Application of electrocoagulation for textile wastewater treatment: A review

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Abstract. The increasing development of the textile industry is always followed by the amount of wastewater produced. The textile industry uses various types of synthetic dyes, and the amount of dyes is still high in its waste. The impact of the discharge of textile wastewater into the environment without rigorous treatment will damage the environment because the dense color of the waste can prevent light penetration for aquatic organisms. Also, various metals and other harmful chemicals can contaminate soil and water sources. One promising method for treating textile wastewater is electrocoagulation. Electrocoagulation can reduce pollutants in textile wastewater efficiently, cheaply, and reliably. In this review article, an explanation regarding the basis and techniques for processing textile wastewater by electrocoagulation will be presented. Various electrocoagulation operational parameters and their relation to the quality of textile wastewater treatment will be reviewed. In addition, problems and limitations of the application of electrocoagulation as a basis for the development of textile waste treatment in the future will be explained.

1. Introduction
The textile industry is one industry that is growing rapidly. Apart from the economic advantage, the textile industry often has a negative impact on the environment [1]. Not a few textile producers in Indonesia discharge their waste into the rivers without proper processing. The investigation showed that the textile industry waste discharged into the water contained a very high content of dyes and COD (Chemical Oxygen Demand). This condition occurs because the waste treatment technology with low cost is not yet popular [2-4].

The content of dyes is one of the problems that interfere in the textile industry waste [5],[6]. Dyes are one of the main raw materials in the textile industry, around 10-15% of the dyes that have been used cannot be reused and must be discarded. On the other hand, the waste contains dyes that can threaten health because they can irritate the skin and eyes, cause cancer and can cause mutagens [7],[8].

The method that is often used in textile wastewater treatment is the adsorption method. However, in several studies stated that this method is less effective because the textile dyes that are adsorbed are still accumulating in the adsorbent which might cause a new problem [9-11]. Therefore a new method for processing textile waste is needed. Thus, the discharged of wastewater is safer and does not damage the environment and does not endanger the living things around [12],[13].
Electrocoagulation is a process of destabilizing suspensions, emulsions, and solutions containing pollutants by providing direct electric current and it causes the formation of flocks that are easily separated. Some of the advantages of electrocoagulation methods are that it does not require chemical compounds (in addition to pH control), the operating costs are quite cheap, the energy consumption is low, the gas bubbles formed will bring pollutants to the surface of the water, electrocoagulation is more efficient than chemical coagulation, its use is easy and simple [14-18]. Even from these advantages, it is possible to use textile wastewater to be reused. Therefore, departing from these advantages, several studies have also applied electrocoagulation technology in textile waste treatment. In this paper, we provide a review related to the development of electrocoagulation in the textile industry along with various weaknesses of this method as a basis for the development of electrocoagulation in the future.

2. Content and impact of textile waste water
The textile industry is an industry that consumes high amounts of water. Therefore, besides the majority of waste in the textile industry is wastewater, the high use of water will add to the concern related to the clean water crisis. In the process of making cloth as long as 35,000 m/day, 1,050 kL/day of water is consumed. It also produced effluents with volumes reaching 800 kL/day. This amount will increase when the factory produces a fabric in greater quantities. In general, 30-40% of the water used in the textile production process is used for the colouring process. While the remaining 60-70% is used for the washing process. Therefore, the development of a textile industry based on clean and sustainable technology is an indispensable effort to protect the environment.

The content of textile waste is dominated by pollutants originating from textile dyes and printing materials in textile processing. This is because most of the colouring agents used in the textile colouring process will be discarded. Textile waste usually contains azo dyes with strong colours that have a pH ranging from 2 to 12, high COD concentrations, and difficult to be degraded by nature. The effluent composition of the dyeing process is urea dyestuffs, oxidizing agents, acetic acids, detergents, and wetting agents. The impact of the presence of these materials in nature will give a strong colour to the water source, high BOD, and the presence of heavy metals. Therefore various studies state that textile waste is carcinogenic. Waste from textile colouring which generally has a solid colour can also prevent sunlight from being able to penetrate the waters. Especially when the level of textile waste COD is high. This, of course, disturbs the growth of various aquatic organisms. Water quality that has been exposed to textile liquid waste generally has low DO levels. These conditions will make aerobic organisms can not survive and anaerobic organisms run rampant. Therefore, it is not surprising that at present many rivers in Indonesia can no longer support the life of underwater organisms such as plants and various types of fish due to the rampant disposal of waste into rivers.

3. Basic principle of electrocoagulation
Electrocoagulation works based on the principle of reduction and oxidation of the electrodes. In an electrocoagulation cell, there is an electrode oxidation (+) event called an anode while functioning as a coagulant, whereas reduction and precipitation occur in an electrode (-) called a water cathode which is processed to function as an electrolyte solution [19]. Schematically, simple electrocoagulation equipment is presented in Figure 1. Some of the electrodes that can be used in the electrocoagulation process are aluminium (Al) and iron (Fe). The choice of Al and Fe in the electrocoagulation process is because both elements can become ions when given direct electricity. The presence of ions formed will have an impact on the release of electrons into the electrocoagulation system to break down water into its hydroxyl component (OH-). In summary, the reaction at the anode for aluminium electrodes is:

$$\text{Al}_{(s)} \rightarrow \text{Al}^{3+}_{(aq)} + 3e^-$$  

Whereas the cathode occurs:
and all of its reactions to the electrocoagulation system with aluminium electrodes are:

\[
\begin{align*}
\text{Al}^{2+} &+ 2\text{OH}^- \rightarrow \text{Al(OH)}_2^{2+} \\
\text{Al}^{3+} &+ 3\text{OH}^- \rightarrow \text{Al(OH)}_3^{3+}
\end{align*}
\]  

(3)

A hydroxyl group is a group that plays a role in binding pollutants in wastewater. In the electrocoagulation stage, the hydroxyl group will bind the pollutants dispersed in the water and then float to form floc as shown in Figure 2.

4. Electrocoagulation in textile wastewater treatment

The selection of electrocoagulation methods in textile wastewater treatment is expected to reduce operational costs and simplify the processing process. There are several developments in the electrocoagulation technology used in the textile industry including the electrocoagulation method which is integrated with photo-Fenton and absorbent such as activated charcoal and zeolite and the development of continuous/dynamic electrocoagulation that allows the electrocoagulation process to run faster and more efficiently.

Some key parameters in the electrocoagulation application process for processing textile waste include wastewater pH, type of electrodes, the shape of electrodes, number of electrodes, the distance between electrode plates, and current and voltage used.

Often the electrocoagulation process carried out on acidic textile waste will change more quickly. This is because the hydroxyl groups produced in the process of reduction and oxidation will easily react with pollutants that produce acid in wastewater. The shape and number of electrodes are related to the contact surface area between the electrode and wastewater. When the contact surface area is large, the
electrocoagulation process can be faster. However, an increase in the number of electrodes usually results in an increase in electrical energy consumption.

As a comparison, in Table 1 the data of research that has been carried out related to the use of electrocoagulation in textile wastewater are presented. From the data presented it appears that the majority of electrocoagulation in textile waste uses the Al, Fe electrodes, or both alloys: Al-Fe. The minimum voltage used in the electrocoagulation process is 5 Volts for Fe electrodes. The most interesting thing from these data is that the use of electrocoagulation can improve the textile wastewater clarity up to 90%.

Table 1. Comparison of electrocoagulation applications in textile waste

| Reference | pH  | Electrode | Electricity condition | COD  | BOD | TSS | Turbidity Reduction |
|----------|-----|-----------|------------------------|------|-----|-----|---------------------|
| [20]     | 9,27| Al-Fe     | 0,5 A/dm²              | 158  | -   | -   | 98,78               |
|          | 9,89| Al-Al     | 30 A                   | 77,23| -   | -   | 98,18               |
| [21]     | 4   | Al-Al     | 10 V                   | 29,67| -   | -   | 49,17%              |
| [22]     | 6,5 | Al        | 0,5 A                  | 33,01| -   | -   | 97,30               |
| [23]     | 2,0 | Fe        | 5 V                    | 98,53| -   | -   | 78,13%              |
| [24]     |    | Al-Fe     | 6V                     | 94,01| -   | -   | -                   |
| [25]     |    | Al        | 20V                    | 94,8 | -   | -   | 93,1%               |

5. Challenges of electrocoagulation applications and future development

Although electrocoagulation has promising potential to be applied in textile waste treatment systems, electrocoagulation has several disadvantages such as:

- Cannot treat wastewater that has high electrolyte properties because it has the potential to occur a short circuit.
- The electrodes must be replaced regularly due to corrosion.
- The formation of layers on the electrodes which reduce the efficiency of the electrocoagulation process
- Electrocoagulation requires electricity which can increase production costs

Departing from these problems, the development of electrocoagulation in the future must be able to solve the existing problems. In the case of waste with high electrolyte properties, the electrocoagulation system can be integrated with the absorption or filtration method. Absorption with high electrolyte cases can be done with pore-based absorbent materials such as zeolites or activated charcoal if the electrolyte source is non-magnetic. However, if it is magnetic, the magnetic absorbent material can be used. The application of the absorbance material must be done before the electrocoagulation process runs and the electrolyte content in wastewater has decreased. The solution to the problem of electrodes that must be replaced regularly in electrocoagulation is to find metal electrodes that are resistant to corrosion or to coat them with an anti-corrosion coating. However, the coating technology applied to the electrode should not obstruct the oxidation-reduction process of the electrode because it can interfere with the efficiency of electrocoagulation. For the other case, the formation of layers on the electrodes can be overcome either by coating the electrodes with a thin layer or by developing an automatic cleaning system. As for the last problem, the use of electricity can be overcome through the use of renewable energy available in nature such as solar and wind to reduce operational costs.

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