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Removal of Remazol Yellow from Textile Industry Wastewater by Quaternary Ammonium Polymer

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ABSTRACT*: The use of Remazol Yellow dyes in the textile industry will produce waste that is mutagenic and carcinogenic. The stable nature of remazol causes Remazol Yellow to not be easily degraded photolytically or chemically. If the waste is directly disposed of into water bodies, it will accumulate and last for a long time. Adsorption is one of the textile waste processing methods that is widely used because it is an effective textile waste processing method for degrading dyes, does not require large costs, the adsorbent can be used several times, and the process is simple. This research seeks to establish the appropriate contact duration, temperature, and ideal adsorption concentration of quaternary ammonium polymers within a Remazol Yellow dye solution. The process of dye adsorption by varying the time (10; 20; 30; 40; 50; and 60) minutes, temperature (25, 30, 40, 50, 60, and 70)°C, and initial concentration (10, 20, 30, 40 and 50) ppm. The adsorption of the filtrate was then measured using a UV-Vis Spectrophotometer instrument. The dye in the Remazol Yellow solution was successfully adsorbed by the quaternary ammonium polymer with optimum conditions at 20 minutes, a temperature of 25°C, and an initial concentration of 10 ppm. The optimum adsorption percentages obtained were 98.44%, 98.54%, and 98.25% respectively. From these results, quaternary ammonium polymers can be further applied for dye degradation. Morphological analysis was carried out using a Scanning Electron Microscope (SEM) instrument, obtaining a distribution of polymer pore values after adsorption in the range of 0.84-2.09 µm. The quaternary ammonium polymer structure is in the form of a solid lump after undergoing adsorption of Remazol Yellow.*

Keywords: *Adsorption; Polymer; Quaternary Ammonium; Remazol; Waste Industrial*

1. INTRODUCTION

Dye is one of the essential raw materials in the textile industry. Types of colors are categorized into two, specifically natural and manufactured. Standard colors are derived from natural sources, either from plant parts (such as blossoms, bark, leaves, stems, and roots) or animal parts (such as lac colors). At the same time, synthetic dyes are artificial dyes made from chemicals. Synthetic dyes are often used in the textile industry because they have bright colors and are easier to use . There are various types of textile dyes such as indigosol, rapid, procion, indanthrene, base, napthol, remazol, and among others (Alamsyah, 2018; Subagyo & Soelityowati, 2021; Sari & Damayanti, 2020). The selection of textile dyes is influenced by the type of fabric used, the desired color, and the required color quality.

Among the many synthetic dyes, Remazol dyes are especially prevalent due to their high stability and color vibrancy (Maghfiroh et al., 2016). For instance, Remazol Yellow is frequently used in the textile industry to achieve bright yellow coloration. However, its widespread use generates significant amounts of wastewater containing toxic dye residues. This liquid waste can be hazardous and even cause environmental disasters due to its mutagenic and carcinogenic properties (Said et al., 2022). Additionally, Remazol Yellow contains aromatic azo compounds. The content of these substances has stable properties and produces bright colors. These stable properties prevent Remazol Yellow from being easily degraded photolytically or chemically. If the waste is directly disposed of into water bodies, it will accumulate over time and persist for an extended period (Cristina et al., 2007; Fitriani et al., 2019; Tamirat et al., 2014; Aini et al., 2024).

Given the environmental threat posed by synthetic dye waste, effective wastewater treatment methods are essential. Adsorption is an occasion where a liquid (gas or fluid) is retained by a solid and then forms a film (lean layer) on the surface of the solid (Abdi et al., 2018). Wastewater treatment by adsorption is widely applied in the textile industry. Some of the advantages of effective textile waste treatment for degrading dyes are that it does not require high costs, adsorbents can be used multiple times, and the process is simple (Agusdin & Setiorini, 2020; Darmawan et al., 2024; Maihendra et al., 2016).

The efficiency of the adsorption process depends on factors such as the type of adsorbent, properties of the dye (e.g., polarity and solubility), and operating conditions (Rahayu et al., 2025; Amrillah et al., 2025). Recent research has explored the use of polymeric materials. Polymers are materials consisting of many monomers (small molecules), where the monomers connect and form long chains (macromolecules) (Joseph et al., 2023). Numerous adsorption studies have utilized polymers. This is because polymers can specifically recognize target molecules and have high selectivity (Mustapa & Zulfikar, 2023). Several studies have shown that polymers have the potential to be adsorbents for textile industry waste.

Quaternary Ammonium Polymer is an organic polymer manufactured using a one-pot approach. Quaternary ammonium polymer has an amine functional group (-C-N-) (Rahayu et al., 2021). The amine functional group is crucial in the processes of pollutant uptake, membrane purification, coagulation/flocculation and photocatalytic reactions (Elhalwagy et al., 2023). This polymer has the potential for use in wastewater treatment, particularly in the textile industry. Quaternary ammonium polymer successfully reduced nitrate levels (94.58%), nitrite (87.44%), and phosphate (95.11%) in synthetic solutions. This polymer has been successfully applied to vinasse waste, resulting in a 75.70% reduction in phosphate components, and has also been used for phytoremediation modification of POME waste, reducing COD values by 75% (Rahayu et al., 2023; Hakim et al., 2025; Veranica et al., 2024). This study aims to optimize the use of quaternary ammonium polymer for the adsorption of Remazol Yellow dye from textile wastewater. Specifically, it investigates the effect of contact time and temperature on the dye removal efficiency, intending to establish a simple, fast, environmentally friendly, and cost-effective wastewater treatment method.

2. MATERIALS AND METHODS

2.1. Tools and Materials

The research was conducted in the Chemical Engineering laboratory at Ahmad Dahlan University. The tools used were pipettes, beakers, scales, magnetic stirrers, UV-Vis spectrophotometers, filter paper, water baths, thermometers, analytical balances, cuvettes, funnels and stopwatches. The materials used to make quaternary ammonium polymers, polyethylene glycol 400, isopropyl alcohol (IPA), and ethanol were purchased from Wako 1st Grade, Japan, 2-[(methacryloyloxy)ethyl] tri methylammonium (META) from Sigma Aldrich, 2,2-azobisisobutyronitrile (AIBN) and ethylene dimethacrylate (EDMA) from China. While the materials for making synthetic dye solutions were distilled water supplied from Yogyakarta, and Remazol Yellow purchased from Jombor.

2.2. Polymer Preparation

Quaternary ammonium polymers were prepared using the one-pot method, following the ideal conditions established in earlier research conducted by Rahayu, 2023 in the investigation titled Synthesis and Characterization of Ammonium Polymer for Anion Removal in Aqueous Solutions. The polymer is made from poly (ethylene glycol) ($(C_2H_4O)nH_2O$) 1.4 mL, isopropyl alcohol (C_3H_8O) 1.75 mL, EDMA ($C_{10}H_{14}O_4$) 0.375 mL, $H_2C{=}C(CH_3)CO_2CH_2CH_2N(CH_3)_3Cl$ (META) 1.25 mL, ethanol (C_2H_6O) 0.35 mL, and AIBN 0.005 g, which was homogenized. Then, polymerization was performed in a water bath for 24 hours at 70°C. An example of the reaction involved in creating a quaternary ammonium polymer is depicted in

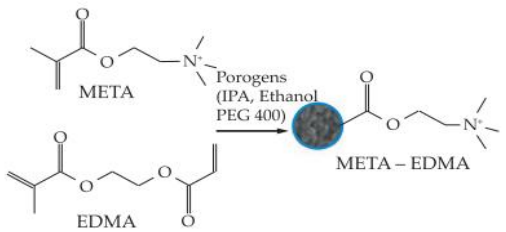


Figure 1. Schematic of the formation of Quaternary Ammonium Polymers (Rahayu, et al., 2023)

2.3. Color Degradation Process

The color degradation process Remazol Yellow solution is adsorbed with quaternary ammonium polymer. Adsorption was carried out with an optimum polymer mass of 0.15 grams (Musnamar, 2024). Various parameter variations are carried out to find optimum conditions with variations in contact time (10, 20, 30, 40, 50, and 60) minutes, temperature variations (25, 30, 40, 50, 60, and 70) °C, and initial concentration (10, 20, 30, 40, and 50) ppm. Furthermore, filtering is performed to separate the adsoebent form the filtrate. The adsorbance value of the adsorption filtrate is determined using a UV-vis spectrophotometer set to a wavelength of 363 nm. The percentage loss (%Re) and adsorption capacity (Qe) can be calculated using equations 1 and 2, respectively (Adawiah et al., 2020; Aini et al., 2023).

$$\%Re = \frac{C_0 - C_e}{C_0} \times 100\% \quad (1)$$

$$Q_e = (C_0 - C_E) \times \frac{V}{W} \quad (2)$$

Description: C_0 represent initial concentration of Remazol Yellow solution (mg/L). V represent volume of Remazol Yellow solution (L). C_E represent final concentration of Remazol Yellow solution (mg/L). W represent mass of quaternary ammonium polymer (g).

3. RESULTS AND DISCUSSION

The removal of Remazol Yellow pollutants occurs by adsorption with liquid and solid phases. The solid-phase quaternary ammonium polymer will adsorb Remazol Yellow pollutants in synthetic liquid waste. The adsorption scheme between Remazol Yellow and quaternary ammonium polymer is shown in Figure 2. The binding of Remazol Yellow to the polymer will decrease the amount of Remazol Yellow present in the liquid waste.

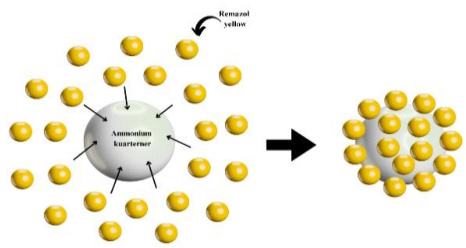


Figure 2. Process of adsorption of Remazol Yellow on quaternary ammonium polymers

3.1. Optimum Contact Time on Remazol Yellow Adsorption

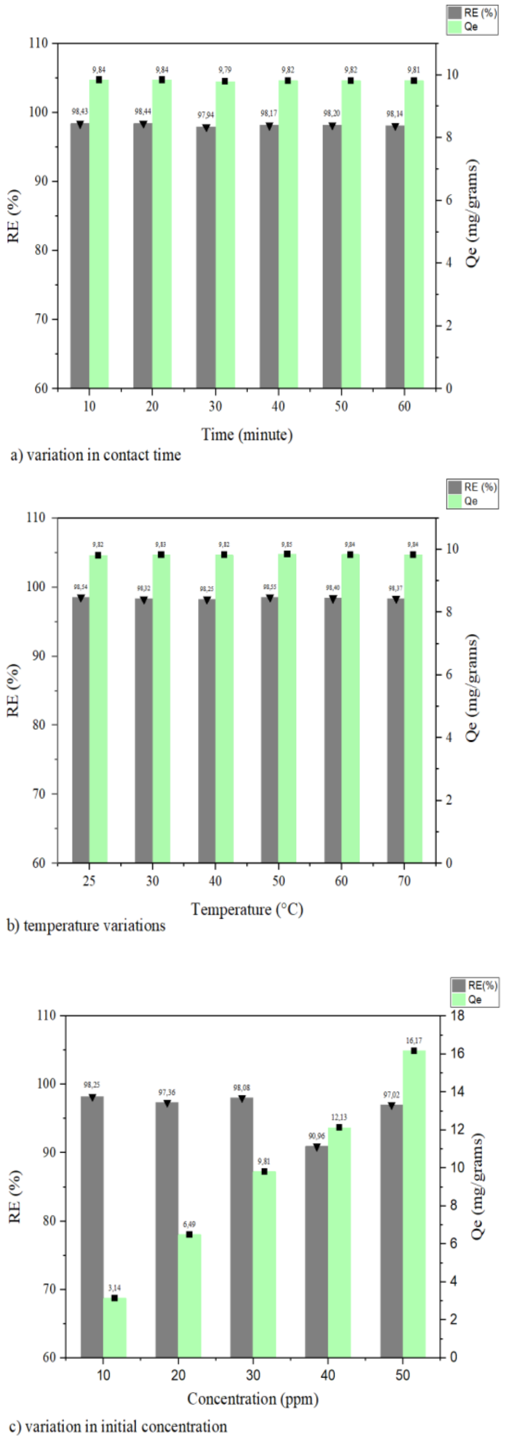


Figure 3. Correlation between the loss percentage and adsorption capacity with contact time, temperature, and initial concentration

One of the elements influencing adsorption is the duration of contact between the adsorbent and the adsorbate. Figure 3 illustrates the variation of the contact time of the quaternary ammonium polymer for (10, 20, 30, 40, 50, and 60) minutes, temperature variations (25, 30, 40, 50, 60, and 70)°C, and initial concentration (10, 20, 30, 40 and 50) ppm.

Based on Figure 3a, the longer the contact time between the Remazol Yellow dye solution and the quaternary ammonium polymer, the lower the adsorption capacity and percent removal values. This occurs due to the desorption process that takes place when the duration of contact between the adsorbent and adsorbate is too extended (Setiawan et al., 2023). Figure 3 b) illustrates that as the temperature increases, both the percentage of removal and the adsorption capacity decrease. This decrease in adsorption capacity is attributed to the degradation of the adsorbent as the temperature increases, resulting in damage to the adsorbent. Damage to the adsorbent causes the dye adsorption process to be inefficient (Vianti & Yustinah, 2015). Figure 3 c) shows that the higher the initial concentration of the dye, the smaller the percent removal value and the greater the adsorption capacity value obtained. The decrease in the percent removal value against the initial concentration is due to the limited active sites, the higher the initial concentration, the greater the need for large active sites (Ifa et al., 2021). The adsorption capacity value increases with the initial concentration of the adsorbate until the adsorbent is saturated and no longer efficient in adsorbing dyes (Hayu et al., 2021). In variations of time, temperature, and concentration, the optimum conditions occurred at 20 minutes, a temperature of 25°C, and a concentration of 10 ppm, respectively. The optimum removal percentage values at time variation and temperature variation were 98.44% and 98.54%, respectively, while at concentration variation, it was 98.25%. The adsorption capacity values under these conditions at time variation, temperature variation, and concentration variation were 9.84 mg/gram, 9.82 mg/gram, and 3.14 mg/gram, respectively. From these results, it can be seen that Remazol Yellow can be degraded well by quaternary ammonium polymers, with a percent removal value of more than 98%.

3.2. Concentration of Adsorbed Adsorbate

The level of Remazol Yellow adsorbed shows that quaternary ammonium is becoming a more effective adsorbent. Figure 3 shows the concentration of Remazol Yellow that can be adsorbed by quaternary ammonium polymer with variations in time and temperature.

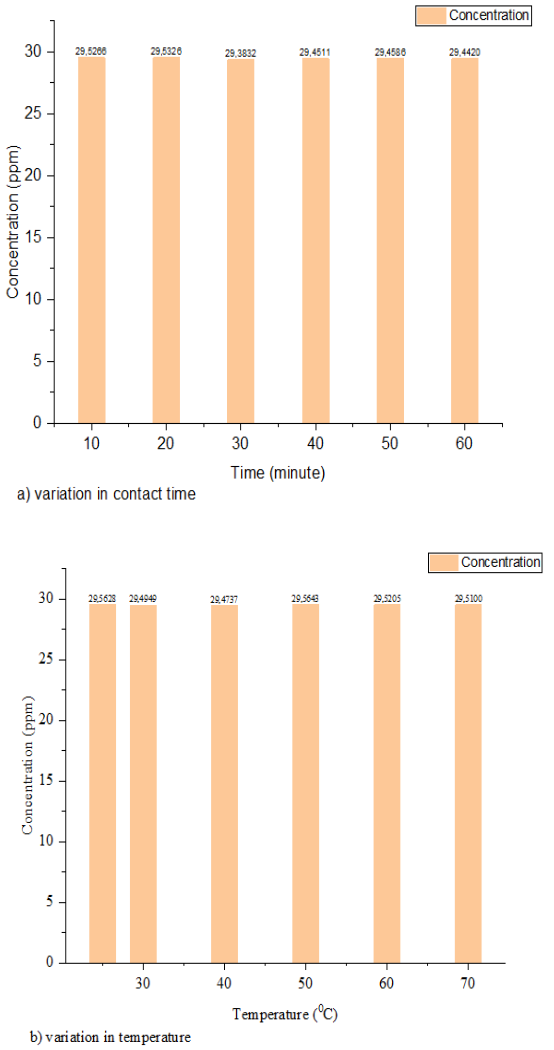


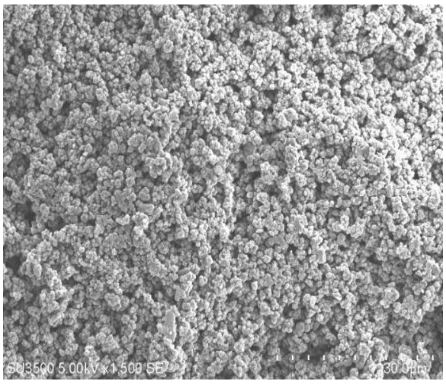
Figure 4. Correlation between the concentration of the adsorbed with the contact time and temperature

Figure 4a shows that the longer the contact time between the adsorbate and the adsorbent, the smaller the concentration of adsorbed adsorbate. The process of Remazol Yellow adsorption with time variation is mainly adsorbed at a contact time of 20 minutes. At that time, the quaternary ammonium polymer adsorbs Remazol Yellow as much as 29.53 ppm. Figure 4 b) shows the relationship between the adsorption process and temperature variation with the amount of adsorbed adsorbate concentration. The higher the temperature used, the less the adsorbed adsorbate concentration. In the temperature variation, it can be seen that Remazol Yellow is mainly adsorbed at a temperature of 25°C of 29.56 ppm. The amount of adsorbed adsorbate is proportional to the percentage of removal produced. The removal percentage and the level of adsorbed adsorbate reach their optimal values at a contact duration of 20 minutes and an operating temperature of 25°C.

3.3. Analytical Morpohology

Morphological analysis of the structure with SEM instrument was carried out with magnification of 1500 and 10004 times. Morphological analysis of the quaternary ammonium polymer structure after experiencing yellow remazol adsorption and the size of the union and macropore can be seen in Figure 5.

The structure of the quaternary ammonium polymer in the form of a solid lump after experiencing Remazol Yellow adsorption can be seen in Figure 5a). The range of macropore size distribution is 0.84-2.09 μm, and the union is 0.72-1.67 μm, which can be seen in Figure 5 b). Based on (Rahayu, 2023), the size of the range decreases from before adsorption with macropores of 0.83-2.41 μm and union size of 1.00-2.08 μm. This indicates that the quaternary ammonium polymer exhibits Remazol Yellow pollutant adsorption with reduced space within the polymer.



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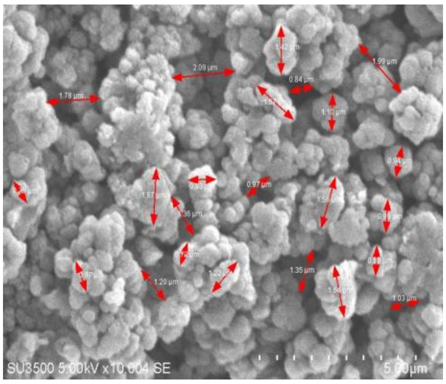

b

Figure 5. Morphology of quaternary ammonium polymer after undergoing yellow remazol adsorption

4. CONCLUSIONS

The quaternary ammonium polymer successfully binds the Remazol Yellow solution dye under optimum conditions, with a reaction time of 20 minutes, a temperature of 25°C, and an initial concentration of 10 ppm. Under these conditions, the percent removal for time variation was 98.44%, for temperature variation, it was 98.54%, and for concentration variation, it was 98.25%. It can be seen that the adsorption percentage between conditions is not significant, which indicates that this system can perform well in a narrow operational range. The concentration of Remazol Yellow adsorbed at a variation in contact time was 29.53 ppm, while at a temperature variation, it was 29.56 ppm. The adsorption capacity values at time variation were 9.84 mg/gram and 9.82 mg/gram at temperature variation, while at concentration variation, it was 3.14 mg/gram. The quaternary ammonium polymer structure is in the form of a solid lump after undergoing adsorption of Remazol Yellow. Quaternary ammonium polymers undergo adsorption with decreasing space. The range of macropore size distribution is 0.84-2.09 µm, and the union is 0.72-1.67 µm.

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