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Parametric Study on the Adsorption of Gold onto Activated Carbon from Gold Cyanide Solutions

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ABSTRACT

The adsorption process using activated carbon is widely adopted in the gold extraction industry. This study investigates the effect of the adsorbent concentration, initial gold concentration, pH, contact time, agitation speed and the total dissolved solids on the adsorption of gold onto activated carbon from gold cyanide solutions. Adsorption was found to be strongly affected by the aforementioned factors, with the exception of the initial gold concentration and total dissolved solids (TDS). The optimum values obtained were 10 g/L (adsorbent concentration), pH 10, and 70 rpm (agitation speed), achieving more than 90% adsorption in less than 40 minutes at ambient temperature and pressure.

1. INTRODUCTION

Adsorption is one of the most important processes in the gold extraction industry. Other processes of equal importance include leaching and desorption.

Gold adsorption is the transfer of gold ions from the leachate solution to the surface and pores of the adsorbent. The most widely used adsorbent in the gold extraction industry is activated carbon.

Activated carbon plays a very important role in this industry. Gold extraction plants are classified into three types based on the positioning of the carbon in the process [1]:

- Carbon in Column (CIC): Carbon exists in a separate column and contact happens between the gold pregnant solution and the activated carbon.
- Carbon in Leach (CIL): Leaching and adsorption occur through a series of tanks. Carbon in Leach (CIL): Leaching and adsorption occur through a series of tanks, activated carbon is present in the same tanks where the leaching occurs. Carbon and slurry come into contact from the very beginning of the process.
- Carbon in Pulp (CIP): Leaching and adsorption occur through a series of tanks series, activated carbon is located in the tanks succeeds the leaching first tanks, the contact between the carbon and the slurry takes place after that.

Various types of activated carbon exist. Different types may be chosen for different applications, with several material characteristics working together to affect how the material performs in a given scenario [1]:

In choosing an activated carbon for use in gold recovery, the characteristics below are of key importance. These characteristics vary as a result of both the physical and chemical properties of the material, which differ depending upon the source of material and processing methods used to produce the activated carbon. In addition to the activated carbon characteristics several other factors affecting the gold adsorption may include the pulp density,particle size of carbon, organic materials in the solution/slurry, inorganic materials in the solution/slurry, temperature, cyanide concentration, pH, Ionic strength, gold tenor and process contact time.[1]

Cyanidation is the most used technique in the world for the processing of gold, but due to cyanide's highly toxic nature the process is very controversial (UNEP/OCHA Environment Unit, March 2000). Once the mineral has been sent through these processes, lime (calcium hydroxide) or soda (sodium hydroxide) is added to ensure that the pH is over 10.5 during cyanidation. At low pH, the toxic HCN gas is formed [2][3][4]:

$$Au(CN)^{-}_{2} + H+ \rightarrow AuCN + HCN \qquad (1)$$

The ore is subsequently treated with either sodium cyanide or calcium cyanide, while Oxygen is introduced into the slurry to facilitate dissolution of the gold.[1]. The cyanide anions release the gold's cations, oxidizing the gold and making a soluble aurocyanide metallic complex, sodium dicyanoaurate (I) (NaAu(CN)2). The resulting gold cyanide complex is very stable. The gold is dissolved according to the Elsner reaction [1]

$$2Au(s) + 4CN^{-} + O2(g) + 2H2O(l) \rightarrow 2Au(CN)2(aq) + 4OH^{-} \qquad (2)$$

Cyanide can be used to extract gold, either in a controlled mill environment, or more crudely on rock piles in the open.

Activated carbon and resins readily adsorb gold from pregnant solution. The main advantages of carbon are its high selectivity towards gold, its efficient elution characteristics and it's relatively large particulate structure. The activated carbon is introduced into the solution, where it traps the gold on it. The carbon adsorbs the gold relatively quickly (8-24 hours) [5].

Methods Other than adsorption are being used in the separation of gold from the leachate (absorption using ionic liquids (liquid extraction) [6], membrane separation [3] but adsorption is the most common process.

Adsorption can be either physical or chemical in nature. Physical adsorption depends on the physical, or van der Waals, force between the solid adsorbent and the adsorbate molecules. On the other hand, when molecules of the adsorbate are held to the surface of the adsorbent by chemical forces or bonds, the adsorption is called chemical adsorption or chemisorption.**[7]**

The adsorption phenomenon occurs at all interfaces: 1) Solid-Gas 2) Liquid-Gas 3) Solid-Liquid 4) Solid-Solid 5) Liquid-Liquid. Adsorption of gold onto activated carbon is observed to be affected by different parameters as: adsorbent dosage concentration, initial gold concentration, contact time, interfering species, total dissolved solids (T.D.S), agitation and pH. This paper aims to investigate the dependence of these parameters on the gold extraction yield.

2. MATERIALS AND METHODS

2.1 Chemicals and materials

All experiments were conducted at Royal Gold Mining SARL. The chemicals used included sodium cyanide (95%), sodium hydroxide (98%), and 2,6-dimethyl-4-heptanone. Gold standard solution, In this study, Fresh activated carbon (Figure (1)), was utilized without any additional pre-treatment. The material used was GoldSorb™ 5500, a high performance activated carbon produced by Jacobi Carbons. It is derived from coconut shell and characterized by a particle size of 8*16 mesh and a specific surface area of approximately 1100 m^2/g. All experiments were carried out using synthetic solutions. Gold standard solution was used for the preparation of gold cyanide solutions.

2.2 Characterization

A pH meter (Model a-AB23PH OHAUS CORPORATION, USA) was used, Infrared absorption spectra were obtained using az(GBC Savant AA Version3.4 spectrometer. A DLAB Mx-T6-Pro LCD Digital Tube Roller was used for agitation. Total Dissolved Solids were obtained using a (LAQUA-PC220-K) water quality meter.

2.3 Preparations of working solutions

Gold solutions with target concentrations of 2 mg/L, 6 mg/L, 10 mg/L were prepared by serial dilution from a certified gold standard solution. To each gold solution, 500 ml of sodium cyanide solution (1g/l by volume) was added.

2.4 Adsorption experiments

The gold cyanide solution was transferred to a bottle and all adsorption experiments were conducted by means of the bottle-on-rolls method. Experiments were performed at the desired agitation rate and pH. The pH was adjusted using NaOH. Activated carbon was placed on the bottle, samples of the solution were taken and analyzed using GBC spectrometer to measure adsorption%.

The percentage adsorption was determined by the following equation:

$$AD = \left(C_0 - \frac{C_t}{C_0}\right) \times 100 \qquad (3)$$

The adsorption capacity was calculated using the following equation:

$$Q_t = (C_0 - C_t)\frac{V}{M} \qquad (4)$$

Where Q_c is adsorption capacity (mg/g), C_o and C_f are initial and equilibrium concentration (mg/L), respectively, M is the adsorbent mass (g) and V is the volume of solution (L).

Activated carbon amounts (1,3,and 5 g) were shaken at (20,50,70) r.p.m. for time intervals (60,120,180) min in different 500ml bottles containing 500ml adsorbate of (2,6,10) mg/L gold cyanide at pH (10,11,12) at ambient temperature and different T.D.S of (distilled(0 mg/L), brackish (5000 mg/L), and saline water(16000mg/L)).

Figure 1. Activated Carbon sample

Every parameter was changed while the other parameters were kept constant.

3. RESULTS AND DISCUSSION

3.1 Effect of Activated Carbon concentration

Gold cyanide solution (5 mg/L Au conc., pH=10, ambient temperature and pressure) Were rolled in 3 bottles, 500 ml liter each by a bottle roll device at a speed of 50 r.p.m, three adsorbent conc. 2,6 and 10 g/l were put each in one bottle in order to examine the adsorption percentage, adsorption rate, and the adsorbent capacity at different concentrations of the activated carbon.

The experiment showed that the amount of gold adsorbed onto activated carbon increased as the adsorbent concentration rose from 2 to 10 g/l. The adsorption rate also accelerated with higher concentrations of activated carbon during the first 80 minutes. However, once approximately 80% of the adsorption capacity was reached (around 40 minutes), the rate of adsorption slowed across all adsorbent concentrations. As shown in Figure(2).

This behavior is typical of adsorption kinetics and is often described by **pseudo-second-order models**. The fast initial stage corresponds to surface adsorption, while the slower stage reflects diffusion into pores and equilibrium effects. **Langmuir isotherm behavior** where maximum capacity is approached and additional adsorption becomes increasingly difficult.

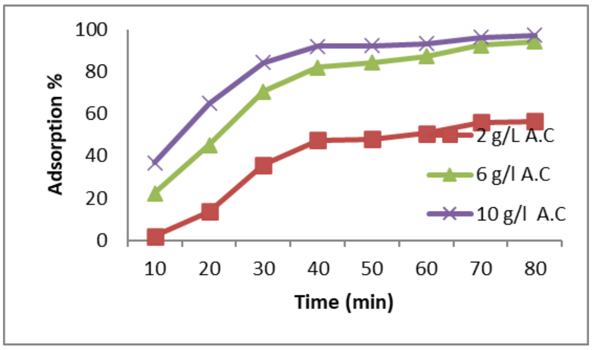

Figure 2. Effect of Activated Carbon concentration on gold adsorption onto activated carbon

3.2. Effect of initial gold concentration

Activated carbon were rolled with gold cyanide solution of gold concentrations 2,5 and 10 mg/L (pH=10, ambient temperature and pressure) by a bottle roll device at a speed of 50 r.p.m, 5g of activated carbon were put in each bottle in order to examine the change in the adsorption percentage, adsorption rate, and the adsorbent capacity at the different initial gold concentrations.

The influence of initial gold concentration is depicted in Figureure (3). The adsorption percentage slightly increased as the initial conc. was increased from 2 to 10 mg/L; the differences in the adsorption percentage between the different initial gold concentrations were not high as shown in Figure. (3). Adsorption rate was observed to be slower after 80% of the (capacity examined) were reached in all the Samples as shown in Figure(2).Gold adsorption observed to be approximately independent of initial gold concentration.

The slight increase in adsorption percentage with rising initial gold concentration (2–10 mg/L) indicates that activated carbon possesses a high affinity for gold ions, enabling near-complete adsorption even at lower concentrations. This explains why adsorption was approximately independent of initial concentration. The observed slowdown after ~ 80% capacity is consistent with adsorption theory: as high-affinity sites become saturated, the concentration gradient between solution and adsorbent decreases, and gold ions must diffuse into less accessible micro-pores, resulting in slower uptake. Thus the system is governed primarily by adsorbent capacity and site availability rather than initial solution concentration.

These results align with Nicol and co-workers [4] who demonstrated that adsorption efficiencies remain above 95% across varying initial gold concentrations, confirming that adsorption percentage is largely independent of solute concentration. McDougall et al. [8] described the mechanism of gold cyanide adsorption on activated carbon as an initial ion-pair formation followed by reduction, accounting for the rapid early uptake and slower rates as sites saturate.

3.3. Effect of pH

The effect of pH was examined by varying the pH of the gold cyanide solution using caustic soda (NaOH) to prepare 3 solutions with pH 10,11, and 12 (pH=9 was excluded to avoid the danger of HCN evolution), three bottles of 500 ml of gold cyanide solution 5mg/L, 5g of activated carbon were rolled in a bottle roll device in a speed of 50 r.p.m, at ambient temperature and pressure.

The adsorption percentage decreased as the pH increased from 10 to 12, adsorption percentage on pH 11 and 12 were close while the difference between the adsorption percentage of pH 10 and 11 were bigger as shown in Figure. (3). Adsorption rate was observed to be slower after 80% of the (capacity examined) were reached after 30 min of the experiment in all the Samples as shown in Figure (4).

The decrease in adsorption percentage with increasing pH from 10 to 12 can be attributed to changes in both solution chemistry and adsorbent surface properties. At pH 10, the carbon surface is less negatively charged, favoring athe decrease can be explained dsorption of the negatively charged $Au(CN)_2^-$ complex. As pH rises to 11, deprotonation of surface groups (hydroxyl, carboxyl) increases electrostatic repulsion and hydroxide competition, leading to a marked reduction in adsorption. Beyond pH 11, the surface is already highly deprotonated, so further increases in pH produce only minor changes in adsorption percentages.

These findings are consistent with earlier studies such as adsorption-desorption experiments reported in the journal of chemical technology and metallurgy, reviews of cyanide leaching technology published in Multidisciplinary Digital Publishing Institute [9][10][11][12][13][14].

3.4. Effect of agitation

Activated carbon 5g and gold cyanide solution of gold concentrations 5 mg/L (pH=10, ambient temperature and pressure) 500 ml each were rolled by a bottle roll device at different agitation speeds 20, 50,and 70 r.p.m, in order to examine the influence of the agitation on the adsorption percentage, adsorption rate, and the adsorbent capacity at the different agitation speeds.

The adsorption percentage increased as the agitation speed increased from 20 to 70 r.p.m as shown in Figure (5),

The increase in adsorption percentage with agitation speed can be attributed to enhanced mass transfer and improved contact between activated carbon and gold cyanide complexes. Higher agitation reduces the boundary layer thickness around carbon particles, decreases external diffusion resistance, and prevents particle settling, thereby exposing more adsorption sites. Consequently, adsorption efficiency rises as agitation speed increases from 20 to 70 r.p.m. These findings align with earlier studies. [12][13]

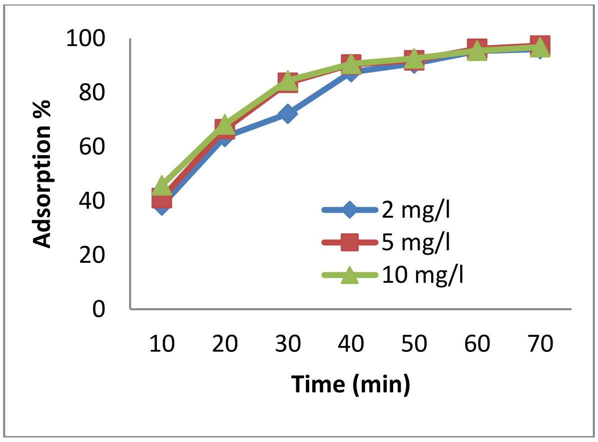

Figure 3. Effect of initial gold concentration on gold adsorption onto activated carbon

3.5. Effect of Total Dissolved solids (T.D.S)

To examine the influence of the total dissolved solids (T.D.S) on the adsorption three water types (fresh/distilled water T.D.S=0), (Brackish water T.D.S= 5000 mg/L), and (saline water T.D.S= 16000 mg/L) were used to prepare the three gold cyanide solutions of gold concentrations 5 mg/L (pH=10, ambient temperature and pressure) 500 ml each. Samples were rolled by a bottle roll device in

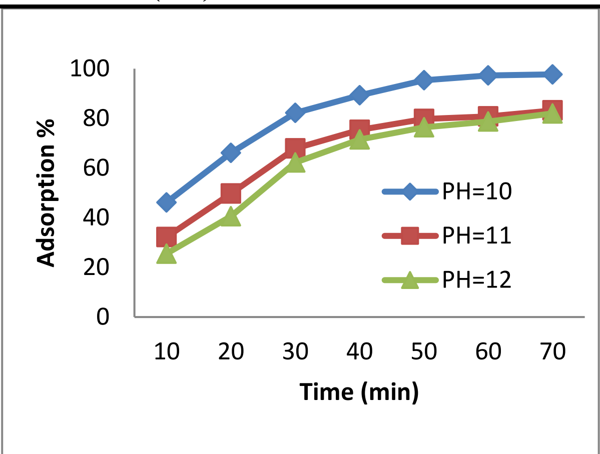

Figure 4. Effect of pH on gold adsorption onto activated carbon

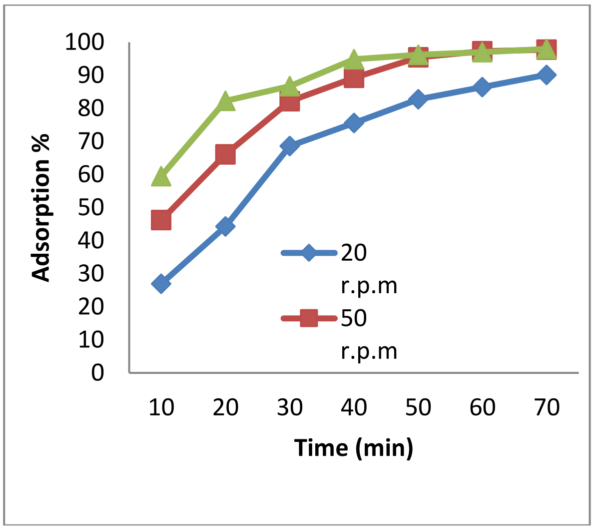

Figure 5. Effect of agitation on gold adsorption onto activated carbon

the presence of 5g of activated carbon on each bottle.

The adsorption percentage slightly decreased as the T.D.S increased from 0 to 16000 mg/L. The decrease can be explained by the fact that at higher TDS levels, fewer adsorption sites are available for gold ions because some pores are occupied by dissolved solids.. As the results illustrate in Figure (6).

3.6. Effect of contact time

All the experiments were conducted versus time. Contact time was observed to be the most effective parameter. A rapid increase in adsorption percentage was initially observed between 10 and 40 minutes because adsorption sites were more accessible during this stage, resulting in a higher adsorption .The influence of contact time was present with every change on the other affecting parameters examined as shown in Figure (2,3,4,5,6).

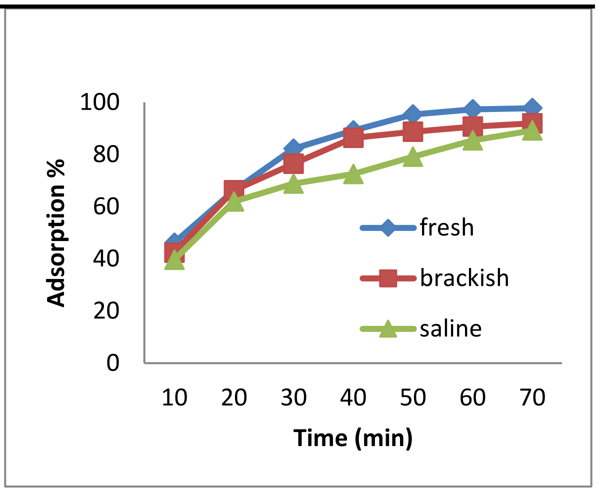

Figure 6. Effect of T.D.S. on gold adsorption onto activated carbon

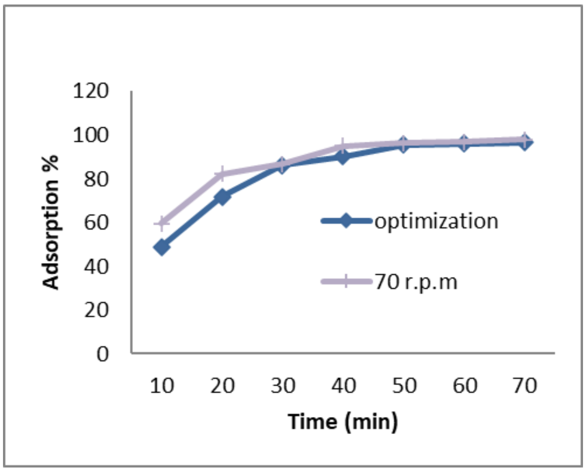

Figure 7. Comparison between the highest AD% obtained from experiment

Based on the experiments conducted it was found that contact time, adsorbent concentration, pH and agitation, were the major parameters affecting adsorption onto activated carbon and has the greater influence.

Final experiment was conducted using the values of all affecting parameters found to achieve the highest adsorption percentage from the previous experiments.

The results obtained from the optimization experiment were observed to be the highest compared to all exceeding experiments results except the results from Figure (5) with identical parameters but the initial gold concentration were 5 mg/L as illustrated in Figure (6). that assists the results concluded that initial gold concentration has low or no effect on gold adsorption onto activated carbon.

4. CONCLUSION

The impact of adsorbent concentration, initial gold concentration, PH, contact time, agitation and total dissolved solids on the gold adsorption from gold cyanide solution onto activated carbon was studied.

Adsorption percentage and adsorption capacity were used to measure the effect of each parameter by varying the values of one parameter while keeping other parameters constant.

The impact of the adsorbent concentration, agitation, contact time and pH was found to be major on gold adsorption onto activated carbon, while the influence of initial gold concentration of gold cyanide solution and the T.D.S was found to be minor.

Higher values of adsorbent concentration, agitation speed, and contact time were found to increase the adsorption percentage, while it was the opposite with the pH values.

Optimum values obtained from the study were 10mg/L,10,70r.p.m for adsorbent concentration, PH, agitation respectively to achieve more than 90% adsorption at less than 40 minutes contact time at ambient temperature and pressure.

Other parameters not covered in this study may also influence the adsorption process; this study simulated the adsorption on (CIC). Adsorption on other forms of gold ore processing as (CIL and CIP) could have different results. Further experiments are recommended to obtain more information about the adsorption of gold onto activated carbon.

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