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Separation of Titanium from Industrial Waste by Falcon Concentrator as Enhanced Gravity Separation

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ABSTRACT

The Falcon SB-40 concentrator is an enhanced-gravity separator used in mineral beneficiation, as their superior gravity field enables them to separate particles within narrow classes of density and size. The process of cutting and finishing garnet mineral produces industrial waste as a fine powder mixture of garnet with a few percent of titanium carbide which is derived from titanium blades. This study aims to shed light on the Falcon concentrator's ability to separate particles within density ranges lower than usual. Specific gravity of the fractions is 3.7 and 4.9 gm/cm^3. Various operating conditions such as bowl speed (G force), water pressure, pulp solid ratio and pulp feed rate were investigated. It was shown that under optimized conditions the Falcon SB-40 concentrator can produce an excellent titanium concentrate with titanium carbide of 92.2 % from a feed waste of about 5% titanium carbide with total recovery of 97%.

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Introduction

Important factors in mineral separation, include relative density, mass, size, and shape of the particle. If only one of these factors is significantly different, separation is relatively easy. The separation efficiency depends on the relative differences between these factors. Some idea of the ease of separating two minerals can be obtained from the concentration criterion (CC), which is defined as follows:

$$CC = \frac{d_h - d_f}{d_l - d_f}$$

Where, d_h is the density of the heavy mineral; d_l the density of the light mineral; and d_f the density of the fluid. In general, if CC > 2.5, then separation is relatively easy; however, if CC < 1.25 separation is not likely to be effective.

In the modern industry, minerals of finest classes (<0.25 mm) are used predominantly, which requires a continuous improvement of the engineering and technological methods of their concentration [1-7]. One of the principal ways of intensification of the separation of such mixtures differing in coarseness and density is the use of a centrifugal field multiply exceeding the effect of gravity. There are many technical devices which use the centrifugal force for separation, classification, dewatering, etc., in mineral processing [8-9].

Centrifugal concentrators have been in operation for more than 60 years in the mining industry [10]. The Falcon concentrator is manufactured by the Falcon Concentrator Company of Vancouver, British Columbia. It is used in both laboratory-scale and commercial-scale operations to upgrade a variety of mineral ores [11]. There are two types of Falcon concentrators, the SB-40 Semi-Continuous and C-Continuous. Fine mineral is introduced from the top of the unit through a central vertical feed pipe and is accelerated by an impeller. Rapid stratification according to specific gravity occurs as the material is driven up the sloping rotor wall by a force of from 20 g's to as much as 300 g's. The centrifugal force causes deposition and stratification of the fine particles against the inside of the smooth bowl. The Falcon concentrator provided the lowest separation density as a result of its ability to provide the maximum centrifugal field of 300 g's [12]. The heavy fraction is withdrawn continuously through a series of ports distributed evenly around the circumference of the rotor. Falcon centrifugal separator has the advantages of bigger capacity, lower water usage and being able to recover minute size particles. The main disadvantage of the SB-40 model is that the unit is semi-continuous and has to be taken off line after each test. A large number of studies and literature has been devoted to using enhanced-gravity separation [13-16].

Titanium carbide blades used in cutting processes of garnet rocks are the source of titanium content of the industrial waste. Titanium is a valuable element due to its corrosion resistance and the highest strength-to-weight ratio of any metal [17, 18]. Garnet is nesosilicates having the general formula $X_3Y_2(SiO_4)_3$, (sp.gr. ≈ 3.7 g/cm^3). The X is usually occupied by divalent cations (Ca^{2+}, Mg^{2+}, Fe^{2+}) and the Y by trivalent cations (Al^{3+}, Fe^{3+}, Cr^{3+}) in an octahedral/tetrahedral framework with $[SiO_4]^{4-}$. Six common types of garnet are recognized by their chemical composition. They are pyrope, almandine, spessartine, grossular, uvarovite and andradite. Garnets are found in many colors and colorless. Garnet's light transmission properties can range from the gemstone-quality transparent specimens to the opaque varieties used for industrial purposes as abrasives [19, 20].

This study aims to study the Falcon concentrator's ability to recover the titanium and optimize the separation parameters of the device.

Material and methods

Characterization tests

A number of qualitative and quantitative analysis techniques were used to characterize the waste sample. The chemical composition of the sample was defined by X-ray fluorescence (XRF). The mineral composition of the tailings was

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determined by X-ray diffraction (XRD) method using a Rigaku-Giger Flex analyzer. The particle size distribution of the sample was obtained using a Retsch AS200 Sieve Shaker.

Separation Technique

The Falcon SB40 used in these experiments is a highly effective centrifugal separating machine. The core part is a plastic inner vertical rotating drum with a slippery inner wall and an inversely tapered lower part. It supper section consists of two reflex circle slots. A ring of small holes is drilled so that water can flow into the reflex circle slots and loosen and fluidize the heavy layer, as shown in Fig.1. The Falcon centrifugal machine separates the heavier material into a separation slot by exposing it to an acceleration of up to 300 g.

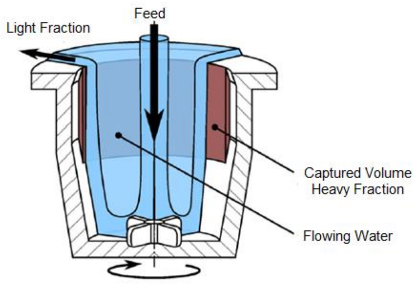

Fig.1. Sketch of Falcon SB-40

The waste sample and water were mixed, then pumped to the Falcon feed inlet with a peristaltic pump. The water flow fluidizes the material in the reflex circles. Under the opposite effects of centrifugal force and reverse water flow the grains of higher density metal “sink” to the rotor wall through gaps in the material layer. But the lower density nonmetallic materials are less affected by the centrifugal force and so the reverse water helps move them out of the inner rotating drum. The effect on the lighter particles is to expel them from the drum with the reverse water to become gangue. The inner rotating drum is unloaded by halting the feed, slowing the rotation speed of the drum and flushing the concentrate into a concentrate trough. The final heavy concentrate is filtered. The adjustable parameters of the separating system are solid content of the feed, feed rate, rotation speed of the drum and reverse water flowrate. Solid content of the feed was adjusted by controlling the proportion of feed and water. The feed rate was adjusted by controlling the rotating speed of the peristaltic feed pump. The speed of the rotating drum was adjusted by controlling the input frequency on the Control panel of the concentrator. The flow rate of fluidizing reverse water was controlled by adjusting the water pressure. The Falcon SB40 centrifugal machine is a batch machine: The concentrate is unloaded from the drum periodically. The effects of solid content, drum rotation speed and the effect of reverse water pressure on metal concentrate recovery were tested in the experiment.

Results And Discussions

Table 1, shows the chemical composition of the industrial waste sample. It consists of 4.95 % Titanium carbide as a valuable content of the waste with about 95 % garnet as silicate mineral. The mineral composition of the garnet sample is mainly Andradite mineral, calcium-iron silicate [$Ca_3Fe_2(SiO_4)_3$], which was confirmed by chemical composition. Table 2, shows the particle size distribution of the waste sample. The particle size of the sample is mainly below 100 µm and more than 34 µm (≈ 97%). The ultra fine fraction –34 µm (≈ 3%) which is mainly silicate was deslimed before separation process.

Table 1: Chemical Composition of the Industrial Waste Sample

Constituent	%
SiO_2	32.23
CaO	31.84
Fe_2O_3	30.21
Al_2O_3	0.43
MgO	0.21
Na_2O	0.07
K_2O	0.05
TiC	4.95
Total	99.98

Table 2: Particle Size Distribution of the Industrial Waste Sample

Size, µm	100 × 74	74 × 34	– 34	Total
%	73.17	23.59	3.24	100

Separation tests were conducted on the waste sample (−100 µm) at bowl speeds ranging from 20 to 200g. The results of the bowl speed variation, through changing the motor frequency, at fixed water pressure (2 psi), solid content (25%) and feed rate (1 liter/min.) are given in Fig.2. It is clear that raising g-force increases Titanium carbide recovery from 59.9 to 99.7%. On the other hand, the increase in the centrifugal force decreases the concentrate grade from 76.6 to 26.5% Titanium carbide. Basically, with higher G force, more Titanium and garnet were recovered into the heavy product stream, and weight increases from 3.8 to 18.6%. At low speed, the heavy particles (titanium) stratification is low, so the light particles (garnet) displace them. At higher speed, the heavy particles are likely to stratify quickly before entering the fluidization zone. As a result, the lower recovery and the high grade were observed at lower bowl speeds.

The results of effect of feed flowrate variation, at fixed water pressure (2 psi), solid content (25%) and 80 g-force, are given in Fig.3. It is clear that raising effect of feed flowrate from 0.5 to 3 liters/min. decreases both recovery from 95.1 to 57.9% and the concentrate grade from 55.4 to 29.8% Titanium carbide. Increasing feed flowrate decreases stratification. Crowded particles are not suitable for re-arrangement and thus low stratification occurred. The lower feed flowrate allows more chance for good stratification and higher quality concentrate was obtained.

The results of effect of feed solid content variation, at fixed water pressure (2 psi), feed rate (1 liter/min.) and 80 g-force, are given in Fig.4. It is clear that rising of feed solid content from 5 to 30%, decreases both recovery from 99.8 to 84.2% and the concentrate grade from 61.8 to 45.1% titanium carbide. Crowded particles in higher feed solid content are not suitable for good stratification. The lower feed solid content allows more chance for good stratification and higher quality concentrate was obtained. The effect of fluidization water pressure on both grade and recovery was investigated. The fluidization water exerts a drag force on the solid particles when they reach the fluidization zone. The results of changing the fluidization water pressure at solid content (15%), feed rate (1 liter/min.) and 80 g-force, are given in Fig.5. Increasing the water pressure (from 1 to 6 psi) increased the concentrate grade from 41.7 to 93.5 % titanium carbide. The concentrate recovery is almost constant from 98.8 to 97.7 with water pressure range between 2 and 5 psi.

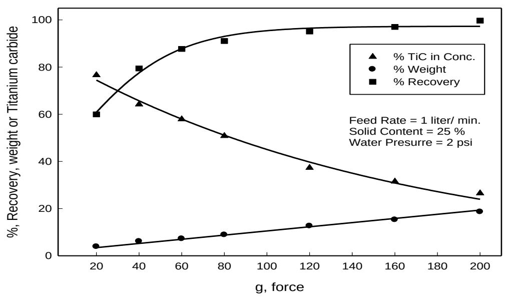

Fig.2. Effect of Centrifugal Force on Separation Effeciency.

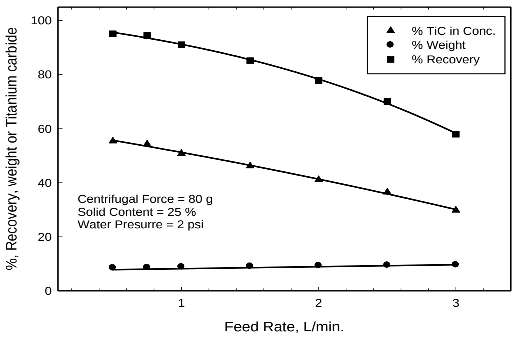

Fig.3. Effect of Feed Rate on Separation Effeciency.

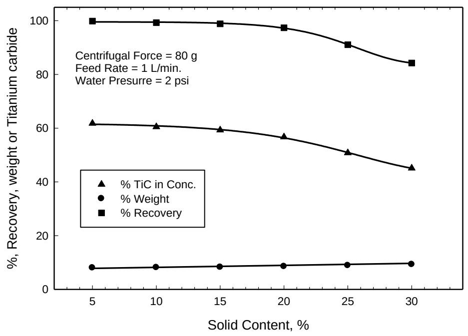

Fig.4. Effect of Solid Content (%) on Separation Effeciency.

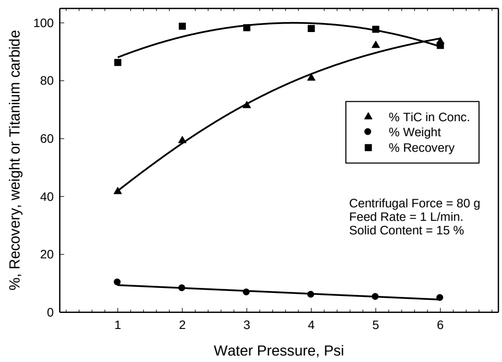

Fig.5. Effect of Water Pressure (psi) on Separation Effeciency.

The increase of concentrate grade, at high water pressure, can be attributed to the increase of the effect of the drag force, which helps on rearrangement of the particles stratification. Also, the entrapment of garnet was diminished and cleaner concentrate was obtained. This is confirmed by decreasing of concentrate weight.

Conclusions

The separation of titanium carbide from its mixture with garnet mineral was investigated using Falcon device at fine size range (below −100 μm). The separation tests indicated that the bowl speed affects the titanium recovery while the washing water pressure affects the grade by reducing the garnet particles entrapment in the Titanium concentrate. The results showed that the higher feed flowrate and higher feed solid content are not suitable for good stratification due to crowded particles and thus, lower quality concentrate was obtained.

Under optimized conditions the Falcon SB-40 concentrator, g-force (80), water pressure (5 psi), solid content (15%) and feed rate (1 liter/min.), can produce an excellent titanium concentrate with titanium carbide of 92.2 % from a feed waste of about 5 % titanium carbide with a total recovery of 97 %.

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