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Research Paper

Adsorption Equilibrium Isotherm Study of Gold Removal Using Regenerated Activated Carbon from Cyanidation Leachate

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Abstract: Regenerated activated carbon is a type of activated carbon that is reused in adsorption processes after undergoing elution and regeneration. This study evaluates the adsorption performance of regenerated activated carbon compared to fresh activated carbon based on the Freundlich isotherm constant and adsorption heterogeneity. Adsorption experiments were carried out on gold-bearing cyanidation leach solutions with an initial gold concentration of 0.804 mg/L using various activated carbon dosages of 0.25 g/L, 0.50 g/L, 1.0 g/L, 2.0 g/L, 4.0 g/L, and 8.0 g/L. All other parameters affecting absorptivity were kept constant for each dosage, including an adsorbate volume of 0.5 L, free cyanide concentration of 200 mg/L, agitation speed of 150 rpm, contact time of 5 hours, ambient temperature, pH of 10.5, and activated carbon particle size between 1.18-2.36 mm. The results indicate that the Freundlich adsorption constant (K_f) of regenerated activated carbon was 1370 (log K_f = 3.1368), closely comparable to that of fresh activated carbon, which was 1632 (log K_f = 3.2127). The adsorption heterogeneity index (1/n) for regenerated activated carbon was 0.47, also like that of fresh activated carbon (0.46). The optimum dosage of regenerated activated carbon was found to be 4 g/L, yielding a gold adsorption efficiency of 98.7% with a relative activity of 100% compared to fresh carbon, and resulting in a low residual gold concentration of 0.011 mg/L.

Keywords: Activated Carbon; Adsorption; Freundlich Isotherm; Gold; Regeneration.

1. Introduction

Activated carbon is a key material used in gold processing industries employing the cyanidation leaching method. Its primary role is to capture gold that has been dissolved during leaching prior to subsequent elution and electrowinning stages. Activated carbon, an organic material with a graphite-like structure, possesses an extremely well-developed internal pore network that gives rise to an exceptionally high specific surface area, often exceeding 1000 m^2 per gram [1]. Commercial activated carbon is commonly produced from coconut shells that undergo pyrolysis at temperatures of approximately 800-1000 °C. This process generates three major products: char, bio-oil, and gas. The char fraction may be further processed into activated carbon or utilized directly as a high-calorific fuel [2].

Repeated use of activated carbon in adsorption circuits gradually diminishes its performance due to the accumulation of organic and inorganic foulants on its surface. Regeneration is therefore required to remove these impurities. Activated carbon that has undergone this recovery process is referred to as regenerated activated carbon. Its adsorption capability must be evaluated and compared to fresh carbon to ensure that it remains suitable for reuse. In adsorption studies, fresh activated carbon is

typically used as a reference standard, with its performance regarded as 100% relative activity for comparison with regenerated samples [3].

The relative capacity of an adsorbent to uptake a solute can be interpreted using the Freundlich isotherm constant (K_f), whereas the interaction strength between adsorbent and adsorbate is associated with the heterogeneity factor (1/n). Higher K_f values indicate greater adsorption capacity, while lower 1/n values reflect stronger binding interactions [4].

Norit Americas Inc., a major activated carbon manufacturer, recommends equilibrium adsorption isotherm testing as a basis for selecting carbon products for industrial applications. Data obtained from isotherm testing may be interpreted in two general ways. The first involves directly plotting the residual solute concentration against adsorbent dosage to determine the carbon requirement associated with a desired residual concentration and to estimate adsorption capacity. The second approach applies the Freundlich isotherm model: the logarithm of the adsorbed solute concentration is plotted against the logarithm of the equilibrium solute concentration. This method provides key equilibrium parameters essential for evaluating process economics. Isotherm experiments are typically conducted by contacting a constant volume and initial concentration of adsorbate solution with various doses of activated carbon while maintaining a fixed contact time [5]. Previous studies have reported adsorption characteristics of activated carbon used in Indonesian gold plants. The investigated the capacity of fresh activated carbon using cyanidation liquor supplemented with synthetic gold solution to achieve an initial concentration of 52.5 mg/L. The study reported adsorption capacities of 4,486 g/ton for gold and 1,307 g/ton for silver, although the equilibrium residual gold concentration remained relatively high at 1.0 mg/L [5-6].

Sasmita I. evaluated the performance of regenerated activated carbon from the same processing plant, reporting adsorption capacities of 713 g/ton at an initial gold concentration of 1.1 mg/L and a carbon dosage of 1.0 g/L with a 5-hour contact time. The capacity increased to 774 g/ton after 24 hours. Adsorption efficiencies were 89.7% at 5 hours and 97.6% after 24 hours, with residual gold concentrations of 0.135 mg/L and 0.033 mg/L, respectively [7]. These earlier works focused primarily on adsorption capacity and percentage removal at specific contact times, without examining adsorption equilibrium behavior or identifying optimum carbon dosages.

In the present study, adsorption tests were performed using cyanidation leach solution with an initial gold concentration of 0.804 mg/L. Activated carbon dosages were varied at 0.25, 0.50, 1.0, 2.0, 4.0, and 8.0 g/L. All other operating parameters were maintained constant across treatments, including a solution volume of 0.5 L, free cyanide concentration of 200 mg/L, agitation speed of 150 rpm, contact time of 5 hours, ambient temperature, solution pH of 10.5, and carbon particle sizes between 1.18 and 2.36 mm.

Despite the extensive use of activated carbon in gold recovery circuits, published studies focusing on regenerated carbon have largely emphasized short-term adsorption performance rather than equilibrium behavior. The literature provides limited information on the isotherm characteristics of regenerated activated carbon, particularly when used directly on low-grade cyanidation liquors that more accurately represent industrial operating conditions. Moreover, the optimum dosage of regenerated carbon required to achieve a specific target residual gold concentration has not been clearly established in previous research [8].

The present study addresses these knowledge gaps by evaluating the equilibrium adsorption isotherm of regenerated activated carbon and comparing its performance with fresh carbon under strictly controlled cyanidation conditions. The work provides new insights into the Freundlich isotherm constant (Kf) and heterogeneity factor (1/n) for regenerated carbon, thereby offering quantitative indicators of both adsorption capacity and surface interaction strength. Determining the optimum

carbon dosage also contributes directly to improving process efficiency and operational cost structures for carbon-in-leach or carbon-in-pulp circuits [9,10,11].

Overall, the scope of this investigation includes assessing adsorption equilibrium across multiple carbon dosages, determining Freundlich isotherm parameters for regenerated and fresh carbon, identifying the optimum carbon dosage for high-efficiency gold uptake, and providing comparative performance metrics relevant to industrial adsorption-desorption-regeneration (ADR) systems. The findings are expected to support improved carbon management strategies and enhance the economic sustainability of gold recovery operations.

2. Research and Methodology

2.1 Equipment and Materials

The primary equipment used in this study was an adsorption test apparatus consisting of an open, mechanically agitated tank equipped with internal baffles. The detailed configuration of the system is illustrated in the schematic diagram presented in Figure 1.

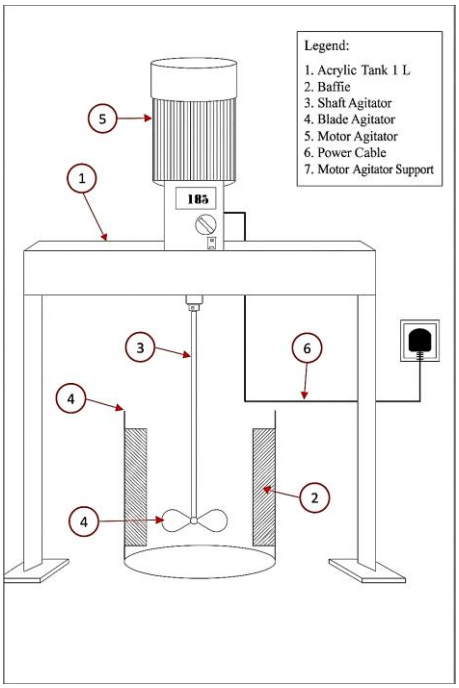

Figure 1. Schematic layout of the activated carbon adsorption testing equipment

The adsorbents used in this study consisted of two types of coconut shell–based activated carbon: fresh activated carbon obtained directly from a commercial manufacturer and regenerated activated carbon that had undergone multiple adsorption cycles in an industrial circuit followed by a regeneration process. Laboratory analysis of the regenerated carbon indicated the presence of 24 g/t of gold and 30 g/t of silver, while data for other metals were not available. The adsorbate solution was an alkaline cyanidation liquor containing 0.804 mg/L of gold, 200 mg/L of free cyanide, and a pH of 10.5. This solution was sourced from the cyanide leaching process of a gold ore treatment facility operating in North Sulawesi Province, Indonesia.

2.2 Experiments

The independent variable selected for this research was the dosage of activated carbon, which was varied at 0.25 g/L, 0.50 g/L, 1.0 g/L, 2.0 g/L, 4.0 g/L, and 8.0 g/L. The choice of carbon dosage

as the key variable was based on recommendations from Norit Americas Inc., a major activated carbon manufacturer, which states that determining the Freundlich isotherm constant (K_f) and the heterogeneity factor (1/n) requires adsorption data obtained over a broad range of adsorbent concentrations. Such data are also necessary for identifying the optimum adsorbent dosage for equilibrium adsorption studies [5, 12, 13].

The experimental procedure began with washing the activated carbon to remove surface impurities, followed by oven-drying at 105 °C for four hours to eliminate moisture. The dried carbon was then sieved to obtain particle sizes in the range of 1.18-2.36 mm. For each adsorption test, predetermined masses of activated carbon corresponding to 0.125 g, 0.25 g, 0.50 g, 1.0 g, 2.0 g, and 4.0 g were contacted with 0.5 L of alkaline cyanide solution containing 0.804 mg/L of dissolved gold.

Adsorption experiments were conducted in a baffled, mechanically agitated tank operated at an agitation speed of 150 rpm for a total contact time of 5 hours. At the completion of the adsorption period, the agitator was switched off, and the slurry was allowed to settle until the carbon had fully separated from the supernatant. A 100 mL aliquot of the clarified solution was then collected for analysis to determine the residual gold concentration. Gold measurements were performed using Atomic Absorption Spectroscopy (AAS), providing the data required for isotherm modeling and evaluation of adsorption efficiency.

2.3 Data Analysis Technique

Interpretation of the equilibrium adsorption isotherm data was carried out using the Freundlich isotherm model. In this approach, the logarithm of the amount of adsorbate adsorbed per unit mass of carbon is plotted on the Y-axis, while the logarithm of the equilibrium concentration of the adsorbate remaining in the solution is plotted on the X-axis. The linear relationship obtained from this plot allows the equilibrium parameters to be determined, providing quantitative insight into both adsorption capacity and surface heterogeneity of the activated carbon samples [5, 14]. The Freundlich isotherm equation can be expressed in its linearized form as follows:

$$\log q_e = \log K_f + \frac{1}{n}\log \mathrm{C_e} \quad (1)$$

The Freundlich constants, K_f and 1/n, were obtained from the linear regression of the log plot of q_e versus Ce, where the intercept represents K_f and the slope corresponds to the heterogeneity factor 1/n [8]. The magnitude of K_f reflects the relative adsorption capacity of the activated carbon, whereas the value of 1/n indicates the intensity and heterogeneity of the adsorption interaction. A higher K_f value signifies greater adsorptive capability, while smaller 1/n values imply stronger interactions between the adsorbent surface and the adsorbate molecules [4, 15].

3. Results and Discussion

3.1 Freundlich Adsorption Constant and Heterogeneity Factor

The Freundlich adsorption constant (K_f) obtained for the regenerated activated carbon was 1370, which is very close to the K_f value of the fresh activated carbon sample, measured at 1632. The Kf value was determined from the antilogarithm of the intercept derived from the linearized adsorption isotherm presented in Figure 2.

This result indicates that the regenerated activated carbon exhibited excellent adsorption performance, suggesting that the carbon regeneration process carried out in the combustion unit (regeneration kiln) was highly effective. Another factor that may have contributed to the relatively high Kf value is the low level of inorganic contaminants, likely due to acid washing prior to feeding the carbon into the regeneration kiln. A study by J. Avraamides et al. (1992) [16] reported that the adsorption efficiency of regenerated activated carbon increased to 86% when acid washing was applied, compared with only 57% for regenerated carbon without acid washing. These findings highlight the importance of impurity removal in restoring adsorption functionality. In general, a higher

Kf value reflects greater adsorption capacity, whereas a lower heterogeneity factor (1/n) signifies stronger interaction between the adsorbent surface and the adsorbate molecules [4, 10,17].

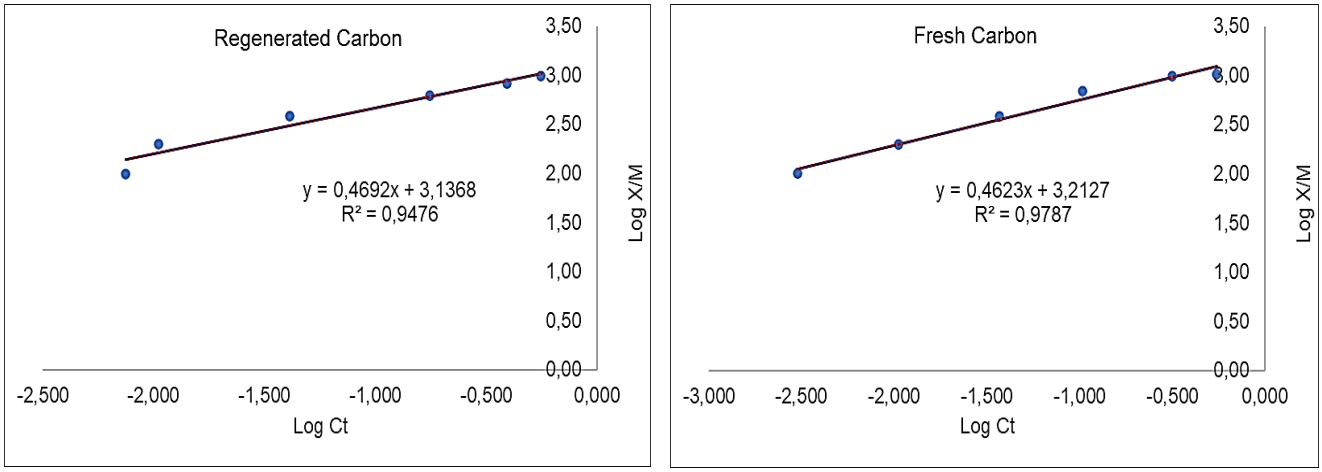

Figure 2. Experimental Freundlich Adsorption Isotherm for fresh and regenerated activated carbon

The heterogeneity factor (1/n) for the regenerated activated carbon was 0.47, which is very close to the value obtained for the fresh activated carbon used as the reference material (0.46). Such low heterogeneity values indicate high adsorption capacity and strong interactions between the adsorbent surface and the gold species in solution [11,18]. A lower 1/n value is also consistent with reduced carbon consumption to reach equilibrium between the gold loaded onto the carbon and the gold remaining in solution [13,19].

The correlation coefficients obtained from the linearized Freundlich model were 0.95 for the regenerated carbon and 0.98 for the fresh carbon, demonstrating that the experimental adsorption data fit the model well and can be considered reliable for isotherm interpretation. The optimum activated carbon dosage was determined to be 4 g/L, achieving 98.7% gold removal and a relative activity of 100% compared with fresh carbon, as shown in Figure 3. The residual gold concentration in solution was reduced to 0.011 mg/L, satisfying the target specifications of the gold processing plant where the study was conducted [20-22].

These findings are generally consistent with the study by Sasmita Irfan (2024), which reported an adsorption efficiency of 89.7% at a carbon dosage of 1.0 g/L. This value is slightly higher than the 78.1% obtained in the present study for the same dosage. The difference is attributable to the higher initial gold concentration used in Sasmita's experiment (1.1 mg/L). This trend aligns with established adsorption theory, where initial solute concentration is recognized as a key factor influencing adsorption performance [23-25].

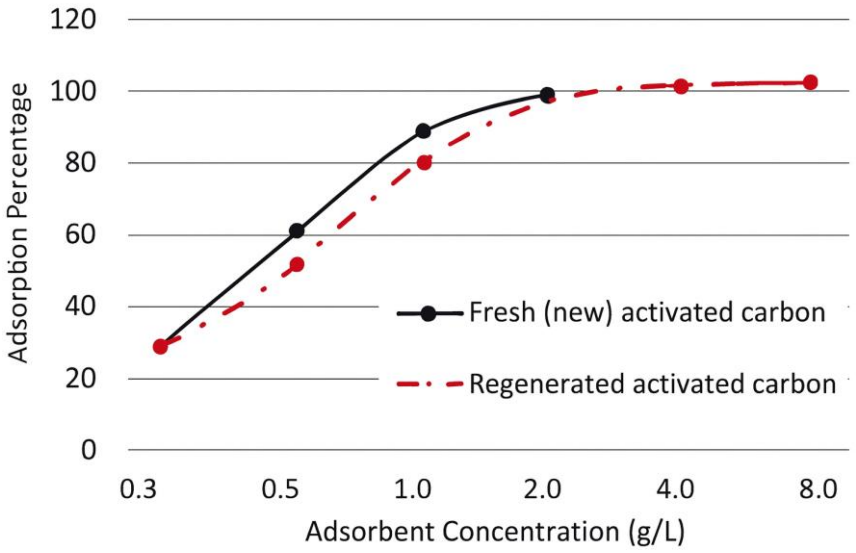

Figure 3. Relationship between adsorption percentage and adsorbent concentration

4. Conclusion

The regenerated activated carbon used as the adsorption medium for gold demonstrated adequate performance, as reflected by its Freundlich isotherm constant (K_f) and heterogeneity factor (1/n), both of which were comparable to those of fresh activated carbon. These results indicate that the regeneration process is functioning effectively and can restore adsorption capacity to a level closely resembling that of new carbon. Further investigation is recommended for eluted carbon discharged from the elution circuit prior to regeneration to evaluate whether its adsorption capacity remains sufficient. Understanding the adsorption behavior of eluted carbon would allow the regeneration frequency to be optimized and potentially reduced, resulting in lower energy consumption within the regeneration kiln and improved operational efficiency. Additional chemical savings and fuel-energy reductions within the gold elution circuit may be achieved through improved carbon management practices, particularly by maintaining the activated carbon dosage at its optimum level of 4.0 g/L and ensuring that residual gold concentrations in the adsorption effluent remain low. A detailed assessment of the organic content of both the feed and the regenerated carbon is also recommended to provide deeper insights into the efficiency of the regeneration process and to identify potential opportunities for further performance enhancement.

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