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Electrochemical removal of brilliant green dye from wastewater

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Abstract. Dyes are one of the most widely used materials in many industrial fields as coloring agents such as textile, wood, and food manufacturing. As these dyes end up in a water source, this high rate of dyes use represents one of the severe risks to the environment and health organizations. Most of the dyes are considered as highly toxic compounds and dangerous to the environment and human health as it consists of heavy metals, carcinogenic elements, oxygen – absorbing chemicals, and other toxic compounds that need to be well treated before discharge them back to environment. As a result, federal legislations have directed that all industrials that waste dyes-containing effluents to ensure a full dyes removal before discharging their effluents back to water bodies. Industries have applied many different treatment methods including physical, chemical, and biological methods in order to meet the required legislations. In recent years, many industries started to use electrocoagulation as the main treatment method. This study is focusing on using electrocoagulation (EC) method to remediate artificial colored effluents from coloring agents (brilliant green dye (BG dye) as a model). Electrocoagulation reactor, uses aluminum electrodes, was employed to remove this dye under different initial pH (40-10.0), direct currents (DC) (244-732 mA), and spaces between electrodes (SBE) (4-12 mm). According to the findings obtained, EC was highly efficient in treatment of colored effluents; 95.3% of BG dye was removed at treatment time, SBE, DC and pH of 30 minutes, 4 mm, 488 mA and 7.0, respectively.

1. Introduction

Dye can be defined as a colored, ionizing and aromatics element that chemically linked to the materials is being applied [1, 2]. Dyes or what known as coloring agents, have different chemical compositions, which are generally categorized into 5 groups basing on the chromophores in their structures, namely antraquinone, azo, indigoid, phtalocyanine and arylmethane [2, 3]. On the other hand, there more categorization systems, but not well-known, for example dyes are categorized into organics and inorganics according to the existence of carbons in their chemical structures, and also they are classified into natural and industrial dyes according to the source of the dyes [1, 2, 4]. Dyes are considered one of the raw materials for large number of industries such as paints, paper, furniture, and food industries.

Nevertheless, textile industry is recognized as the most significant consumer of dyes and pigments among all other industries [3, 4]. Textiles industry dates back to before Christ and so considered as one of the oldest industries around the world. It was developed and grows in Egypt, in 5000 B.C., as domestic units, and then it was scaled up to factory producing units in the 1500s [1]. Before the 18th century, textile was not recognized as an industry until machines were firstly used for fabrics manufacturing in the UK. After that, textile industry have seen a vast development in the last century, where millions of tons of fabrics were produced every year [1, 5]. Nowadays, and regarding the global economy, textile industry considered one of the most essential industries. For example, more than 1 million jobs are ensured only by the textile industries in Europe[2]. As the fresh water is an integral part of the textile industry, this development and growth is necessarily accompanied by the same growth in water consumption and quantities of wastewater [6]. One of the biggest problems is that the textile wastewater contains complex chemical compounds that exert toxic effects on all forms of life in the freshwater environment and also on public health [1]. Many researchers have stated that the composition of textile industry have elevated levels of organic matter, phosphate, heavy metals, corrosive materials, intermediates, suspended solids and many other toxic materials [2]. Moreover, it was proven that dyes consumption is vastly increasing around the world. Experts are expecting that the dyes production may reach millions of cubic meters around the world, which results in production of massive quantities of dyes containing effluent. Hence, the recent studies confirmed that the availability of freshwater is being very limited due to the vast discharge of industrial effluents and due to global warming [7-13]. As a result, federal legislations forces textile industries to undertake treatment for the effluent dyes in wastewater to ensure quality of the receiving water bodies. Many treatment methods (chemical, physical and biological) therefore have been applied by the textile industries to fulfill these legislations [2, 4]. At the same time, the literature indicates significant drawbacks for the traditional methods, for example, the biological methods are sensitive to the chemistry of wastewater and generate significant volumes of sludge, the physical methods (especially the membrane ones) are expensive, and the chemical coagulation produces secondary pollutants [14-18]. Countless number of researchers has suggested electrocoagulation (EC) method as an efficient and environmentally safe for the conventional methods [19-21]. For example, the EC method does not consume chemicals in treatment and consequently it does not produce secondary pollutants [22]. Additionally, the EC unit is small in size [23], easy to be operated [24, 25] and relatively cheap [26, 27]. Furthermore, when using the EC method, minor volume of sludge will be produced in comparison with the traditional methods [22, 25], which minimizes the need for the expensive management of the solid wastes [28, 29] and the investment cost of the landfills [30]. Furthermore, many researchers have successfully recycled the sludge of treatment units in different fields, such as the building blocks and concretes [31-36]. The simplicity of the EC units facilitates the integrating of the EC method with other technologies, such as the ultrasonic method [27], to achieve efficient treatment. Therefore, it could be possible to employ the sensing technologies, which witnesses successful applications [37-41], to optimize the performance of the EC units.
Basing on these advantages of the EC, this study is allocated to examine the suitability of the EC to remove textile dyes (brilliant green dye (BG) as model) from artificial textile effluents. The EC treatment was commenced using aluminum electrodes at different operational conditions, including different initial pH (40-10.0), direct currents (DC) (244-732 mA), and spaces between electrodes (SBE) (4-12 mm). BG dye, which is an azo dye, was chosen to be studied as it is broadly used in fabrics manufacturing, and it is dangerous to the environment and human health [42].

2. Methodology

2.1. Chemicals

Brilliant green dye ($C_{27}H_{33}N_2HO_4S$) with 97% purity, caustic soda, sodium chlorides and hydrochloric acid were purchased from Fisher Scientific, UK. Purification processes were not applied for these chemicals.

2.2. Solutions

The required amount of BG dye was dissolved in deionized water to prepare the colored samples (with concentrations of 30 mg/L). pH value was modified for the needed values (4,7 and 10) by adding HCl or NaOH. Colored samples conductivity has been fixed, at 320 µS/cm, using sodium chlorides.

2.3. Apparatus

Using aluminum plates with 1 mm thickness and 99% purity, four rectangular electrodes (with 10cm x 7 cm dimensions) were manufactured by LJMU technicians. To mix water, 35 holes were created by drilling the electrodes. Accordingly, the net area of single electrode is 61.2 cm^2. As illustrated in Figure 1, these electrodes were set up in a plastic container with 1400 mL volume. To provide the required current, a DC power device (with voltage range 0-30 volts) was used in this study.

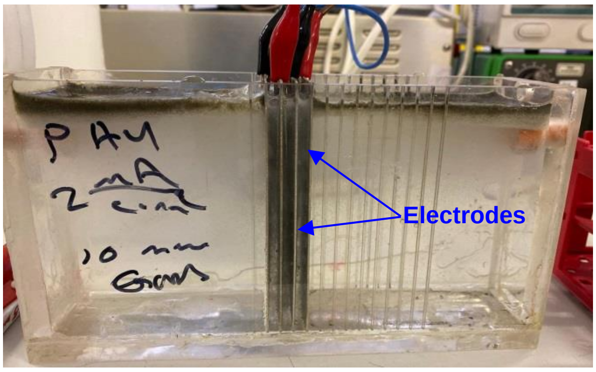

Figure 1. EC unit.

2.4. Electrolyzing of BG dye solution

At the beginning, the artificial colored solutions were poured into the EC unit, followed by installing the electrodes at the required SBE and connecting them to the electricity. Then, the electrolyzing process was initiated by applying the electricity to the electrodes. The treatment process target was to examine the applicability of electrocoagulation method for BG dye removal, and to understand the effects of the SBE, DC and the initial pH on the removal of BG dye by the EC method. Each experiment was commenced for three times to avoid any human error.

2.4.1. Initial pH

Removal of any contaminant, using the EC technology, could be significantly influenced by the pH of solution as it affects characteristics of the polymeric hydroxides [43]. Hence, electrolyzing process was commenced at three different pH values, alkaline (at 10), neutral (at 7) and acidic (at 4).

2.4.2. Electric current

In general, electric current has a directly proportional relationship with the removal efficiency as it the solely reason for anodes desolation (production of coagulation agents) [44]. Hence, influence of electric current on BG dye removal was studied at three different current values, namely 244, 488, and 732 mA.

2.4.3. SBE

It is acknowledged, in the literature, that the SBE influences the resistance for electric currents that, in turn, affects the electrocoagulation efficiency. At wide SBE, high electrical current resistance is developed in the EC unit, which causes faster development of the inert layers on the anodes, and it reduces the removal of BG dye in turn [3, 22]. Thus, three different values of SBE (4,8, and 12mm) were investigated to obtain the best BG dye removal.

3. Results and discussion

3.1. Initial pH

Three different pH values were considered to study pH effect on the removal of BG dye from artificial colored wastewater. As illustrated in Figure 2, it is very clear that pH variation has a significant impact on BG dye removal, where the removal of BG dye dropped from 97.6% at pH 4 to only 70.1% at pH 10.

This effect of pH on the EC performance can be attributed to impact of pH on the chemistry of the formed polymeric hydroxides. In neutral or slightly acidic pH ranges, the prevalent types of polymeric hydroxides have high ability to absorb dyes, which enhances the removal of GB dye [6].

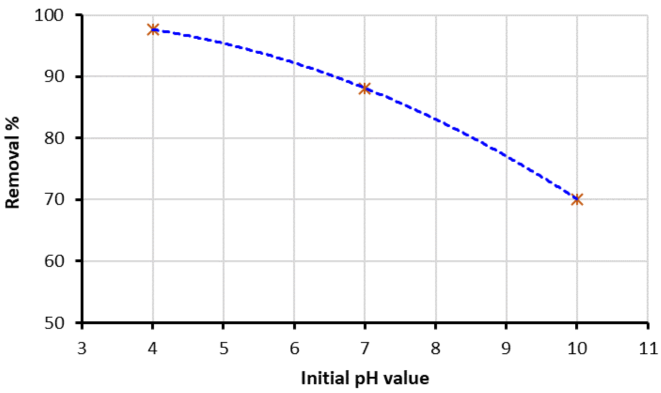

Figure 2. Impact of initial pH on BG dye removal.

3.2. Electrical current

Electrical current has an essential role and impact on the electrocoagulation performance. It is obvious from Figure 3 that BG dye removal is highly influenced by the electric current value. When higher electric current was used, higher removal was obtained. For example, the removal of BG dye was decreased from 99.8% at 732 mA to 88% at 244 mA. This can be attributed to the fact that at high current value, faster desolation of anodes happens, which leads to faster pollutant treatment [3].

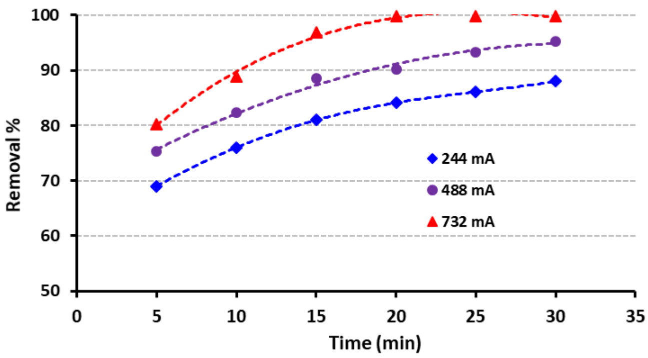

Figure 3. Effects of DC value on BG dye removal.

3.3. SBE

Using initial pH of 7.0 and electric current of 488 mA, the effect of distance between electrodes were investigated using three values (4,8, and 12 mm). It was found that BG dye removal was negatively influenced when increasing SBE, and the best removal (95.3%) was obtained using SBE of 4mm, as shown in figure (4). The decreased in BG dye removal at high SBE is attributed to the negative effect of the SBE on the electrical resistance of EC system, which in turn decreases electrodes desolation and consequently the BG dye removal [3].

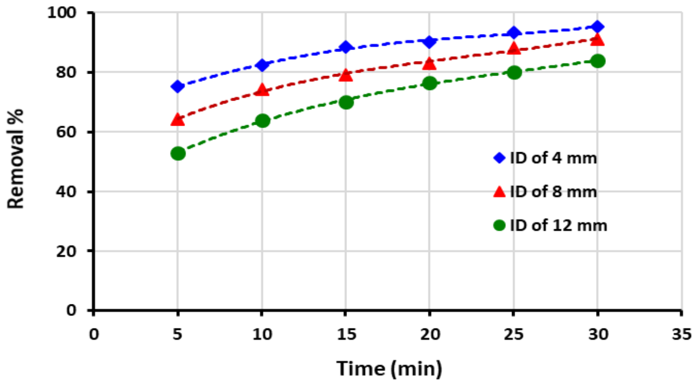

Figure 4. Relationship between SBE and removal of BG dye.

4. Conclusions

One of the main contemporary sources of water pollution is the effluents of textile industry that normally heavily contaminated with various kinds of complicated pollutants; therefore, many different ways were used to reduce the health and environmental risks of these pollutants. The present study investigated the removal of textile dyes using the electrocoagulation process, which has been proven as an efficient alternative to the conventional methods. Electrolyzing of colored solution using aluminum electrodes resulted in 95.3% removal of BG dye within 30 minutes at SBE of 4.0 mm, DC of 488 mA and initial pH of 7.0. Generally, this investigation proved that the removal of BG dye is inversely proportional with both initial pH value and SBE, while it has a direct proportion with the applied DC.

Electrocoagulation is widely used for different kinds of pollutants with various operational conditions, therefore, it is recommended, for future studies, to explore the EC performance on other dyes considering other treatment conditions, such as solution conductivity and temperatures.

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