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Original research article

GRAVITY CONCENTRATION OF FINE PARTICLES COMPLEX ORES-CONTAINING BARYTE USING LABORATORY-BUILT MINERAL JIG

David Oluwasegun Afolayan[1#], 0000-0002-7274-0222,
Adamu Hassan Abubakar[2], 0000-0001-7878-8406,
Samuel Olumide Ogunmodimu[3], 0000-0001-7186-7005,
[1]Mechanical Engineering Department, African University of Science and Technology, Abuja, Nigeria
[2]Materials Science and Engineering Department, African University of Science and Technology, Abuja, Nigeria
[3]Energy and Minerals Engineering Department, Pennsylvania State University, PA, USA

ABSTRACT – This study uses environment-friendly and indigenous processes to liberate, separate and recover barite from gangue minerals. Barite ores were randomly selected, comminuted, screened, characterized, and beneficiated using a laboratory-built mineral jig. The effect of mineral liberation on separation efficiency, recovery, and yield was examined. The specific gravity of the barite ores was increased from 3.97±0.0105 to 4.17±0.20 and from 4.00±0.0458 to 4.20±0.2 without the use of chemicals. Likewise, higher barite recovery and yield were observed. However, the separation efficiency of the jigging process was low due to middling (a complex particle consisting of barite and gangue minerals).

Keywords: Baryte Ores, Liberation Size, Lab-Scale Mineral Jig, Middling Particles, Drilling Fluid.

INTRODUCTION

Barytes are typically associated with silicates, carbonate, iron oxide, sulphide, and clay minerals [1–3]. Barytes can be liberated from non-barite minerals (gangue phases) in coarse or very fine fractions by gravity concentration, flotation, or leaching to increase the density and quality of the ore [3–5]. Baryte is easily liberated from other minerals when ground into fine particles within the liberation size range for the minerals of interest. Chemical leaching, froth flotation, and hydrostatic pressure for baryte recovery have been recommended and reported on a laboratory scale for fine particle processing, as the best alternative to jigging [2,3]. However, these emerging baryte processing methods are expensive and require materials and resources manufactured on a laboratory scale. Using chemicals such as frothers, collectors, depressants, and other industrial chemicals in large-scale barite processing is not sustainable. In Nigeria and Africa, artisanal and small-scale (ASS) mining dominate barite mining and processing. These miners cannot afford chemicals other than the usual barite processing method by

[#] corresponding author: dafolayan@staff.aust.edu.ng

gravity separation. Jigging and other gravity separation methods are the most sustainable and widely used methods for barite processing.

Laboratory-scale mineral processing research involves optimizing jigging conditions and ore characteristics, and the effect of a dependent variable is measured over a range of other independent variables. Such an experiment is carried out using large quantities of research samples; in most cases, lab-size processing devices are unavailable. Baryte processing by jigging and tabling has been reported in the literature [6,9]. Jigging of baryte is usually carried out on coarse particle sizes to pre-concentrate valuable minerals (-841 + 90 µm) [9–11]. The jigging process is limited to coarse particle processing and cannot significantly improve the quality of baryte when the particle is liberated in fine-size fractions [4,8]. However, the recovery of barytes and other gangue minerals in ores-containing-barytes depends on the degree of liberation. Similarly, there are few studies on barite processing by jigging and tabling at different process conditions. These studies are carried out on coarse particles, usually at particle size ranges, where specific fractions of both barite and non-barite minerals are expected to be locked in the ores.

This paper presents the use of an entirely fabricated laboratory-built mineral jig (prototype) to process fine particles in complex ores containing baryte, iron, lead, and more than five (5) other minerals as impurities in the ores. It demonstrates a mineral jig with fully separated water and jigging columns pulsed by a rubber-end cap diaphragm and driven by a reciprocating device. The paper also discusses the beneficiation of barite ore (barite rocks) of particle sizes -75 µm, -106 µm, -150 µm, and -250 µm using the laboratory-built jig. The particle size was narrowed to examine the degree of liberation of baryte and non-baryte minerals, jig frequency and amplitude on barite recovery and yield, the recovery and rejection of gangue minerals, separation efficiency, and baryte quality (specific gravity).

EXPERIMENTAL

Baryte rocks were randomly selected from the Kumar barite mining site, crushed and ground by a laboratory jaw crusher and ball mill. The pulverized ore was screened, separated into different particle size ranges by a mechanical sieve shaker and processed using the laboratory-built mineral.

The recovery and yield of barite, the rejection of impurities (non-baryte minerals), and the separation efficiency of the jigging process are calculated and analysed using equations 1- 4.

Separation efficiency calculated based on the mineral to be separated (alumina).

$$Yield\ of\ the\ process:\ Y = \frac{(f-t)}{(c-t)} \times 100\% \tag{1}$$

Percentage of alumina in the feed (f), concentrate (c), and tailings (t): impurities.

$$Rejection\ of\ impurities: {R_t}^1 = 100 - Y\frac{c}{f} \tag{2}$$

$$Recovery\ of\ alumina: {R_c}^1 = 100 - {R_t}^1 \tag{3}$$

$$Recovery\ of\ other\ fractions\ of\ the\ feed: {R_c}^2 = \frac{Y(100-c)}{(100-f)} \tag{4}$$

Separation efficiency: $Z = {R_c}^2 - {R_c}^1$ Higher separation efficiency, better separation process.

RESULTS AND DISCUSSION

Baryte Yield by Jigging Barite Ore

Figure 1a shows the yield of baryte from barite ore during the jigging process. Baryte ore of particle size less than 250 µm has the highest baryte yield. This outcome indicates that coarse ores have better mineral yield, as reported in previous work [6,9]. As jig frequency increases, the baryte yield of the jigging process varies across particle size fractions. A jig frequency of 115 RPM gave the best yield of baryte for particle size less than 106 µm, while the highest baryte yield of particle size fractions -75 µm and -150 µm is at 126 RPM. The coarse feed has good mineral yield at high and low jig frequency and amplitude. However, an optimum jig condition is required to increase barite yield for particles less than 150 µm. Optimum barite yield is attainable for large particle sizes at higher jig frequency (153 RPM) and lower jig amplitude (1.5 cm).

In contrast, higher amplitude (2.5 cm-3 cm) and lower frequency (115 RPM-126 RPM) are preferred for small-size baryte concentrate. This outcome agrees with conclusions from previous research [8,14]. Thus, baryte yield by jigging is size-dependent and is improved by optimizing jigging conditions.

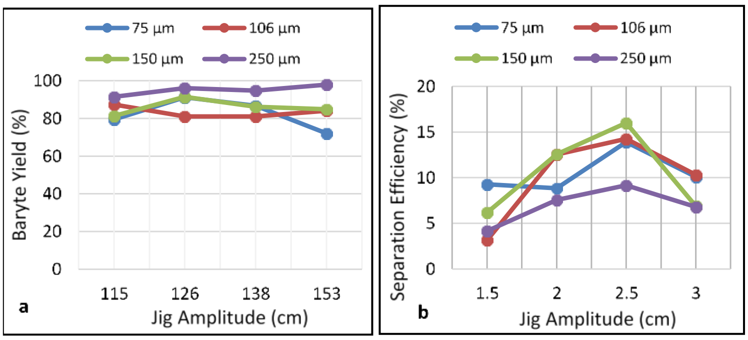

Figure 1 (a) Baryte yield at different jigging conditions and particle size; (b): Separation efficiency of baryte at different jigging conditions (water flow rate, jig frequency, and amplitude

Separation Efficiency of the Jigging Products

Figure 1b shows the separation efficiency of barite (value mineral) and non-baryte minerals in the ore across particle size ranges. Jig feeds of particles greater than 150 µm (-250 µm) have the least separation efficiency at the lowest jig amplitude. The separation efficiency increases as the jig amplitude increases and a sharp increase in separation efficiency is observed for jig concentrate of particle sizes less than 150 µm (-75 µm, 106 µm, and -150 µm). This implies that better separation was achieved at high amplitude, caused by high water pulsation, to allow effective differential settling based on particle size and density.

Effective differential settling does not translate to efficient mineral separation. Despite high mineral liberation for particle size less than 150 µm, the separation efficiency cannot be raised beyond 16% at optimum jigging conditions (126 RPM, 2.5 cm). This explains the consequence of a strong, cohesive force between fine particles, responsible for the middling formation and reduction in mineral separation. Also, high specific gravity was observed at the optimum separation efficiency of the ore (-150 µm). Optimum baryte separation depends on the fraction of baryte and gangue minerals free or fully liberated by grinding and screening baryte ore into different particle sizes.

Specific Gravity of Jigging Products

Figure 2 presents the specific gravities of jig tailings, feeds, and concentrates at different jigging conditions.

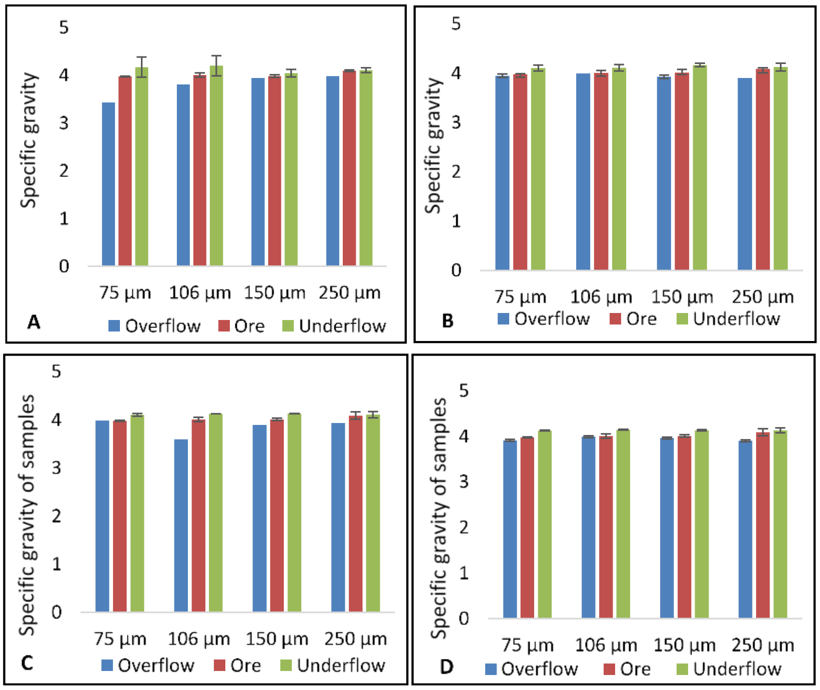

Figure 2 Specific gravities of jigging products and feeds at different jigging conditions and particle sizes (A): Water flow rate [369 cm^3/min], Jigging frequency [115 RPM], and Jig amplitude [3 cm]; (B): Water flow rate [369 cm^3/min], Jigging frequency [126 RPM], and Jig amplitude [2.5 cm]; (C): Water flow rate [369 cm^3/min], Jigging frequency [138 RPM], and Jig amplitude [2 cm]; (D): Water flow rate [369 cm^3/min], Jigging frequency [153 RPM], and Jig amplitude [1.5 cm]

A water-flow rate of 369 cm^3/min, jig frequency of 115 RPM, and jig amplitude of 3 cm contribute to the increase in specific gravities of barite ore of particle size less than 75 µm and 106 µm. The specific gravities increase from 3.97 to 4.17 and 4.00 to 4.20.

However, there was no significant increase in the specific gravities of ores of particle sizes greater than 106 µm (-150 µm and -250 µm) under the same jigging condition. The percentage improvement of the jigging process, based on the specific gravity, increases from 0.98 (-250 µm) to 4% (-150 µm) and 5% for finer jig concentrate (-75 µm and 106 µm). Thus, the recovery of quality baryte from its ores depends on the feed characteristics, jig amplitude, and frequency.

At a jig frequency of 126 RPM, the specific gravities (SGs) increase from 4.00 to 4.16 for ore of particle size less than 150 µm. Likewise, the specific gravity of barite ores (-250 µm) increases from 4.08 to 4.12. However, there was no significant increase in the specific gravities of smaller-size jig concentrates (-75 µm and -106 µm) at higher jig frequency (138 RPM and 153 RPM) as compared to the improvement observed at 115 RPM and high jig amplitude (2.5 cm-3 cm). Similarly, the specific gravities of the tailings/overflow are high and very close to that of the feed in all cases. This indicates that the barite of finer particles are lost in the tailing at high frequency.

The optimum jigging condition to increase the specific gravities of jig concentrate is size- and density-dependent. Baryte concentrates of fine particles (-75 µm) retain the dense materials and have the highest SGs at low jig frequency (115 RPM) and high jig amplitude (3 cm). In contrast, higher jig frequency (>115 RPM) are suitable for coarse particles jig feed of size less than 150 µm increases. However, the SGs of particles above 150 µm remain unchanged at high jig frequency. This is due to the high proportion of quartz in the coarse ore fraction, as observed in previous work. Hence, the high baryte yield of coarse jig concentrate does not translate to efficient mineral separation and recovery, and a significant increase in specific gravities.

Rate of Baryte Recovery and Rejection of Other Non-baryte Minerals in the Feed

Figure 3 presents the assaying of the ore and describes the baryte ore grade. Baryte mineral recovery is ≥ 74% for all size fractions. The recovery rate vary across particle size ranges and is affected by jigging conditions. Baryte ore of particle size greater than 150 µm (-250 µm) has the highest baryte recovery (value mineral). The rate of recovery increases from ~ 90% to ~ 99% for coarse jig concentrate (-250 µm) while the jig frequency increases from 115 RPM to 153 RPM. Similarly, the recovery rate of baryte in ore of particle size less than 150 µm increases from 79% to ~ 94% at a jig frequency of 126 RPM. Although the recovery of coarse ore deposits is high, the rejection of impurities is low, and more undesired minerals are retained within the jig concentrate. This indicates that complex particles containing one or more gangue minerals associated with the value minerals exist in the slurry and affect the sharpness of mineral separation during jigging.

Beyond the optimum jigging condition, the recovery dropped for all materials of different particle sizes. Likewise, the number of impurities (undesired minerals) retained in the jig concentrate increases. The recovery for fines (-75 µm, -106 µm, and -150 µm) is high, and the undesired minerals are less retained in the jig concentrate than in the coarse jig concentrate. It is important to note that baryte recovery or yield is affected by the liberation size of the valuable mineral, the quantity of middling (i.e., composite particles containing barite still locked with one or more non-barite minerals), and jigging conditions. Thus, the recovery of value minerals is improved at optimum jigging conditions for each particle size range.

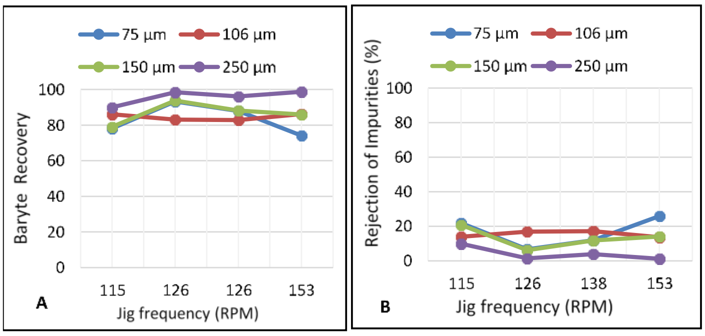

Figure 3 Rate of baryte recovery and rejection of other non-baryte minerals in the feed (A): percentage recovery of barite during jigging, and (B): removal of non-barite minerals and other light-weight minerals from the ore

Optimum Jigging Conditions to Increase Specific Gravities (SGs) of Jig Concentrates

The best values are 4.17 and 4.20 for fine baryte ores (-75 µm and -106 µm), obtained at the jig frequency of 115 RPM and jig amplitude of 3 cm. However, coarse jig concentrates (-150 µm and -250 µm) have lower SGs (4.10 and 4.05) at low jig frequency (115 RPM), as shown in Figure 4.

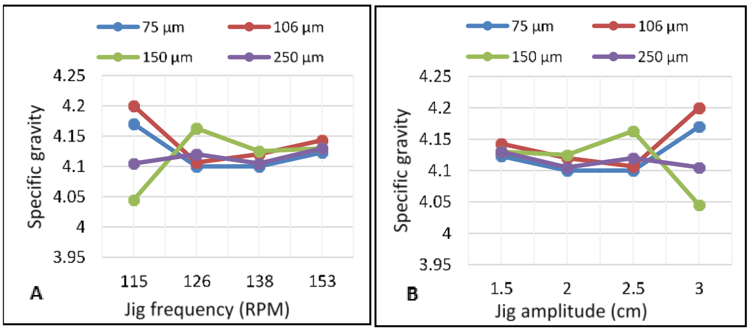

Figure 4 Specific gravities of jigging products as a function of (a): jig amplitude, and (b): jig frequency

Optimum specific gravities of 4.16 and 4.14 were achieved at jig frequency of 126 RPM and 158 RPM for coarse jig concentrates of particle size less than 150 µm and 250 µm. This implies that the small particle size ore requires lower jig frequency (fewer cycles) and maximum displacement of solids to allow differential settling of solid under gravity. This agrees with conclusions from previous works on baryte jigging [1–5]. However, the quality of the value mineral (specific gravity) in -250 µm size fraction cannot be increased beyond 4.13, which is far below the requirement of a weighting agent in oil drilling mud. Hence, increasing jig frequency at a jig amplitude of 2.5 cm helps improve the specific gravities (SGs) of the coarse jig concentrates (-150 µm and -250 µm).

CONCLUSION

This study assessed the efficiency of locally fabricated mineral jigs for barytes processing in artisanal and small-scale mineral processing. It also indicated that fine particles-complex barite ores can be processed, and narrowing the particle size range increases the separation and recovery of barite mineral and other non-barite minerals in barite ore. While the mineral jig performed better for coarse particle size range in agreement with previous works on barite, fine jig concentrates show better separation efficiency and retain fewer undesired minerals (impurities).

A laboratory-built mineral jig is capable of small-scale processing of baryte ore as a weighting material in oil drilling mud. However, the sharpness of mineral separation was limited due to middling during jigging. Stage-wise or step-wise jigging of barite ore is recommended to ensure re-jigging of concentrate, recovery of value minerals in the tailings, and removal of gangue minerals from the concentrate.

The use of a high-intensity and high-shear agitator within the jigging column to disperse or break aggregates of sticky particles in slurry during jigging will help reduce the influence of middling and improve the separation efficiency of value minerals during barite jigging. These devices can be incorporated into the laboratory-built design without depending on imported processing equipment for barite processing.

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