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Research Article

Adsorption Behavior of Rose Bengal Dye onto Eucalyptus Powder: Equilibrium, Kinetics and Thermodynamic Studies

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Abstract
Adsorption is a commonly utilized surface phenomenon which is mainly used for the removal of contaminants from liquid and gas phase. In this paper, the bio adsorption properties of Eucalyptus powder towards the removal of Rose Bengal dye were studied at various conditions including contact time, size of biosorbent, pH value, dose of biosorbent, temperature, and concentration of the initial solution. Adsorption efficiency was investigated through adsorption isotherms, kinetics, and thermodynamics to determine the mechanism and nature of the adsorption process. It has been found that the amount of adsorption is increased up to the contact time of 50 min, at 35 g/L dosage the % removal obtained is 89 % with the optimum pH of 6. The results obtained for adsorption isotherm have shown that the equilibrium data agreed with the Langmuir and Freundlich isotherm models, thus monolayer and heterogeneous adsorption were observed. In addition, kinetics studies showed that the pseudo-second-order kinetics model best fitted for the adsorption mechanism, thus chemisorption was confirmed as the main process involved in the adsorption process.
Keywords: pH, Kinetics, Isotherms, Size, Temperature.

1. Introduction

Adsorption refers to the surface phenomenon wherein molecules, ions, and/or atoms from the liquid/gaseous phase get concentrated on the surface of a solid material called adsorbent. Being relatively simple, economical, effective, and easy to perform, adsorption has become one of the major processes used for removal of contaminants from industrial effluents and water resources [1-2].

Fast-paced development of industry and urbanization result in release of toxic substances, for instance, dyes, heavy metals, pharmaceutical residues, and organic compounds, thus creating severe ecological and health hazards. Thus, there is a need to create effective remediation technologies. A number of technological approaches have been developed for treatment of pollutants, including adsorption that became of interest due to its ability to remove pollutants at relatively low concentrations. Different adsorbents have been developed, among them being activated carbon, biochar, natural clays, agricultural waste, nanomaterials, and polymeric composite materials [3-4].

Adsorption largely depends on the presence of different factors, e.g., surface area, porous structure, pH, temperature, contact time, nature of adsorbate, and adsorbent. Adsorption studies normally include the study of equilibrium adsorption isotherms, kinetic adsorption studies, and adsorption thermodynamics in order to better comprehend the adsorption phenomenon and improve operational conditions. Adsorption isotherm models, such as Langmuir and Freundlich adsorption isotherm models, can be used to describe the adsorbate-adsorbent interactions, while kinetic adsorption models provide an insight into the rate-limiting factors involved in the adsorption process [5-6]. Additionally, thermodynamic parameters are used to determine the feasibility and spontaneity of adsorption reactions and their type. In this study, the biosorption efficiency of Eucalyptus powder in removing Rose Bengal dye is studied.

2. Experimental Procedure

2.1 Reagents and Materials

All of the chemicals used during the experiment were analytical grades and there was no further purification done on them. For the preparation of the required pH, 0.1N HCl and 0.1N NaOH solutions were used in the dye solution.

2.2 Preparation of Biosorbent

Collect Eucalyptus leaves and wash off any dust that is adhering to them. In order to cleanse any dust and other soluble impurities from the sample, it is required to be washed in distilled water thoroughly. Repeat this step until the rinse water becomes clear. In order to reduce moisture, place the leaves under the sun or in a hot air oven between 40 to 60 °C until they stabilize in terms of weight. For grinding the dried shells into a powder form, a mechanical grinder must be used. For obtaining fractions of the appropriate particle size (53, 75, 105, 125, and 152 μm in the present study), the powder should be sieved.

2.3 Preparation of the 1000mg/L of Rose Bengal Solution

The required solution is prepared using analytical grade reagents and double distilled water. 1 gram of Rose Bengal was fully dissolved in distilled water in a 1-liter volumetric flask to form 1000 ppm Rose Bengal stock solution.

2.4 Studies on Equilibrium Biosorption

A measured amount of Eucalyptus powder was added to a known volume of aqueous solution in the presence of a known time period using an orbital shaker for performing biosorption in a batch mode. The following is the description of techniques employed to study various factors: temperature, pH, initial concentration of lead in aqueous solution, biosorbent particle size, biosorbent dosage, and shaking time.

3. Results and Discussion

3.1 Effect of Agitation Time

A graph showing the percentage biosorption of the Rose Bengal dye against agitation time can be seen in Figure 1, which can provide an equilibrium agitation time with interaction time intervals of 3 to 180 minutes. During the study, the biosorbent particle size was 53 μm, and the dosage was 10 g/L (0.5 g dissolved in 50 mL of water). Initially, the rate of biosorption was fast. From 0 to 50 minutes, the percent elimination was rapidly increasing. The biosorption was near to being constant from 50 minutes onwards since the equilibrium state had been achieved with a start concentration of 20 ppm. The biosorption clearance value was 69% after 50 minutes of agitation time. Fewer available surface sites and electrostatic repulsion between the adsorbed dye and the bulk dye are the reasons why there is less dye sorption on the biosorbent surface [7].

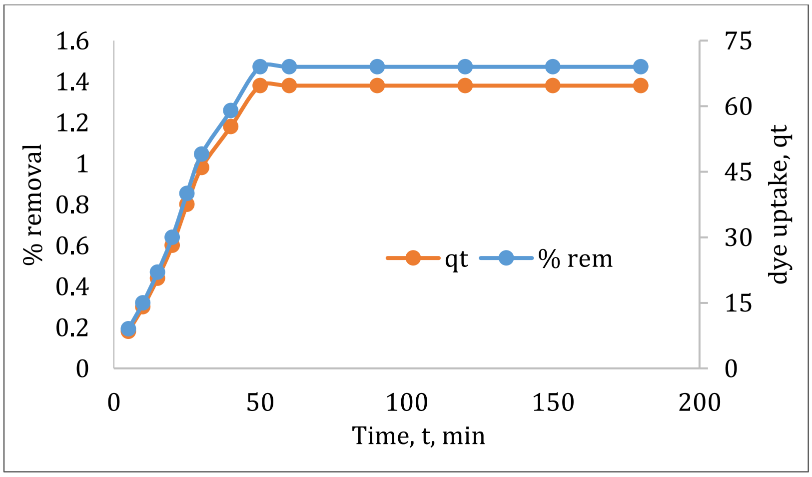

Figure 1. Effect of time on % removal of dye.

3.2 Effect of Biosorbent Size

The relationship between the biosorbent size and the biosorption percentage of the Rose Bengal dye from the aqueous solution are determined. Figure 2 presents the findings, which illustrate the percentage of the biosorption of the Rose Bengal dye with respect to the biosorbent size. The reduction in the biosorbent size from 150 μm to 53 μm resulted in an increase in the removal efficiency of the dye from about 45% to 69%. It can be expected that this will happen since the increase in the biosorbent size [8].

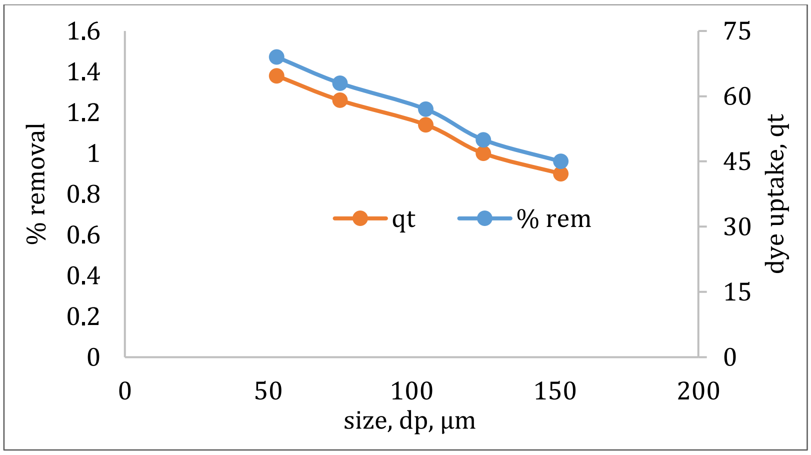

Figure 2. Effect of size on % removal of Rose Bengal dye.

3.3 Effect of pH

The relationship between the pH level of the aqueous solution and the biosorption efficiency of Rose Bengal dye is illustrated in Figure 3. As can be seen from the graph, the pH significantly influences the % biosorption of the RB dye. The highest biosorption was observed at pH = 6, during which about 75% of the dye was removed. The increase in pH leads to the negative charge of the surface due to lower hydrogen ion concentration [9].

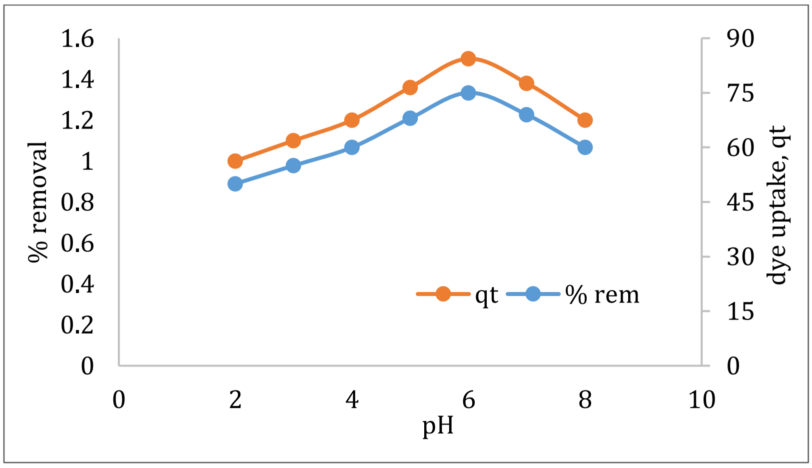

Figure 3. Effect of pH on % removal of Rose Bengal dye.

3.4 Effect of Initial Concentration of Rose Bengal Dye

As seen from Figure 4, there is a direct relationship between the starting concentration of Rose Bengal dye in the aqueous phase and the percentage biosorption of Rose Bengal dye. As the value of C0 changes from 20 mg/L to 150 mg/L, there will be a corresponding drop from 75% to 46% of biosorption of Rose Bengal dye. This is due to the increasing amount of biosorbate relative to the constant active sites [10].

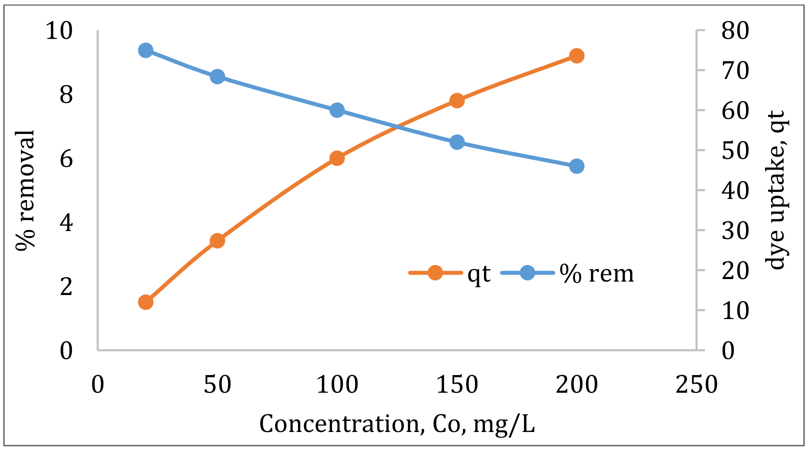

Figure 4. Effect of initial concentration on % removal of Rose Bengal dye.

3.5 Effect of Biosorbent Dosage

Figure 5 represents the amount of Rose Bengal dye biosorption relative to the dose of the biosorbent with a 53µm size of the biosorbent. As can be seen, increasing the biosorbent dosage from 10g/L to 35g/L increased Rose Bengal dye biosorption from 75% to 89%. This can be explained by the fact that the higher the biosorbent dosage, the greater the number of active sites for biosorption [11].

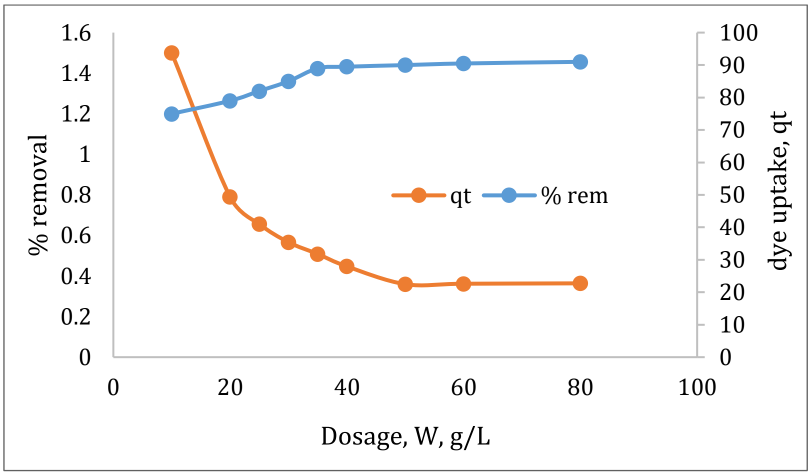

Figure 5. Effect of dosage on % removal of Rose Bengal dye.

3.6 Effect of Temperature

Equilibrium adsorption of the dye was found to be affected greatly by the temperature. Figure 6 demonstrates how changes in temperature influence the Rose Bengal dye uptake. As it can be seen from the graph, an increase in the temperature resulted in a higher Rose Bengal dye uptake, only at temperatures greater than 303 K. These findings indicated different interactions between the dye and ligands of the cell wall. Biosorption was usually exothermic at temperatures below 303 K [12].

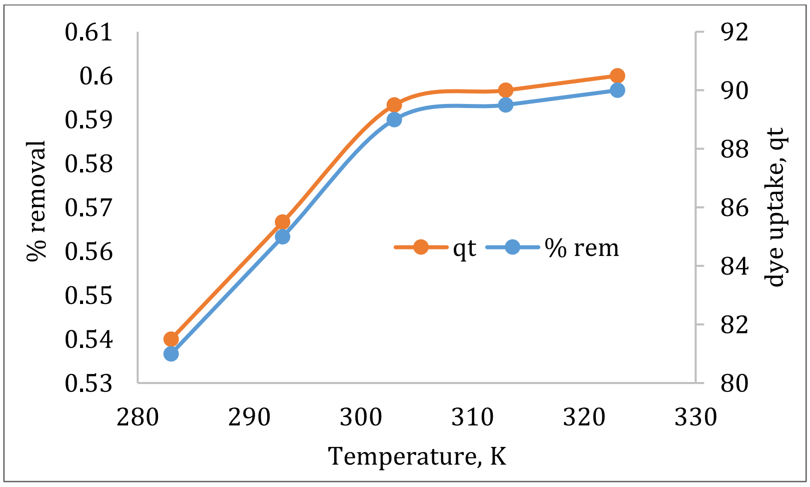

Figure 6. Effect of temperature on % removal of Rose Bengal dye.

3.7 Isotherms Studies

3.7.1 Langmuir Isotherm

Langmuir isotherm is drawn for the present data between (Ce/qe) and Ce and shown in Figure 7.
The plot has yielded the equation:

$Ce/qe = 0.0807\ Ce + 3.2333$, $R^2 = 0.9952$

3.7.2 Freundlich Isotherm

Freundlich isotherm is drawn for the present data in Figure 8 between log Ce and log qe.
The equation obtained is:

$\ln qe = 0.593 \ln Ce - 0.4783$, $R^2 = 0.9894$

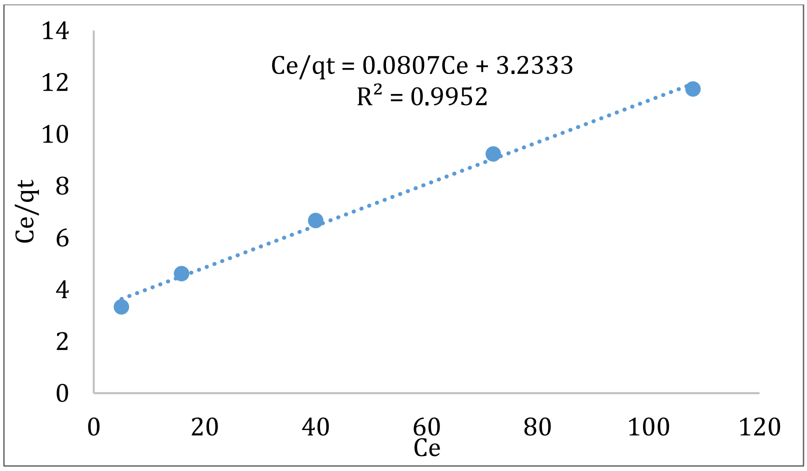

Figure 7. Langmuir isotherm.

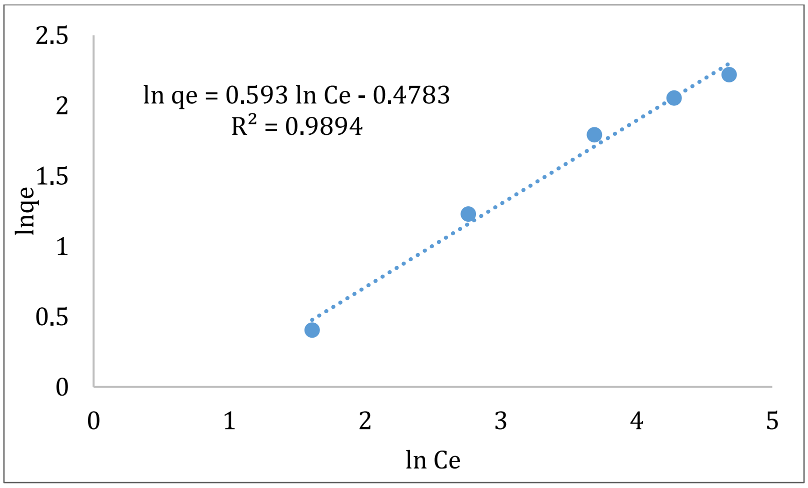

Figure 8. Freundlich isotherm.

3.7.3 Temkin Isotherm

The present data are analyzed according to Temkin isotherm equation and the linear plot is shown in Figure 9 [13]. The resulting equation is:

$q_t = 2.5193 \ln C_e - 2.9902$, $R^2 = 0.9815$

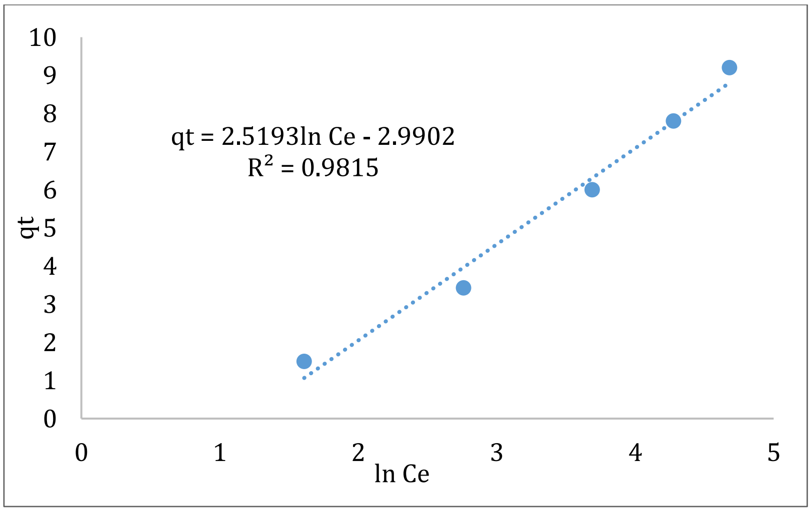

Figure 9. Temkin isotherm.

3.8 Kinetics Studies

3.8.1 First Order Kinetics

The order of adsorbate – adsorbent interactions have been described using kinetic models.

Applying the initial condition qt = 0 at t = 0, we get log (qe – qt) = log qe – (K_1/2.303) t [14].

Plot of log (qe–qt) versus 't' gives a straight line for first order kinetics, facilitating the computation of first order rate constant (K_1). If the experimental results do not follow the above equation. The resulting equation is:

log (qe-qt) = -0.0224t+0.2713, R^2 = 0.9543

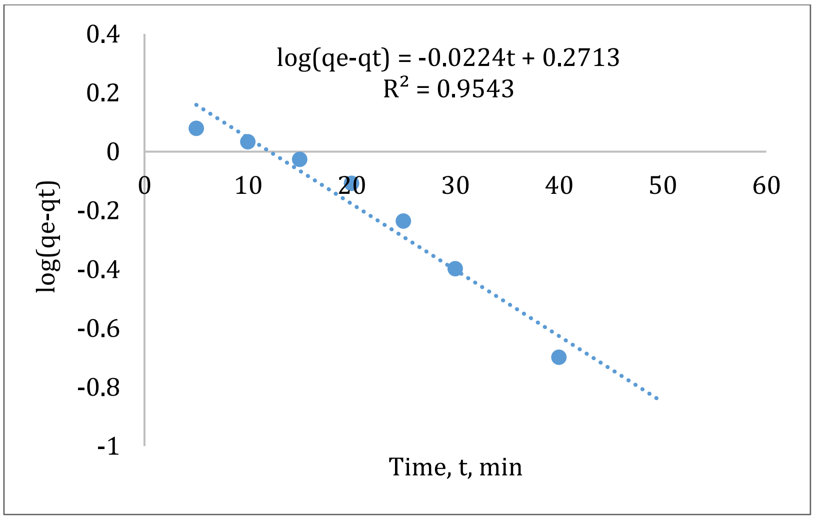

Figure 10. First order kinetics studies of Rose Bengal dye.

3.8.2 Pseudo Second Order Kinetics

If the pseudo second order kinetics is applicable, the plot of (t/qt) versus 't' gives a linear relationship that allows computation of qe and K_2. In the present study, the kinetics are investigated with 50 mL of aqueous solution (C0= 20 mg/L) at 303 K plot between (t/qt) and 't' for 53 μm [15]. Pseudo second order kinetic equation: Rearranging the terms, we get the linear form as: (t/qt) = (1/ K_2qe^2) + (1/qe) t. The resulting equation is:

t/qt = 0.0685t + 30.624, R^2 = 0.1284

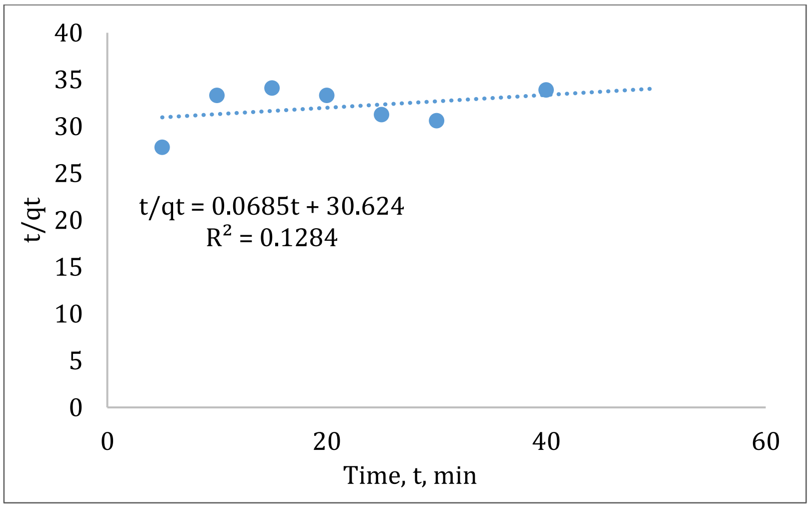

Figure 11. Second order kinetics studies of Rose Bengal dye.

3.9 Thermodynamics Studies

Preliminaries are directed to understand the Rose Bengal dye removal varying the temperature from 283 to 323 K [16]. The Van't Hoff plots showing the effect of temperature on removal of nickel metal is showed up in Figure 12. The resulting equation is:

log(qt/Ce) = -0.7646/T +1.8872, R^2 = 0.9031

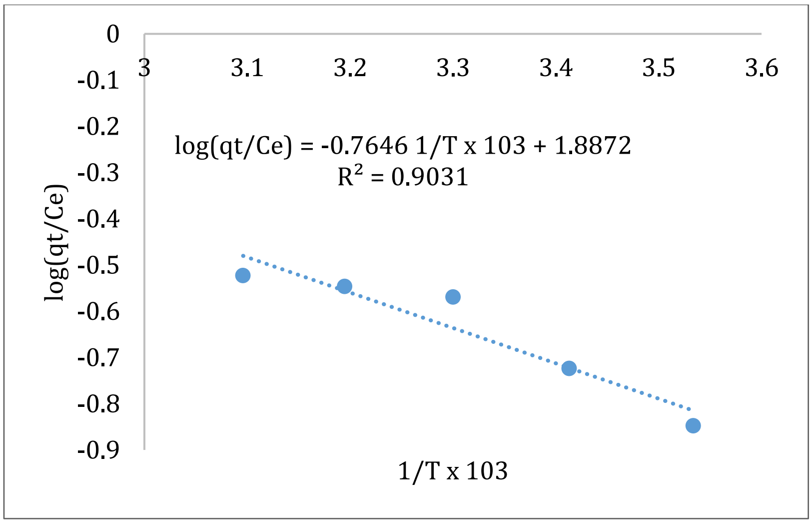

Figure 12. Thermodynamics studies of Rose Bengal dye.

4. Conclusions

The goal of this research is to identify whether Eucalyptus powder could be used as a biosorbent to extract the Rose Bengal dye, leading to the following results:

- ✓ The equilibrium agitation time to perform dye biosorption is 50 minutes.
- ✓ The percentage biosorption of RB dye was reduced due to the rise in the biosorbent size from 53 µm (69%) to 152 µm (45%).
- ✓ Percentage biosorption of RB dye from the aqueous solution increases significantly due to an increase in pH from 2 (50%) to 6 (75%).
- ✓ The ideal dose for biosorption is 35 g/L.
- ✓ Consequently, the powdered Eucalyptus mentioned above is a very effective biosorbent that may remove dye Rose Bengal.

Declarations

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Author Contributions: CAIR: Conceived and supervised the study, designed the experimental methodology, interpreted adsorption, kinetic, equilibrium, and thermodynamic results, critically reviewed and edited the manuscript, and approved the final version; JA: Conducted laboratory experiments, prepared Eucalyptus powder biosorbent and Rose Bengal dye solutions, performed batch adsorption studies, collected experimental data, analyzed adsorption parameters, and contributed to manuscript drafting; RMK: Assisted in data processing, literature review, interpretation of adsorption isotherm and kinetic studies, preparation of figures and tables, and manuscript revision; IMD: Contributed to literature review, interpretation of findings, manuscript editing, critical revision for intellectual content, and approved the final manuscript.

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