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Optimum Conditions For The Recovery Of Gold Using Electrowinning Machine For Artisanal Miners, A Case Of Study Of Ragada, Niger State

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ABSTRACT

The research work involved the study of the optimum conditions for the recovery of gold using electrowinning machine for artisanal miners. Gold ore sample was collected from Ragada, in Niger State. The ore was analyzed using SEM. The ore was upgraded using panning. The upgraded material was leached and the leachate which was analyzed using AAS was served as the electrolyte for the electrowinning of Ragada ore. A simple electowinning cell was designed and fabricated using locally sourced materials and gold metal was recovered using electrowinning process. The study was achieved through sample collection and sample preparation of gold ore using different processes which include: characterization (SEM),crushing, grinding, particle sizing, concentration,washing, drying, and leaching and electrowinning.. A very simple electrowinnig cell was designed and fabricated using locally sourced materials. The electrowinning processwas carried out using the fabricated cell by varying pH, of the electrolyte,extraction temperature and time as optimization parameters in order to obtain high electrowinning efficiency. The studies shows that the optimum conditions for gold recovery using the fabricated electrowinning cell is at a pH of 6, temperature of 90 °C and time of 90 minutes. During the electrowinnig process, the container showed some sign of rusting indicating that the ore is a sulphide ore. The process is simple, environmentally friendly and affordable to artisanal and small-scale miners. It is recommended that further research and modifications should be carried out in order to improve on its design and efficiency.

Keywords: Extraction, Concentration, Leaching, Electrowinning, Fabrication, Recovery.

I. INTRODUCTION

Metals are needed for survival. Our bodies rely on metals to perform many vital functions. Metals form a foundation for our modern standard of living. They are continuously transported and transformed by geological processes. They usually originate as minerals that are discovered, mined, and transformed into metal (Hansoo, et al 2008).

Gold is a precious metal found in nature as free metal, sometimes pure as nuggets, flakes, or very fine colloidal particles. Gold is the oldest and valuable metal known by man. The demand is based on the grade and purity of these metals (Afzal, et al, 2007).

The mining sector in Nigeria consists of the formal large-scale subsector, the formal small-scale miners and the informal (illegal miners) small scale or artisanal miners (Svotwa and Mtetwa, 1997). Many artisanal and small-scale miners in Nigeria especially in the North-western part of the country are usually involved in the mining of gold and other valuable metals and these practices are done mostly in traditional methods (the use of mercury and other toxic substances), which are considered to be harmful and less effective. At the end a very low recovery and low grade of metal is produced and most of valuable gold will be lost to tailings. According to “Roadmap for the Growth and Development of the Nigerian Mining Industry” gold is a strategic mineral commodity, which should be mined and processed in an environmentally safe and sustainable manner for both domestic and export markets (Sada, 2016).

Artisanal and Small-scale Gold Mining isa subsistence or livelihood activity primarily carried out in rural areas. Artisanal and Small-scale Gold Mining is generally viewed negatively because of its potential health hazards caused by mercury used in gold ore processing. Alternative method of gold processing which is environmentally safe should be developed for use in Artisanal and Small-scale Gold Mining which is commonly carried out in rural areas. Artisanal and Small-scale Gold Mining carries a significant environmental burden, especially mercury use in gold ore possessing and its attendant pollution, which is acknowledged. Plans must be made to mitigate the consequences of mercury use in Artisanal and Small-scale Gold Mining in a sustainable and environmentally safe manner (Phiri, 2012).

The mining world has been seeking ways of eliminating the use of mercury completely in Artisanal and Small-scale Gold Mining in line with the Minamata Convention and one of the techniques is the use of environmentally safe processes; concentration of the ore using gravity method and extractive metallurgical process using electrowinning method to purify the gold concentrates. It must be noted that the reagents used for the electrowinng process must be safe to actually purify the gold concentrate in line with Article 2, paragraph 4 of the Minimata Convention, “using the most appropriate combination of environmental control measures and strategies” not only to purify but also to concentrate the gold (MSF, 2010).

Furthermore, for the well-being of present and future generations of Nigerians and humanity generally, mercury use in Artisanal and Small-scale Gold Mining should be reduced or eliminated. To illustrate this point: if a pregnant woman is exposed to mercury, she may give birth to a mentally and/or physically disabled child. Methylated mercury can pass the placental barrier and cause development deficiencies such as a loss of intelligence, decreased language skills, memory and attention. Methylated mercury in adults has also been linked to increased risk of cardiovascular disease including heart attack. It can also cause neurological symptoms such as loss of physical coordination, difficulty of speech, narrowing of the visual field (tunnel vision), hearing impairment, blindness and death (GEUS, 2013).

Extraction of metals from aqueous solutions or their salts is called electrowinning. Electrometallurgy is a very young technology that was born just after the discovery of electric current in the nineteenth century. In 1800, Alessandro Volta made the first electric pile and in the same year, Carllisle and Nicholson used Volta’s pile to decompose water into hydrogen and oxygen. Humphrey Davy in 1807 officially was the first one who used the knowledge in electrochemistry for metallurgical aims (Zadra, et al 1950). Humphrey decomposed sodium and potassium from caustic soda and caustic potash in a large battery and, for the first time, identified these two elements as metals. His assistant, Michael Faraday, in 1830 found relationships between the current and amount of deposited material. Since then, considerable developments in purification of metals via electrometallurgical methods have been achieved.

The process of EW simply involves passing an electric current through the electrolyte (eluate). Electricity is passed from the cathode; the negative electrode through the solution into the anode; the positive electrode completing the electrical circuit. The current causes the gold to plate out onto the steel wool cathodes. The electrolyte in gold EW is the solution. High throughput of the EW cells provides low-cost option for silver producers in particular and therefore leads to increased productivity.

EW is applied to a wide variety of chemical solution found in extractive electrometallurgy industry. Most common metals recovered by EW are copper, gold and silver. For practical purposes, the degree to which a metal can be recovered by electrowinning depends on its position in the electromotive series. In general, metals with higher electrode potential plate easier compared to metals with lower electrode potential. For example, noble metals like gold and silver can be removed from solution to less than 1 mg/l using flat plate cathodes whereas with copper and tin, concentration in the range of 0.5 to 1 g/L or more is required for a homogenous metal deposit (Zadra, et al 1952).

The EW of metal, or the production of metals from their ores one put in solution or liquefied, is the oldest industrial electrolyte process. Metal deposition rates are key parameters in developing an effective EW unit. EW is not a viable recovery technology for all metals, while the process works well for metals with high electro potential, such as gold, silver, copper, cadmium and zinc, it does not work as well on others, such as chromium. Nickel can be recaptured also. However, the process is pH sensitive and thus must be rigorously maintained for any deposition to occur (Lundstrom, et al 2019)

Operation of the EW process differs depending on the elution procedure that is used. In the case of Zadra elution, where the electrowinning cell is in series with the elution column, the column and cell must be designed to elute and recover the gold by recirculation of the eluate until the gold content is low enough (< 100 g/t) to be reactivated and returned to the adsorption circuit (Mike, 2015).

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Electrowinning cell is design based on a cylindrical packed bed of steel wool as cathode. The electrolyte was introduced to the center of the cell and flowed through the packed bed and out of the top of the cell. The anode was a cylinder of punched plate or mesh stainless steel located around the cell's outer circumference.

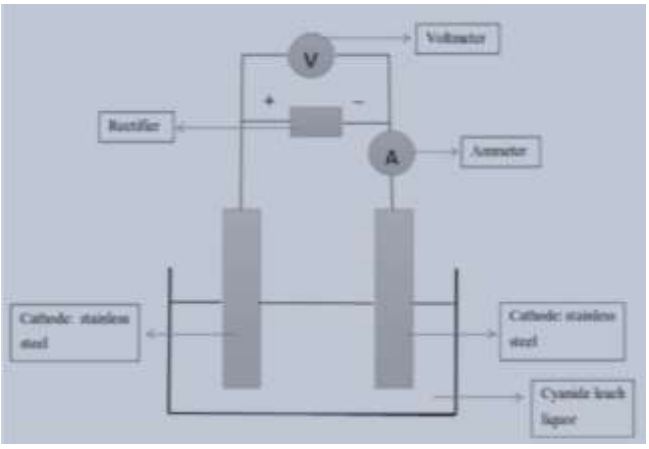

Figure 1: Schematic diagram of an electrowinning cell

Gold is recovered from pregnant (gold-bearing) solution by the process of EW. An electric current is passed through the solution causing solid gold to plate on steel wool cathodes. EW is performed in cells, constructed of non-conducting plastic materials. The cell contains a set of cathodes (negative electrodes) and anode (positive electrodes) immersed in the gold bearing eluate delivered from the elution circuit. The eluate acts as a conductor between the cathodes and anodes. When the rectifier is switched on, the EW circuit is complete and current begins to flow from the cathodes to the anodes (Arumugam, 2019).

Factors Affecting Gold Electrowinning

According to Seyed (2009), several factors affect EW cell performance. Some of these factors are outline below.

i. Current Density: At low current densities, the electrochemical reactions occurs slowly and the process is controlled chemically and as a result coarse-grained crystallization occurs at the cathode. The rate of gold deposition increases with increasing current, up to a limiting amount, at which point the maximum cell current efficiency is obtained. Above this point, the current is consumed by other side reactions such as the evolution of hydrogen and deposition of other metals such as copper and does not contribute to further gold deposition.
ii. Cell Voltage: The voltage and the current that must be applied to a cell for most efficient gold recovery depends on several factors including eluate conductivity, pH, temperature, and the concentration of different species in solution. The cell voltage that must be applied should be around 3.5 V for optimum gold recovery.
iii. Temperature: Temperature influences many parameters in solution such as dissolved oxygen, activity coefficient and corrosion. Temperature of the eluate marginally increases both the rate and efficiency of gold deposition. When temperature is low, the process is inevitably controlled by diffusion. Increase in temperature increases diffusion and the rate of crystal growth becomes larger than nucleation rate.
iv. pH: EW is affected by pH. High pH favourdeposition, prevents corrosion of the anodes and limit evolution of hydrogen gas. In addition to its effect on solution conductivity, pH is also important for electro-stability. Majority of commercial electrowinning cells use stainless steel anode which corrode in solution below pH of approximately 12.5.
v. Gold (Eluate) Concentration: When the concentration of the eluate is low, then the process is diffusion controlled and therefore the products at the cathode are of powdery form. The reverse is also true.
vi. Duration: Duration of EW does not have major adverse effect on efficiency. Long duration of EW will lead to further increase in base metal deposition in the system.
vii. Flow Rate: The solution flow rate is important because it determines the mass transport of

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species in the cell. Lower flow rate will decrease the limiting current density and promote the formation of powder and sludge under a given set of operating conditions; conversely, the of higher flow rates of product at the cathode.

viii. Caustic Strength: Caustic is required in the electrolyte to firstly maintain the conductivity of the electrolyte and secondly to ensure that the pH value remains sufficiently high thus minimizing anode corrosion.

The recommended caustic strength in the eluate should range between 1 to 2% NaOH and the conductivity of the electrolyte should be above 1.7 S/m. (Ocran, 2017) studied the influential factors in gold EW using Response Surface Methodology. The effects of three main factors namely temperature, caustic strength and current density on gold EW were evaluated in order to obtain high EW efficiency.

II. MATERIALS AND METHODS

2.1 Sample Collection and Preparation

The gold ore sample was collected from Ragada village in Niger State. The ore was then prepared in the laboratory to get a representative sample. The ore sample was divided using chute riffle sample division process to adequately divide the sample and obtained a fairly very reasonable representative portion for mineralogical characterization (SEM).

2.2 Mineralogical Analysis using SEM

SEM-PHENOM PRO X MODEL was used to determine the morphology of the ore sample. The sample was prepared and pulverized to a particle size of 100µm using a disc miller. The SEM equipment is then calibrated. The voltage, current, resolution level and identification input were adjusted. The machine was then prompted from standby mode to analysis mode after an automatic period of few second for stability.

Double adhesive carbon is peeled and stickled on the smooth surface of sample stub. The powdered sample was then smeared on the stub using a tweezer. With the aid of the tweezer, the sample stub is placed on a located point on the sample holder. The machine sample port was open and the sample holder was placed. The compartment was closed and the sample was run for 20 seconds. The machine was then prompted to SEM mode and the image was generated. The generated image which was automatically displayed was collated through contrasting and brightening. Manual and auto-reviewing were done one after the other. Magnification of various sizes ranging from X500 to X150, 000 are applied to the sample and EDS system was refreshed and morphology of SEM was transferred for analysis, composition and weight concentration was obtained.

2.3 Upgrading and Leaching of Ragada Gold Ore

1200g of ground ore sample was thoroughly mixed with water forming a pulp of 40% solid/water ratio. The pulp was subjected to pre-concentration process so as to reduce barren material. Sluice box which is a slightly sloping wooden trough is arranged and inclined at 7 degrees. The pulp is poured over the sloping trough, on the surface which is lined with a mat. Water is poured over and the lighter particles are washed down and the heavier particle are trapped to the mat. At the end of the process, the heavier particles were trapped in the mat and collected as concentrate and the lighter particles which are washed down were also collected. The collected products were dried in the oven at 105℃.

The pre-concentrate was then mixed thoroughly with water to form a pulp of 40% solid/water ratio was subjected to panning to upgrade the ore. The pan was first filled halfway with the ground ore material. The pan was then immersed in water and the mixture was thoroughly wetted and stirred. The pan still under the water was swirled gently (combination of shaking and gyration). This allows the heavy particles to settle and the lighter material are brought to the surface. At intervals the pan was tilted and the light surface material is washed off. This process continued until only heavy materials (gold and other heavy minerals) remain in the pan. The panning process requires a lot of patience because it is a slow and tedious process. The collected products that is, the concentrate and tailing were dried in the oven at 105℃.

500g of the upgraded gold ore was dissolved in 1 liter of aqua regia (600ml of HNO_3 + 400ml of HCl). The mixture was heated to 50^0C. The dissolved gold was then filtered and residues were removed. The filtrate was then served as the leachate or electrolyte for eletrowinning process.

2.4 Design and Fabrication of Electrowinning Cell

The electro wining cell (EW) was designed to have special features such as metal frame structure, heating system, fluid tank consisting of the electrodes-cathode and anode, leachate tank, battery, switch, converter, digital ammeter, voltmeter, hydrometer. All the materials for this research work used for the fabrication of the machine were selected based on some engineering considerations such as durability, strength, cost, efficiency, availability, overall weight and life of the machine.

The machine was designed using Auto-Card software to produce a working drawing. The equipment was then fabricated using the selected materials in the (BEME as shown in appendix A).
The procedure for the fabrication of the electrowinning cell involved

(i) Material selection
(ii) Purchasing of the materials
(iii) Marking and cutting operation
(iv) Welding of parts together
(v) Painting and
(vi) Assembling of components

The electrowinning cell was set up for the deposition of gold from the pregnant solution onto a cathode surface. The configuration included the installation of electrodes, with the cathode being a critical element for gold deposition. The cathode, typically made of materials like stainless steel, was placed within the electrowinning cell. This served as the surface onto which gold ions would be reduced and deposited during the electrowinning process. The anode, often composed of inert materials (lead), was introduced into the electrowinning cell. The anode facilitated the oxidation of gold ions, enabling their reduction and subsequent deposition onto the cathode.

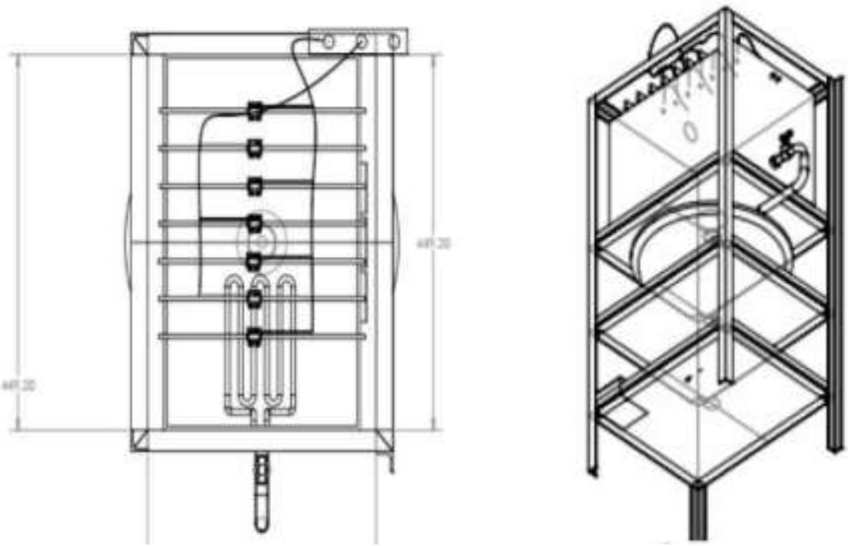

Figure 2. Design Of Machine To Be Fabricated

2.5
Electrowinning Process

Ragada Gold Ore concentrate was subjected to a leaching process. Aqua regia (with a pH of 6, 5 and 4) was used as a lixiviant to dissolve Ragada gold concentrate, creating a pregnant solution rich in gold ions for 24 hours. The pregnant solution was filtered to remove and the filtrate was used as the eclectrolyte. The pregnant solution, now containing dissolved gold ions from the concentrate, was introduced into the electrowinning cell. An electric current was passed through the cell. After 30, 60 and 90 minutes, metallic gold accumulated and deposited on the cathode surface. The gold-ladened cathode was washed and dried.

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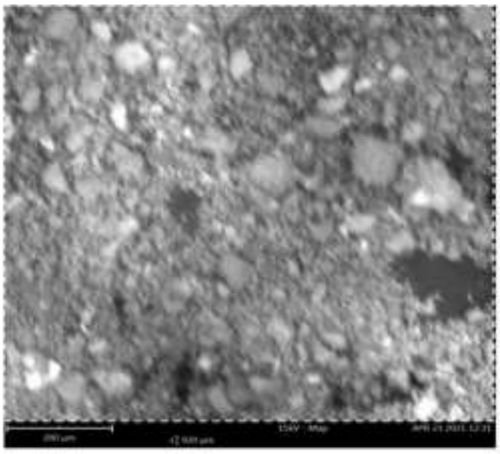
III. RESULTS AND DISCUSSION

3.1 Characterization using SEM

FOV: 920 µm, Mode: 15kV - Map, Detector: BSD Full, Time: APR 23, 2021 12:31am



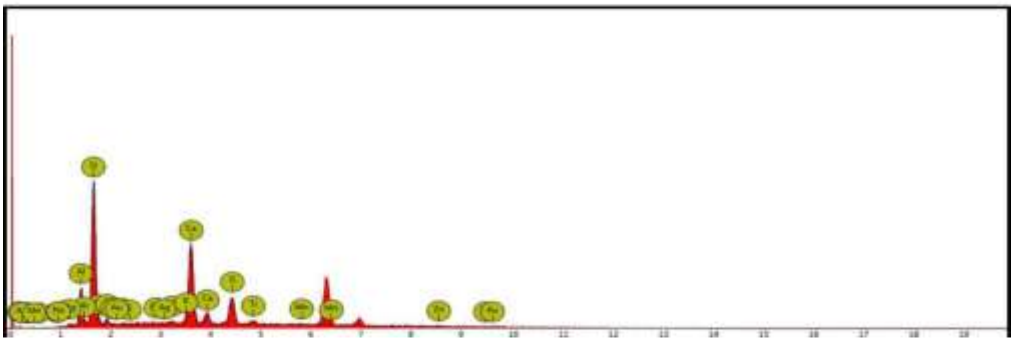


Figure 1: Graph Showing the Elements Present In the Ore.

Table 1: Table showing the elements present in the mineral with their respective weight concentration

Element Name	Element Symbol	Element Number	Concentration	Weight Concentration
Calcium	Ca	20	29.78	32.16
Silicon	Si	14	35.75	27.06
Titanium	Ti	22	14.22	18.35
Aluminum	Al	13	10.99	7.99
Gold	Au	79	0.81	4.32
Zinc	Zn	30	1.59	2.79
Silver	Ag	47	0.65	1.89
Phosphorus	P	15	2.17	1.81
Potassium	K	19	1.24	1.31
Manganese	Mn	25	0.45	0.67
Magnesium	Mg	12	0.90	0.59
Sulfur	S	16	0.67	0.58
Sodium	Na	11	0.77	0.48

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3.2 Concentration and Leaching of Ragada Gold Ore

Gravity concentration method using panning was carried out on Ragada ore to upgrade the gold content in the ore thereby reducing the amount of impurities. The concentration method relies on the high density of gold relative to other minerals. Gold has a very high density that is why it is easily separated from other associated lighter mineral particles with gravity method of concentration. According Stamboliadiset al, 2002 reported that gold metal can be recovered by gravity concentration which can be attained at relatively lower sizes (250µm - 10µm).The gravity concentrationresult gave 469.4g concentrate and 729.2 g tailing per 1200g feed assaying 0.019 %Aurepresenting 39.2 % by weight which was successfully yielded a concentrate assaying 0.061 % of gold.

The upgraded ore gotten from panning of Ragada gold ore was then subjected to leaching. The gold sample was mixed with aqua regia (a solution of HNO_3 and HCl) and heated to a temperature of 50^0C. The dissolved gold formed gold chloride solution which is then filtered to remove impurities. The leachate was then analyzed using AAS. The result of the AAS shows that the leachate contains 0.82%Au, 22.8%Fe and 2.2%S. The presence of sulphur shows that the ore is a sulphide ore.

3.3 The Electrowinning Cell

After necessary design and fabrications were done, the individual parts fabricated are being coupled together with the aid of welding and some other parts just fixed in without welding which is detachable as a separate entity if needs be. All other fittings and accessories were fixed and incorporated appropriately, the entire machine was painted, and ready for operation as shown below in figure below.

Plate 1. Picture Showing the Fabricated Electrowinning Cell

3.4 The Electrowinning Process

During the electrowinning process, oxidation took place and also there was deposition gold metalat the cathode. The process was

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optimized using three different variables; pH, extraction temperature and extraction time on the electrowinning process of Ragada Gold Ore. These factors were identified as key parameters requiring precise control and optimization to enhance the efficiency and purity of the extracted gold.

3.4.1 Effect of pH on the Electrowinning of Ragada Gold Ore

	Feed		Products	
PH	Wt (g)	% Au leached	Wt of metal recovered (g)	% Au
4	1000	0.82	97.45	91.08
5	1000	0.82	99.91	93.56
6	1000	0.82	103.2	94.21

The effectof pH on the electrowinning of Ragada gold ore was analyzed by varying the pH of the electrolyte: (4, 5 and 6). It was observed that there is increase in deposition of gold at the cathode as the pH increases from 4 to 6 that is, there is increase in the efficiency of the process at lower acidity.

3.4.2 Effect of Extraction Temperature on the Electrowinning of Ragada Gold Ore

	Feed		Products	
Temperature	Wt (g)	% Au leached	Wt of metal recovered (g)	% Au
30	1000	0.82	99.21	90.3
60	1000	0.82	101.82	92.46
90	1000	0.82	107.33	93.01

The effect temperature in Ragada gold EW shows that the higher temperatures generallyfavourincreased reaction rates and efficiency, there is an upper limit beyond which adverse effects may occur, such as increased energy consumption or potential damage to equipment. Temperature was identified as a significant parameter affecting the electrowinning process. Higher temperatures generally enhance reaction rates and mass transfer, contributing to improved gold recovery. Therefore, careful monitoring and control of temperature are essential during the processes of optimizing the Ragada Gold Ore electrowinning process.

3.4.3 Effect of Extraction Time on the Electrowinning of Ragada Gold Ore

	Feed		Products	
Time (min)	Wt (g)	% Au leached	Wt of metal recovered (g)	% Au
30	1000	0.82	95.46	92.56
60	1000	0.82	96.24	94.58
90	1000	0.82	99.38	96.18

The study shows that the higher the extraction time the higher the gold recovered. Therefore, recovery of gold is time-dependent, that is, longer electrowinning times leading to increased recovery.

IV. CONCLUSION AND RECOMMENDATION

It was concluded from the study that at higher pH, high temperatures of90^{0}C and extraction time of 90 minutes are the optimum conditions for the electrowinning of gold from Ragada ore.

1. The extraction of gold from Ragada ore is viable using the fabricated electrowinning cell, understanding the ore's characteristics and optimizing parameters accordingly are crucial for achieving the desired recovery rates and purity.
2. The research is recommended for further studies as the findings indicated that the optimization of cell potential or voltage is vital for efficient gold recovery. Balancing deposition rates and energy consumption is essential to enhance the overall effectiveness

of the electrowinning machine. Therefore, a careful balance must be struck to avoid excessive energy consumption and potential contamination. However, careful monitoring is required to prevent adverse effects on equipment and energy consumption.

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