International Journal of Nonferrous Metallurgy, 2024, 11, 21-31
https://www.scirp.org/journal/ijnm
ISSN Online: 2168-2062
ISSN Print: 2168-2054

Applicability of Gravity Separation Method on the Ashashire Gold Ore Deposit from Benishangul Gumuz Region, Western Ethiopia

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How to cite this paper: Kabeta, M., Cheru, M.S. and Berhe, G.G. (2024) Applicability of Gravity Separation Method on the Ashashire Gold Ore Deposit from Benishangul Gumuz Region, Western Ethiopia. *International Journal of Nonferrous Metallurgy*, **11**, 21-31.
https://doi.org/10.4236/ijnm.2024.112002

Received: March 22, 2024
Accepted: April 27, 2024
Published: April 30, 2024

Abstract

The study was conducted to determine the applicability of gravity separation method on the Ashashire gold ore deposit Benishangul gumuz region, western Ethiopia. The Ashashire composite was produced to provide sufficient mass for this study and experiment, including sample preparation, mineralogical analysis of gold and associated elements, gravity concentration, and data interpretation and analysis. During the study, a grind optimization was conducted on the composites sample with varying grind size to evaluate the effect of grind size on gold recovery. The ore was moderately ground to the standard grind size of 80%, passing 106 µm, 75 µm, 53 µm and this nominal size was selected for the preliminary assessment for concentration optimization for this deposit. The gravity testing comprised three-stage concentration using Knelson concentrator. High recovery of gold from the gravity concentrates was achieved from the second gravity concentration. Based on the laboratory experimental result analysis, a grind size of P80 75 µm is selected as optimal size for the Ashashire gold deposit. Increasing the grind size from P80 of 75 µm to 106 µm decreases the recovery rate from 75% to 54%, or decreasing the grind size from P80 of 75 µm to 53 µm decreases the gold recovery rate to 37%. The native gold grain in the ores is mostly associated with quartz and fine gold is closely associated with pyrite. According to analysis of the fire assay, chemical, and mineralogical data, only gold and telluride is commercially valuable elements in the ores. Predominantly gold was occurred in the native form of Au-Te. The sample subjected to gravity separation assayed about 2.6 g/t Au.

Keywords

Ore, Gangue, Ashashire, Gravity Method, Gold, Telluride, Concentration, Knelson

1. Introduction

Mineral Beneficiation is any process that improves the economic value of the ore by physical and chemical methods by removing the gangue minerals to increase the concentrate enrichment [1]. Gold (Au) is a significant element found in nature both as native and as compounds with other elements and used for wide applications [2]. Based on its mode of occurrence, gold can be classified as visible gold, refractory gold and surface adsorbed onto other minerals [3]. Gold-bearing ores can generally be classified into placers, free-milling, oxidized, silver-rich, gold antimonides, gold bismuthites, gold sulfides, gold selenides, copper-sulphides, gold tellurides, and carbonaceous ores based on their mineralogical characteristics [1].

Gravity separation, flotation, cyanidation, or combinations of these processes are typically used in the beneficiation and processing of gold bearing ores [1] [4].

The physical, chemical and mineralogical characteristics of the gold and associated gangue minerals of specific deposit often determine best gold ore processing techniques [1] [5]. However, gold bearing ores require an appropriate processing method which is environmentally benign [6]. Conventional gold processing method with aid of chemicals poses a risk on human health and environment [5]-[10].

Gravity separation is one of gold ore beneficiation method depending on the size, shape and density characteristics of gold and associated minerals [6]. Gravity concentration techniques are environmentally benign method for the beneficiation of gold-bearing ores and useful in situations where the ores are not amenable to flotation or where the use of cyanide is not desirable due to environmental concerns [11]-[13]. Gravity separation is one of the commonly used techniques in gold ore beneficiation due to its effectiveness in concentrating the gold particles and removes the unwanted gangue minerals based on their densities. This effectiveness of gravity separation depends on factors such as the size, shape and liberation characteristics of gold particles and other associated minerals in the ore [6] [14]. Gravity concentration method remains the dominant and important mineral beneficiation method and does not lost its importance despite widespread use of flotation and cyanidation beneficiation methods, as well as hydrometallurgical processes, because a substantial improvement is made to gravity concentration methods to boost its efficiency and effectiveness through technological advancements [15].

Jigs, pinched sluices, shaking tables, spirals, Knelson concentrator, Falcon concentrator, and multi-Gravity separator are among some of gravity concentrating tools that have been developed and utilized in the gold processing [1] [15]-[17]. All methods of gravity separation processing approach are being highly productive and environmentally benign and friendly. Gravity separation is always the first consideration in any flow sheet development program when there are substantial variances in the specific gravities of the valuable and gangue minerals [11].

The main objectives of the previous works on the Ashashire Gold ore deposit, which located in the Benishangul Gumuz Region of western Ethiopia, were to locate economic gold deposit and to determine grade and tonnage of deposit; however, they did not mention processing option for this specific deposit [18]-[29].

This project study focused on the investigating the applicability of the gravity separation method specifically to the Ashashire gold ore deposit, from Benishangul gumuz Region, western Ethiopia. This procedure involved analyzing the optimum particle size for the deposit to achieve high recovery of gold using gravity separation method. Additionally, the gold and associated elemental contents of the ore deposit were analyzed to assess the potential economic viability of the deposit. By analyzing particle size and elemental contents of the ore, the appropriate size fraction for effective separation based on the specific characteristics of the deposit and presence of other elements that may affect the processing were determined.

2. Materials and Methods

2.1. Sources of Materials

All sources of materials used for this project study were gained from Ministry of Mines and sample collection approach was employed as company's procedures that obtained from documents with some modifications to suit the specific requirements of the project and for information confidentiality. The collected laboratory data information was analyzed and interpreted to extract meaningful insights and conclusions were drawn. Previous work data on the area including published and unpublished articles was collected and reviewed.

2.2. Sample Preparation and Experimental Procedure

The sample selection was focused on the producing representative sample from different location of Ashashire gold ore deposit to reflect the composition and characteristics of the entire ore body. To ensure that a representative sample was obtained, samples weighing 6 kg was selected from various locations within the Ashashire gold ore deposit. Sample preparation activities were accomplished at ALS Johannesburg, South Africa. In a sample preparation, sample underwent a typical volume reduction by crushing and grinding. Samples were individually crushed to a size of 100% less than 1.3 mm through a Boyd jaw crusher then thoroughly blended to produce homogenized composite sample. From this composite sample, a representative 3 kg subsample was taken for further testing.

This subsample was then split into 120 g and 2 kg portions. The 120 g portion of the subsample was obtained by rotary splitter and used for head assay analysis and the 2 kg portion was used for gravity separation testing with 80% passing grinding size of 106 µm, 75 µm and 53 µm.

First the sample was ground in a rod mill to achieve a product size of 80% passed through screens of 106 µm. The ground sample of mill product was fed as slurry to a laboratory Knelson concentrator KC-MD-3 at a cone rotational speed suitable to provide 60 g centrifugal force and fixed fluidizing water flowrate of ±2.5, fluidizing water pressure 1.5 psi, feed pulp density 38% - 25% solids under specific conditions as presented in Table 1. The primary gravity concentrate, which contains the enriched gold particles, was collected from the Knelson concentrator. The entire tails from KC-MD-3 of the first separation was further reground with help of a rod mill to provide a product grading nominally 80% passing size of 75 µm and filtered, re-pulped to required slurry density and then fed through the KC-MD-3 again as above step and concentrate products were removed. At last, the entire KC-MD-3 tails from the second step was further reground to an 80% passing size of 53 µm using a rod mill and filtered, re-pulped to required density and was fed to the Knelson concentrator once more as above, and the final concentrate products were collected.

Table 1. Gravity concentration operating parameters.

Knelson KC-MD-3 laboratory test unit	
Grind	80%: 106 µm, 75 µm, 53 µm
Gravitational acceleration	60 g
fluidizing water volume	±2.5 L/min
fluidizing water pressure	1.5 psi
feed pulp density	38% - 25% solids by weight

3. Result and Discussion

3.1. Ashashire Gold Ore Deposit Analysis Techniques

Beneficiation of the ores was conducted using laboratory Knelson concentrator KC-MD3 at ALS with all required test conditions as described above in Table 1 to evaluate the effectiveness of gravity separation method at different particle sizes for the recovery of gold from the Ashashire gold ore deposit. The mineralogical characteristics of the deposit were further analyzed for their gold content and other chemical elements. Sample analysis involved Mineralogical analysis, gravity concentration efficiency and gold recovery analysis and optimal grind size and size effect on the gold recovery analysis.

3.2. Ore Sample Mineralogical Analysis

Ore sample mineralogical analyses was performed by quantitative evaluation of minerals by scanning electron microscope (QEMSCAN) and X-ray diffraction

(XRD) and using scanning electron microscope (SEM) particle scanner for gold-telluride phase mineral grains search.

These were focused on the determining the elemental and chemical composition of the ore, identifying, quantifying and characterizing the nature and mode of occurrence of the gold bearing minerals, the type of gold ore and gangue minerals species present in the ore sample. The gold content of ore sample was determined by fire assay with AAS (Atomic Absorption Spectrometry) finish to 0.01 parts per million (ppm) detection limits and a chemical element analysis were accomplished using full Inductively Coupled Plasma ("ICP") scan.

The repeated gold head grade assay analyses carried out on the composite sample yielded an average gold grade of 2.6 g/t Au. Mineralogical analysis reveals the presence of high ratio telluride to gold. The composite sample contains low silver, arsenic, bismuth and organic carbon levels. Presence of Arsenic indicates minerals that may host refractory gold and arsenic grade is negligible (<10 ppm). A Mercury grade is very low (<0.1 ppm) and confirms that this is not a possible health and safety threat. Organic carbon grades (possible preg-robbing) are low (<0.1 ppm) and are not considered significant for further concentrate treating.

According to mineralogical analysis a non-sulphide gangue species and their abundance are variable and the main gangue minerals composition were dominated by quartz, Ankerite-dolomite, Albite, Chlorite, Muscovite with lower levels of calcite and Paragonite and group of metal minerals mainly pyrite and trace amount of chalcopyrite (**Figure 1**). Quartz minerals are the largest portion and dominant gangue in the ore whereas pyrite has been less distributed in the deposit and chalcopyrite distributed as trace.

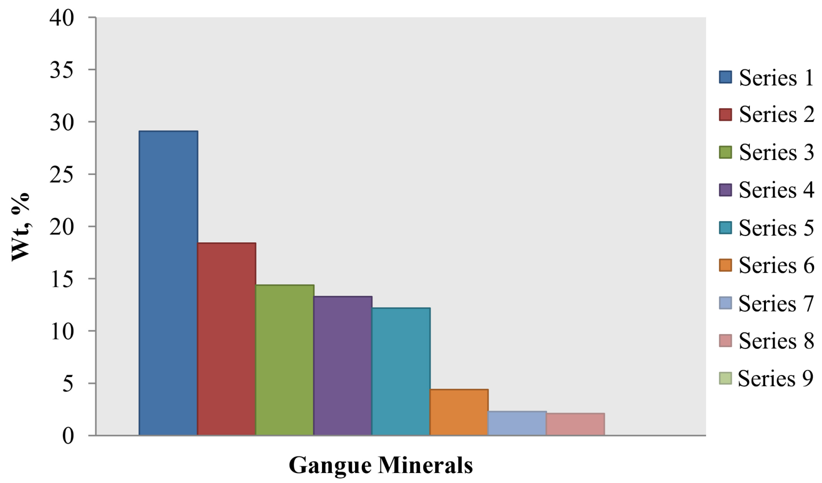

Figure 1. Ore sample gangue minerals abundances.

The assayed and calculated gold head grade exhibit variation. This variation would indicate that the gold is not evenly distributed within the ore and occurs as localized a coarse "spotty" gold component locked in particles. Gold in the ore occurs in the form of free native gold and small gold grains. Primarily native gold grains occur from medium to coarse are liberated. The analysis outcome shows that the main gold minerals detected are native gold and gold-telluride. Gold-telluride phase (probably calaverite, $AuTe_2$) is the dominant gold-bearing phase detected with some petzite (Ag_3AuTe_2) and muthmannite ($AuAgTe_2$). Native gold grains were dominant gold-bearing phase detected and grains are ranged in size between <2 μm to 27 μm while Au-Te grain size reaches more than 75 μm.

Some gold grains were not well-liberated because gold is finely disseminated and/or encapsulated in gangue minerals, or associated with and/or locked in sulphides. All non-liberated fine gold grains are closely associated with pyrite, forming inclusions and hosted by pyrite and dispersed within pyrite as invisible gold, except for a calaverite ($AuTe_2$) grain hosted by chlorite. Some gold grains are associated with chalcopyrite and melanite ($NiTe_2$) inside the hosting pyrite. Gold grain high finesse and occasional association with pyrite indicates secondary and remobilized character of the gold mineralization.

Gold that is not amenable to gravity separation could occur as small gold grains in low density minerals, or as liberated flaky gold grains that are smaller than the gravity efficiency cut-off. Consequently, the small or flaky gold particles and hidden gold within pyrite as solid solution may have deported to tails, because pyrite may host proportion of undetected very fine gold grains. This shows that these occurrences of fine gold grains are more difficult to recover by gravity method as these particles tend towards gravity tails. To recover gold from this gravity tails another gold recovery methods may use.

Other Gangue minerals are typically forms fine to medium grains indicating moderately mutually intergrown. Muscovite shows some intergrowths with major mineral phases. The majority of the iron elements are contained in the pyrite. The majority of the Aluminium is contained in the dominant muscovite while impure iron oxides and other aluminosilicates contain most of the remaining Aluminium. The majority of abundant calcium is confined in carbonates. Trace of calcium is from locked in minor silicates, titanite and apatite (Figure 2 and Figure 3).

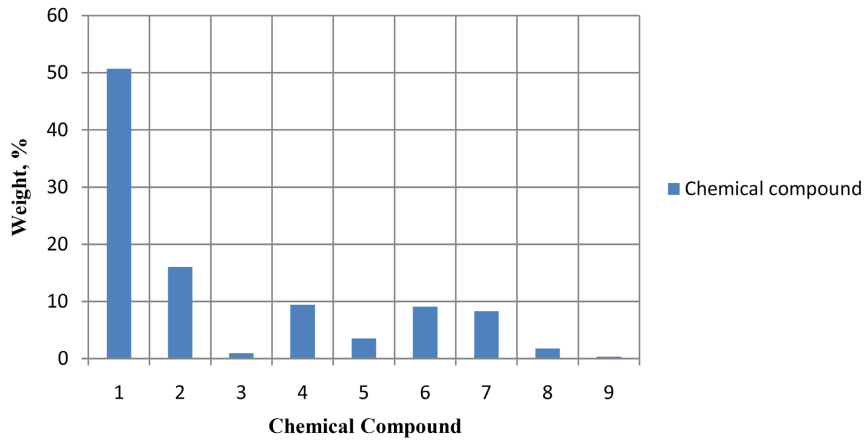

Figure 2. Ore sample chemical composition.

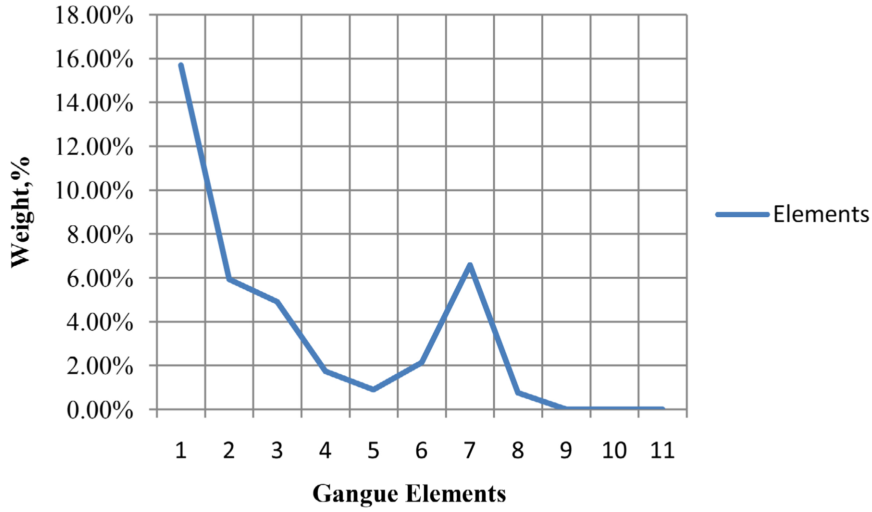

Figure 3. Ore sample gangue elements composition.

3.3. Gravity Concentration Efficiency and Gold Recovery Analysis

A nominal grind size of 80% passing 106 μm, 75 μm and 53 μm was selected for purpose of this project study. The representative ore sample subjected to experimental studies was assayed about 2.6 g/t Au. The main objective was to assess effectiveness of gravity separation method on the Ashashire gold ore deposit to recover gold at different particle sizes. The gravity concentration comprised three-stage process by centrifugal Knelson concentrator to produce gravity concentrate.

The first gravity concentration test work yielded a concentrate containing 54% of the gold, assaying 296 ppm Au, collected in 0.79% of the feed mass and the second gravity concentration test work achieved the gold recovery containing 75% of the gold, assaying 352 ppm Au, collected in 1.06% of the feed mass while the last gravity concentration test work on composite sample yielded a concentrate containing 37% of the gold, assaying 285 ppm Au, collected in 0.60% of the feed mass. Maximum gravity recoverable gold was more than 75% and mass distribution to the gravity concentrates was 1.06%.

Figure 4 shows gravity concentration recovery efficiency of each stage during gravity method applicability test. The highest gold recoveries were achieved at the second stage concentration where 80% of ore particles passing 75 μm and moderate gold recovery is attained at first stage with 80% passing 106 μm. This indicates that presence of relatively gravity recoverable free coarse gold grains in the ore. Total percentage of gravity recoverable gold depending on the ore grain size is present in Figure 5.

3.4. Optimal Grind Size and Size Effect on the Gold Recovery

The optimal grind size was conducted with varying grind size to evaluate the effect of grind size on gold recovery. To liberate gold particle from associated minerals and determine the optimal size, the ore sample is subjected to comminution

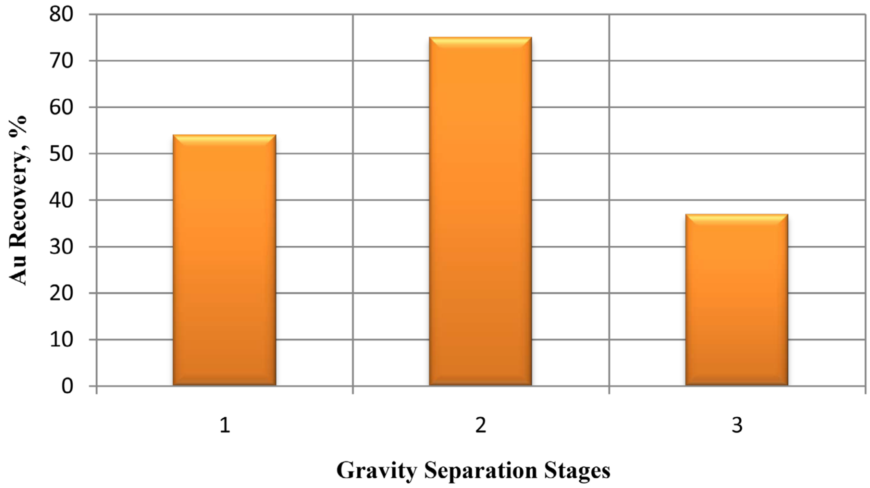

Figure 4. Gold recovery by concentration stages.

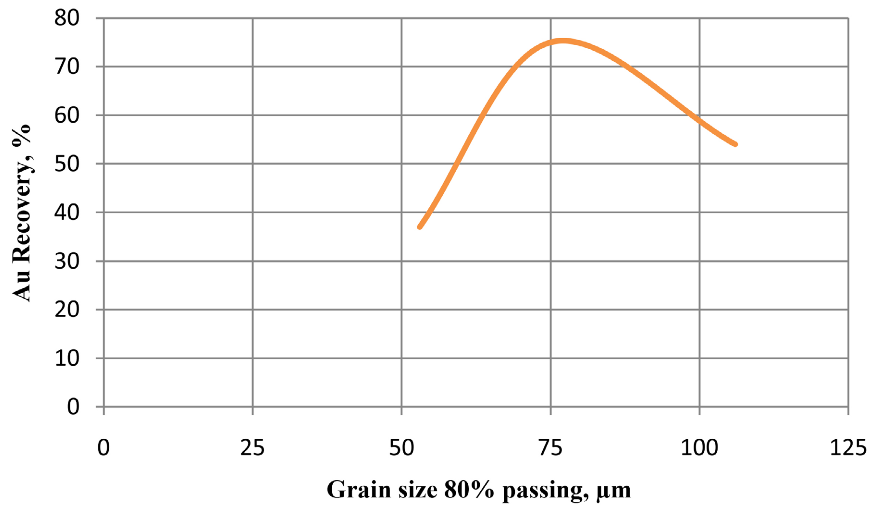

Figure 5. Gravity recoverable gold depending on the grain size.

stages through crushing and grinding. This comminution liberates the gold grains particles from the rest of gangue minerals using selected grinding size. The crushing was performed at a size of −1.3 mm while grinding was conducted at grinding size of 106 µm, 75 µm and 53 µm to get optimum particle size for separation optimization. Based on the analyzed results gained from this test, the grind size of P_{80} 75 µm is selected as optimal size for the Ashashire deposit using gravity methods. Increasing the grind size from P_{80} of 75 µm to 106 µm decrease recovery rate from 75% to 54% or decreasing the grind size from P_{80} of 75 to 53 µm more decrease gold recovery rate to 37%.

4. Conclusions

This study shows that high gravity gold recoveries from the Ashashire deposit which contain some tellurides can be achieved using gravity separation method, Knelson concentrator. The Ashashire gold ore deposit is amenable to the gravity separation methods to recover gold at coarsest grain size. According to the fire assay, chemical, and mineralogical analysis data, only gold and telluride is commercially valuable component in the ores.

Gravity recoverable gold was 75% at 80% passing 75 μm. Based on the experimental results of these tests, a grind size of P_{80} 75 μm is selected as optimal size for the Ashashire deposit using gravity methods. Increasing the grind size from P80 of 75 μm to 106 μm decreases the recovery rate, or decreasing the grind size from P80 of 75 μm to 53 μm further decreases the gold recovery rate.

The mineralogical characteristics of the deposit such as the gold and associated element, the gold grain sizes, and the gold distribution in the ore, associated gangue minerals and liberation characteristics of the ore were determined. Pyrite is the dominant sulphide mineral detected in the ore. The non-sulphide gangue species and their abundance are variable and the main gangue minerals were quartz and Ankerite-dolomite, with lower levels of muscovite and chlorite present. Only trace amounts of chalcopyrite were detected in the ore. The high ratio of telluride to gold might have impact on the further processing.

Acknowledgements

Above all, I want to thank very much Almighty God. I would like to express my deepest gratitude to my advisor Dr. Mulugeta Sisay and co-advisor Mrs. Abaynesh Mitiku for their decisive guidance, follow-up, support and recommendations from the beginning to the end of my project study. Also, I am extremely grateful to Mr. Kiros Alemayehu, minister office secretariat head, ministry of mines, Ethiopia and Dr. Sophia Abdulqadir director of mineral license and administration, ministry of mines, Ethiopia for their permission, the requirement of all necessary valuable documents to do my project.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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