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An extraction of copper from recycling plant slag by using falcon concentrator

Introduction

The gravity concentration is a physical process and separation of one mineral from another depends upon their density differences and some other hydrodynamic forces. It is producing clean concentrates with less value (Burt 1984). Generally, the separation efficiency decreases as the particle size of the processed mineral become finer (Oruç et al. 2010). Gravity concentration has lower efficiency at below 100 µm particle sizes. It has disadvantages at these sizes for separation without imparting an extra force on the particles, which led to the development of enhanced gravity separators (Traore et al. 1995; Burt et al. 1995; Honaker et al. 1996; Ancia et al. 1997; Honaker 1998; Oruç et al. 2010). The concentrators, using centrifugal force for separation, are known and used for nearly 60 years in the industry. The falcon concentrator was manufactured by the Falcon Concentrator Company of Vancouver British Colombia. It has both laboratory-scale and commercial-scale concentrators to upgrade of minerals such as gold, titanium, iron and some other metal ores (Abela 1997; Fonceca 1995; Oruç et al. 2010). That's why; the Falcon concentrators are used increasingly in mining and related industries. Falcon (enhanced gravity separators) is consisting of a fast-spinning bowl which creates centrifugal forces. The separation principle depends on the enhancing the gravity with centrifugal force and separate minerals in order to their density differences. The separator is fed from its top and drained the slurry in a thin flow-

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ing film at its wall. The centrifugal force can be increased between 20 and 300 times of gravitational acceleration effects depending upon rotation rate. This force makes the heavy particles retained inside the bowl, whereas the other particles went out with the fluid (Abela 1997; Deveau 2006; Laplante et al. 1994; Laplante and Nickoletopoulos 1997; Laplante and Shu 1993; McAlister and Armstrong 1998).

The falcon separator has been increasingly used in gold mining, fine coal cleaning and other valuable minerals which have density differences. They are commonly used by the mining industry to achieve physical separation of fine particles. They are efficient density-based separators that operate well over a wide range of conditions, so there are some researches about the application at light fine material recoveries such as in Waste Electrical and Electronic Equipment (WEEE) treatment (Duan et al. 2009), tailings dewatering in the oil sands industry, handling of dredged sediments (Kroll-Rabotin et al. 2013).

Every mine eventually is depleted and there is an exponentially increasing production of copper in the world. Many concerns about the availability of copper in short or long term are an indicated of world copper production over the last 110 years rise dramatically (Singer 2017). Nevertheless, this huge amount of copper production cannot obstacle the copper prices increase. By focusing on copper supply concerns should be on resources such as natural copper ore deposit or recycling copper. The developing mining technologies increase the success of exploration and concentration of copper ore and reducing the costs of mining. However, it causes the destruction of the surrounding area. That's why; the recycling of metals especially copper has gained an importance not only economically but also environmentally. The recycling copper is returning to the industry in nugget metal form, hence eliminating any kind of mining activities, destruction of mining areas, any concentration process, using tons of chemicals or refinery processes.

1. Materials and methods

This study is concerned with the extracting nugget copper particles from jig tailings of copper recovery plant slag which were recycled copper scrap. The origin of the copper sample, used in the tests, is coming from used metal which is collected from cities. Then this metal waste is treated in copper recycling plant to reproduce copper metal for the metal industry. However, all copper pieces cannot be recovered by recycling plant and some of them is running of plant slag. This slag, which contains copper pieces, is ground by the ball mill, screened by double-deck industrial screens and concentrated by jig as the first and shaking table as second. The disposal of all these processes is used for test material for Falcon Concentrator. The Flowsheet of the plant is given as Figure 1.

The samples were processed with Falcon concentrator to determine the best operational conditions for extracting copper. Firstly, the operational parameters such as particle size, centrifugal force, and washing water pressures were determined. Secondly, the test sample was divided into two groups and one of them was classified in narrow particle sizes. The test sample was already ground in a recycling plant and all material was under 300 microns, that's why the particle size distributions were determined as geometric series from 300 microns to 75 microns. Lastly, all parameters were tested in different steps and results were evaluated together. The particle sizes of the sample, used in the tests, and their chemical analyses were given in Table 1. The test conditions were applied to both the whole distribution sample and narrow size distribution samples in the same way. The L-40 model laboratory-scale falcon concentrator was used in the tests, as given in Figure 2.

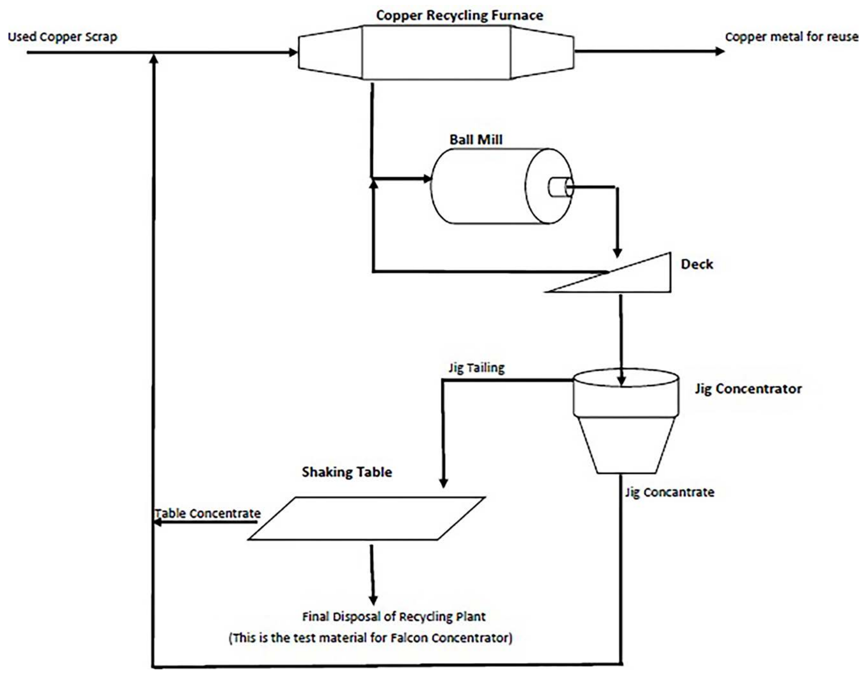

Fig. 1. The Flowsheet of Copper Recycling Plant

Rys. 1. Schemat zakładu recyklingu miedzi

Table 1. Copper Metal Content of Test Sample in Different Particle Sizes

Tabela 1. Zawartość metalu miedzi w badanej próbce o różnych wymiarach cząstek

Sample Number	Particle Size	Cu%* (as metal content)
1	–300 + 150 μm	1.11
2	–150 + 75 μm	0.89
3	–75 μm	1.09
4 (Whole Fraction)	–300 μm	1.04

* Chemical Tests are in ASTM Standards.

Fig. 2. The L-40 Laboratory Scale Falcon Concentrator

Rys. 2. Koncentrator Sokoła Laboratoryjnego L-40

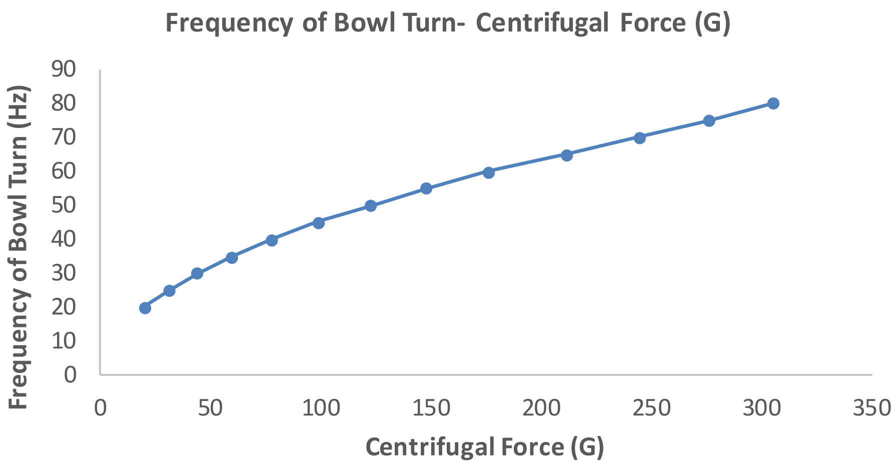

Fig. 3. Relationship between bowl frequency and centrifugal force

Rys. 3. Związek między częstotliwością obrotu misy a siłą odśrodkową grawitacji

All test samples were treated in the same way and tested with different washing water pressures from 0.3 bar to 1.5 bar and different centrifugal force from 20 G to 305 G. Water pressure was controlled by a pressure control valve. Centrifugal force was calculated according to the relationship with the frequency of bowl turns as indicating in falcon manual as given Figure 3.

Although there are some other hydrodynamic forces can be effected on the particle such as drag force, friction force and water buoyant force, the particle escaping from or stick to the concentrator wall is depending on the main acting forces such as centrifugal force, gravity force and water pressure force. If the *Fw*, is greater than *Fr* then the particle escapes from the concentrator wall otherwise it sticks on. It is given as eq. 1–4.

$$Fc = \frac{mV^2}{r} \tag{1}$$

$$Fw = P \cdot A \tag{2}$$

$$Fg = mg \tag{3}$$

$$Fr = \left[\left(\frac{mV^2}{r} x \sin\alpha\right) + (mg\, x \cos\alpha)\right] \tag{4}$$

↳ *Fc* – the centrifugal force,
Fw – the water force,
Fg – the gravity force,
m – the mass of the particle,
V – the linear velocity,
r – the radius of Falcon bowl,
P – the water pressure,
A – the waterhole total cross-sectional area,
Fr – the resultant force,
g – the gravitational acceleration.

The forces, acting on an individual particle inside of the concentrator, are shown as Figure 4.

The solid content of feed was fixed at 45% by weight which was determined according to pre-experiments. All tests conditions were operated as batch processes. There were two determined discharge units in the system in order to obtain products as a concentrate and tailing. The samples were fed into the separator directly and the products were taken in the form of concentrate and tailings respectively. The products were dried and weighed out.

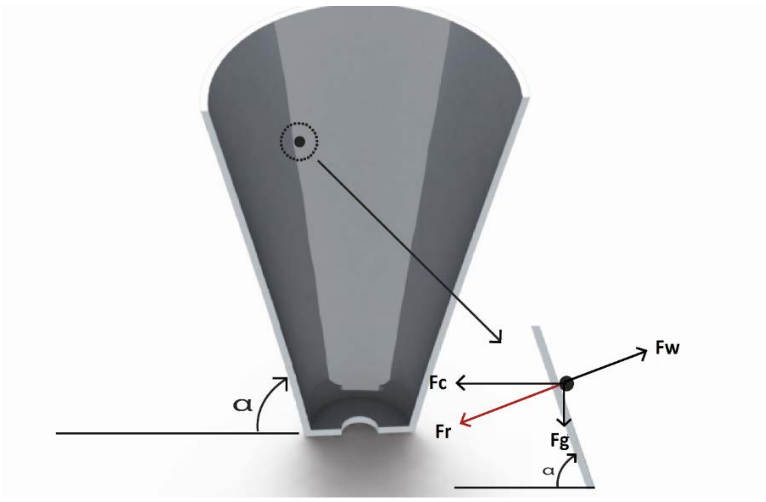

Fig. 4. The Forces, acting on an individual particle

Rys. 4. Siły działające na pojedynczą cząstkę

For each test, the concentrator was cleaned, controlled and then operated in a manner appropriate to the new test conditions. In this way, the best operational conditions were determined to extract more copper from double recycled disposal.

The Falcon concentrator did not perform in some specific test conditions. In fine sizes, all the material was washed by the effect of washing water even at the maximum centrifugal force whereas the concentrator being choked up by centrifugal force even at the maximum washing water pressure in coarse sizes.

That's why the minimum washing water pressure and maximum centrifugal force were used for fine sizes while the maximum water pressure and minimum centrifugal force for coarse sizes. These two parameters were evaluated together as a new variable of G/P (where: G is a centrifugal force which is multiple times of gravitational acceleration effects and P is a water pressure) and its' relationships with recovery and grade were investigated separately for each particle size fractions and the whole distribution.

2. Result and discussion

In this study, the effects of centrifugal force, the particle size distribution of feed and water pressure on the copper extraction efficiency from double recycled disposal in Falcon concentrator were investigated. The affecting operating parameters were determined as centrifugal force (G), water pressure (P) and particle size distribution of feed in light of past investigations and pre-experiments of study samples. The favourable conditions were tested in Falcon concentrator by keeping solid content constant in the value of 45%. The particle sizes were tested as – 300 µm, –300 + 150 µm, –150 + 75 µm and –75 µm and centrifugal forces were varied between 305 G and 20 G, whereas the water pressures were varied between 0.3 bar and 1.5 bar. These ranges stayed within the industrial operational limit of equipment.

The results indicate that the water pressure and centrifugal force have an inversely proportional relationship. This relationship is shown as Figure 5.

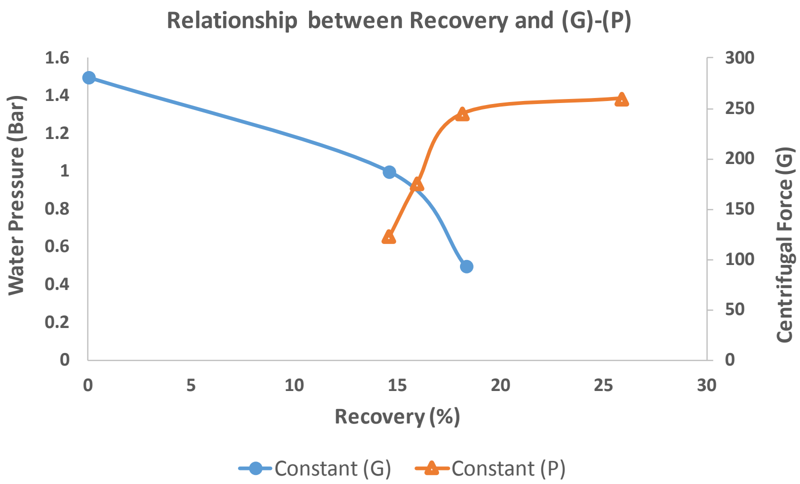

Fig. 5. Water pressure and centrifugal force relationship

Rys. 5. Ciśnienie wody i zależność siły odśrodkowej

Because of this phenomenon, the G/P parameter was created for a simple analysis of the relationship between operating parameters of Falcon concentrator and its performance. The relationships between G/P and recovery, grade were investigated in detail. By this way, the minimum washing water pressure and maximum centrifugal force were used for fine sizes while the maximum water pressure and minimum centrifugal force for coarse sizes and were compared to each other. The test material was processed in two different ways. One of them was the whole particle distribution which has the particle size of –300 microns and the other way was narrow particle size distribution which has the three different particle size of –300 + 150; –150 + 75 and –75 microns. All test results were compared and evaluated each other. They are given in Tables 2–5.

The tests from 1 to 6 show that the best results were an obtained in the 1st, 4th and 5th tests with the enrichment ratios were 415.94%; 413.08% and 419.76% respectively while the worst results 2nd which has the most higher G/P rate of all six tests conditions, as shown in Table 2.

The tests from 7 to 13 show that the best results were an obtained in 9th and 12th tests with the enrichment ratios were 665.77% and 507.21% respectively while the worst results 11th which has the most higher G/P rate of all seven tests conditions, as shown in Table 3.

Table 2. Whole Fraction (–300 µm) Tests Results

Tabela 2. Wyniki testów klasy ziarnowej –300 µm

Number of tests	Centrifugal Force (G)	Washing Pressure (P) (bar)	G/P	Concentrate Amount (%)	Recovery (%)	Grade (%)	Enrichment (%)
1	44.00	0.50	88.00	3.18	13.24	4.36	415.94
2	60.00	0.50	120.00	13.68	23.67	1.80	171.72
3	78,00	1.00	78.00	3.44	12.60	3.81	363.47
4	99.00	1.00	99.00	3.00	12.50	4.33	413.08
5	123.00	1.50	82.00	3.02	12.77	4.40	419.76
6	148.00	1.50	98.67	3.54	12.99	3.82	364.42

* Feed grade is 1.04.

Table 3. –300 + 150 µm Fraction Tests Results

Tabela 3. Wyniki testów klasy ziarnowej –300 + 150 µm

Number of tests	Centrifugal Force (G)	Washing Pressure (P)(bar)	G/P	Concentrate Amount (%)	Recovery (%)	Grade (%)	Enrichment (%)
7	20.00	0.70	28.57	0.77	3.80	5.49	494.59
8	44.00	0.70	62.86	5.13	11.82	2.56	230.63
9	60.00	0.90	66.67	1.63	10.83	7.39	665.77
10	70.00	1.00	70.00	3.71	15.07	4.51	406.31
11	78.00	1.00	78.00	10.16	18.67	2.04	183.78
12	78.00	1.50	52.00	1.52	7.73	5.63	507.21
13	99.00	1.50	66.00	3.08	13.53	4.88	439.64

* Feed grade is 1.11.

The tests from 14 to 22 show that the best results were an obtained in the 18th test with the enrichment ratio was 725.84% while the worst results 21st which has the most higher G/P rate of all eight tests conditions, as shown in Table 4.

The tests from 23 to 29 show that the best results were an obtained in the 29th test with the enrichment ratio was 784.40% while the worst results 28th which has the most higher G/P rate of all seven tests conditions, as shown in Table 5.

Table 4. –150 + 75 µm Fraction Tests Results

Tabela 4. Wyniki testów klasy ziarnowej –150 + 75 µm

Number of tests	Centrifugal Force (G)	Washing Pressure (P)(bar)	G/P	Concentrate Amount (%)	Recovery (%)	Grade (%)	Enrichment (%)
14	78.00	0.50	156.00	4.10	14.43	3.13	351.69
15	111.00	0.50	222.00	5.41	17.03	2.80	314.61
16	123.00	0.50	246.00	7.37	18.30	2.21	248.31
17	135.00	0.60	225.00	6.48	17.26	2.37	266.29
18	123.00	1.00	123.00	2.01	14.60	6.46	725.84
19	176.00	1.00	176.00	4.73	15.94	3.00	337,08
20	245.00	1.00	245.00	6.91	18.17	2.34	262.92
21	260.00	1.00	260.00	13.40	25.90	1.72	193.26
22	305.00	1.50	203.33	4.68	16.04	3.05	342.70

* Feed grade is 0.89.

Table 5. –75 µm Fraction Tests Results

Tabela 5. Wyniki testów klasy ziarnowej –75 µm

Number of tests	Centrifugal Force (G)	Washing Pressure (P)(bar)	G/P	Concentrate Amount (%)	Recovery (%)	Grade (%)	Enrichment (%)
23	78.00	0.30	260.00	2.54	14.32	6.15	564.22
24	123.00	0.30	410.00	5.53	20.29	4.00	366.97
25	148.00	0.50	296.00	4.29	19.46	4.95	454.13
26	176.00	0.50	352.00	5.19	19.03	4.00	366.97
27	245.00	0.50	490.00	9.12	22.35	2.67	244.95
28	305.00	0.50	610.00	9.93	23.13	2.54	233.03
29	305.00	1.00	305.00	1.89	14.84	8.55	784.40

* Feed grade is 1.09.

Conclusion

The tests results indicate that the concentration processes have limited success with the extracting nugget copper from jig tailing of copper recovery plant slag. However, the process was promising and can be used to regain a certain amount of nugget copper. The all copper source, used in tests, were coming from doubled recycling materials.

The test material was processed as the whole particle distribution, the particle size of – 300 microns, and a narrow particle size distribution the three different particle size of – 300 + 150; – 150 + 75; – 75 microns. In the whole distribution tests, the best results were 4.51% grade and 15.07% recoveries with 406% of enrichment ratio, whereas the narrow particle size distribution has 6.50% grade and 14.81% recoveries with 619% of enrichment as the average of all three particle size distributions. There were 44% grade and 52% enrichment ratio differences between the whole distribution and the narrow particle size distribution in similar recovery values. The falcon concentrator has specific working conditions and it needs the operation of its optimum conditions for different particle size distributions to reach better performances. Moreover, the concentrate material can be washed in a shaking table and reached better grade values.

Although the grade and recovery values are not much as usual separation efficiency of gravity concentration methods, even if a limited amount of copper gaining makes a significant difference not only economically but also environmentally. Moreover, the sample is not original copper ore, it is the metal form of copper nuggets and this issue makes it valuable in spite of low grade and recovery values. The basic reason for low beneficiation is that the copper particles are not liberated as much as the process need. One of the other factors is the shape factor, during the grinding operation, the copper nuggets take the flaky shape and this causes to float the particles in water and entrained to the outside of the bowl. It must be remembered that the feed resource was double recycled disposal. In addition, the concentrates can be added to the initial feed of copper recycling plants. In this way, tons of copper can be saved and re-used.

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AN EXTRACTION OF COPPER FROM RECYCLING PLANT SLAG BY USING FALCON CONCENTRATOR

Keywords

Nugget copper extraction, Falcon concentrator, recycling of copper

Abstract

This investigation is concerned with the extraction of nugget copper particles from copper recovery plant slag which recycled of copper scrap. For this purpose, the Falcon concentrator was used because of its enhanced gravity properties. The Falcon concentrator has a fast spinning bowl which creates a centrifugal force to separate fine size minerals on the basis of their density differences. In the tests, the tailings of the copper recovery plant were used and the test sample was divided into two groups and one of them was classified in narrow particle sizes. The operational parameters were determined as particle size, centrifugal force and washing water pressures. The water pressure and centrifugal force have an inversely proportional relationship. Because of this phenomenon, the G/P parameter was created. The test conditions were applied to the whole distribution sample and narrow size distribution samples in the same way.

The test results indicate that the average grade was elevated from 1.04% to 6.50% with the recovery of 15.07% and 619% enrichment ratio for narrow sizes, whereas grade was elevated to 4.36% with 13.24% recovery and 415.94% enrichment ratio for the whole distribution. As a result, the recovery and grade values of concentrates are not good enough for gravity concentration process for both samples. However, this process was applied to the double recycled material and the lower recovery, grade values can be tolerated because of concentrate is nugget copper metal. The concentrate can also be washed in cleaning table for increasing the grade value for adding to initial feed of plant. This process can, therefore, supply important earnings not only economically but also environmentally.

EKSTRAKCJA MIEDZI Z ŻUŻLU Z ZAKŁADÓW RECYKLINGU ZA POMOCĄ WZBOGACALNIKA FALCON

Słowa kluczowe

ekstrakcja miedzi rodzimej, wzbogacalnik Falcon, recykling miedzi

Streszczenie

Badanie dotyczy ekstrakcji rodzimych cząstek miedzi z żużlu z zakładów recyklingu. W tym celu zastosowano wzbogacalnik Falcon ze względu na jego zwiększone właściwości wzbogacania grawitacyjnego. Wzbogacalnik Falcon ma szybko obracającą się misę, w której wytwarzana siła odśrodkowa powoduje rozdział minerałów o niewielkich wymiarach cząstek w zależności od ich różnych gęstości. W testach wykorzystano odpady z instalacji odzysku miedzi, a próbkę podzielono na dwie grupy, jedną z nich zaklasyfikowano do klasy cząstek o niewielkich wymiarach. Parametry technologiczne zostały określone i są to: wielkość cząstek, siła odśrodkowa i ciśnienia wody płukającej. Ciśnienie wody (P) i siła odśrodkowa grawitacji (G) charakteryzują się zależnością odwrotnie proporcjonalną. Z powodu tego zjawiska został utworzony parametr G/P. Zastosowano takie same warunki testu do rozdzielonych próbek o niewielkich wymiarach cząstek. Wyniki wskazują, że średnia ocena została podwyższona z 1,04 do 6,50% przy odzysku 15,07% i stopniu wzbogacania 619%.

Dla cząstek niewielkich wymiarów ocena została podniesiona do 4,36% przy odzysku 13,24% i stopniu wzbogacania 415,94% dla całej dystrybucji. W rezultacie odzyski i wartości stopni wzbogacania koncentratów nie są wystarczająco dobre dla procesu wzbogacania grawitacyjnego dla obu próbek. Jednak proces ten został zastosowany do materiału z podwójnego recyklingu, a niższy poziom odzysku i stopnie wzbogacania mogą być akceptowane, ponieważ koncentrat stanowi rodzima miedź. Koncentrat może być również wzbogacany na stole koncentracyjnym w celu zwiększenia wartości stopnia wzbogacania do dodania do nadawy na zakład przeróbczy. W ten sposób proces ten może przynieść istotne zyski nie tylko w wymiarze ekonomicznym, ale także środowiskowym.