It is also essential to investigate all aspects involved in reducing emissions and waste products because it does not only improve environmental performance but also leads to significant savings.

From the results of several tests conducted and observation of the colored, smelly and cloudy synthetic textile processing, it can be concluded that the pollutants can be physically removed by using the AOP process. The experiment result shows that COD reduction is 51.73%. This result shows that the content of chemical compounds contained in the wastewater can be effectively removed through the oxidation. Therefore, the AOP process is a promising alternative to traditional processing methods for textile waste treatment.

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