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Recovery of Metals from Aluminum Dross and Saltcake

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ABSTRACT

Various aluminum-smelting by-products from three production sources were received and characterized. The waste materials were tested for compound identification and environmental acceptance. A coarse metallic aluminum recovery test using an Eddy Current separator (ECS) was performed using two different Circuit configurations. White dross performed equally well with either Circuit, while black dross processing shows significant difference on the separation results. It was found that ECS technology was effective for particle sizes down to 6-10 mesh.

Keywords: *Eddy current, recycling, aluminum slag*

INTRODUCTION

Aluminum is a critical material in the U.S. construction, packaging, and transportation industries. The aluminum industry produces approximately one million tons of waste by-products from domestic aluminum smelting annually. The most significant by-products are called salt cake and dross, and are generated in the smelting process.

Over the last two decades, aluminum recycling has grown rapidly in terms of both size and importance to the U.S. economy. Between 1950 and 1974, recycled aluminum constituted only about 5% of the total domestic aluminum market [1]. Since then, both the fraction of recycled materials and the total domestic aluminum market have grown substantially. In January 1997, for example, total aluminum shipments to domestic markets were 1,591 million lbs., an increase of 12.5% over January 1996 levels. Of this total, 639 million lbs., or about 40%, was recovered from new and old metallic scrap. In most applications, recycled aluminum materials perform as well as primary material, and provide significant savings in both production costs and energy usage.

At present, most aluminum-bearing scrap is recycled through a smelting process. Although the details of the smelting process differ between various installations, most involve melting the scrap in the presence of chloride-based slag, generally using either a reverberatory or rotary furnace. This slag is typically a eutectic or near-eutectic mixture of sodium and potassium chlorides containing low levels of fluorides (cryolite) or other additives. It serves two primary functions. First, since the material is molten and fairly fluid at typical aluminum smelting temperatures, the slag coats the metallic aluminum being melted and minimizes oxidation losses during processing. Second, the presence of the fluorides and other additives assists in breaking down prior surface oxide layers on the aluminum charge and promotes improved separation between the aluminum and the residual nonmetallics in the charge.

The aluminum-bearing scrap for recycle may be either reclaimed metallic aluminum products (e.g. castings or used beverage containers) or metal-bearing aluminum oxide drosses skimmed from primary aluminum melting furnaces. Drosses obtained from primary melting operations (so-called “white drosses“) consist primarily of aluminum oxide (with some oxides of other alloying elements such as magnesium and silicon) and may contain from 15 to 70% recoverable metallic aluminum. Drosses from secondary smelting operations (so-called “black drosses“) typically contain a mixture of aluminum/alloy oxides and slag, and frequently show recoverable aluminum contents ranging from 12 to 18%. Commercial smelting of both white and black drosses is often done in a rotary salt furnace. The nonmetallic byproduct residue, which results from such dross smelting operations is frequently termed “salt cake“ and contains 3 to 5% residual metallic aluminum. It is normally disposed of in a landfill [2].

In response to increasing environmental pressures, the domestic primary aluminum smelting industry has initiated a number of efforts to both minimize dross/salt cake generation and to reprocess/recycle the byproduct wastes generated. The most common approach has been to upgrade the metallic aluminum content of dross wastes prior to re-melting. This is typically done by mechanically pulverizing the dross down to a coarse powder and then screening it with a 10 to 20-mesh screen. The oversize fraction (the concentrate) typically contains 60% to 70% metallic aluminum and is remelted. The undersize fraction is then landfilled. This approach substantially reduces the amount of dross smelted, lowering both the amount of energy and the amount of salt cake generated during the smelting operation. Metal-rich salt cake residues can also be processed in the same manner, further reducing the amount of material landfilled. Typical costs for this concentrating operation generally range from about \$5 to \$60 per ton of material processed [3].

The amount of waste material also can be minimized by minimizing the amount of salt used during the smelting operation. This so-called “dry“ smelting process uses about half the amount of salt employed for the more traditional “wet“ operation, but requires that the furnace be tilted at the end of the run to remove the residual salt cake material [4]. In addition, smelting operations are using improved control of aluminum oxidation after dross removal to maximize metallic aluminum recovery and minimize the amount of aluminum oxide, which must be landfilled. The approaches employed include protective coverings, forced cooling (typically in water-cooled steel drums), and storage under a protective inert atmosphere [5]. Mechanical pressing of the hot dross to squeeze out (a portion of) the metallic aluminum is sometimes also used as an alternative to salt smelting.

While the smelting by-product is viewed by industry as a disposal problem, costing producers millions of dollars in landfill costs and exposing them to severe environmental liabilities, we view the by-products not as a waste stream, but as raw materials, which need further processing to create value-added products to economically enhance the bottom line of the aluminum industry. In this project, we are trying to develop a technology to divert the aluminum smelting by-products into valuable feedstock materials for the manufacturing of concrete products such as lightweight masonry, foamed concrete, and mine backfill grouts.

Methods for the separation of aluminum from the waste stream include manual separation as well as density separation methods such as hydraulic or pneumatic classifiers [6]. These methods are either labor intensive or of limited applicability since many plastics have the same density as aluminum. More recently, very promising methods have been developed based on the idea of eddy current separation [7]. An alternating magnetic field induces eddy current in conducting bodies, which in turn combine with the magnetic field to cause a Lorentz force which is capable of accelerating conducting materials away from nonconducting products. The ratio of electrical conductivity to the mass density, δ/ρ, is an indication of the separability of the various materials. The δ/ρ ratio of aluminum is 13.0 [8].

In the present paper, characterization of dross and salt cake by-product material will be discussed. Also the efficiency of Eddy Current Separation (ECS) to recover metallic aluminum will be evaluated.

EXPERIMENTAL

Toxicity Characteristics Leaching Procedure (TCLP)

An Inductively Coupled Plasma (ICP) Emission Spectrophotometer (Leman Labs Inc., Lowell, MA) was used for TCLP quantification. TCLP [9] extraction procedure was performed as follows: a portion of by-product material was treated with known volume of extraction fluid composed of glacial acid and sodium hydroxide whose pH was kept at 4.88 to 4.98. The slurry was contained in a jar with a cover and mixed in a Burrell‘s Wrist Action Shaker (Pittsburgh, PA) for 22 hours. The slurry was filtered through no. 1 Whatman filter paper (acid washed) and the liquid phase (defined as the TCLP extract) was collected for the ICP analysis. The acidified extract (pH 2) was stored in the refrigerator.

Gas Analysis of Aluminum Salt Cake

Evolution of gases during the salt cake process was determined with a Gas Chromatographic method using thermal conductivity detector (GC/TCD). Known amounts of saltcake sample (-100 mesh) were reacted with a known volume of deionized water in a headspace analysis jar (250 mL). The headspace of the jar was collected after a certain time (from 0.5 to 48 hours) and analyzed with a GC/TCD at the operating conditions listed in Table 1.

A toxic gas monitor (GC Industries, Inc.) for hydrogen sulfide (H_2S) gas was employed in addition to GC analysis. For the H_2S analysis, the headspace of the jar was released through tubing (valve attached) to the gas monitor. The slurry mixture in the jar was mixed using a magnetic stirrer.

Table 1. GC Operating Conditions

Column	Molecular Sieve 5A, Haysep Q
Detector	Thermal conductivity detector
Column temperature	50^{o}C
Detector temperature	60^{o}C
Injector temperature	60^{o}C
Filament temperature	150^{o}C
Carrier gas	Helium
Flow rate	20 mL/min

Characterization

In order to identify constituents of -100 mesh fines of the aluminum by-product materials, Scanning Electron Microscopy (SEM) analysis has been performed on the materials at a state of as pulverized, after water wash and after NaOH treatment. The SEM was JEOL, JSM-820. Secondary electron image resolution was at 30 kV and 10^{-12} to 10^{-6} A of probe current with 10X to 300,000X magnifications.

X-ray diffraction (XRD) phase analysis was carried out to characterize the crystal phases in aluminum wastes. Parameters used for the analysis were target: Cu; count time: 1.800 sec; scan range: 20-89.99^o; scan rate: 1.00 deg/min.

Metallic Aluminum Assay

Two grams of sample were mixed with 50 ml of 3N NaOH in a beaker and left under the fume hood overnight. The slurry was filtered through #4 Whatman filter paper. The filtrate was diluted to 250.0 mL with deionized water and analyzed with ICP.

Flowsheet of Eddy Current Separation Process

Circuit 1 flowsheet

White dross and black dross samples processed using Circuit 1 (Figure 1), were crushed to -6" and then screened at 2”. The +1/2" fraction and -1/2" fraction were separately fed to Eddy Current Separators with machine parameters adjusted for optimized separation.

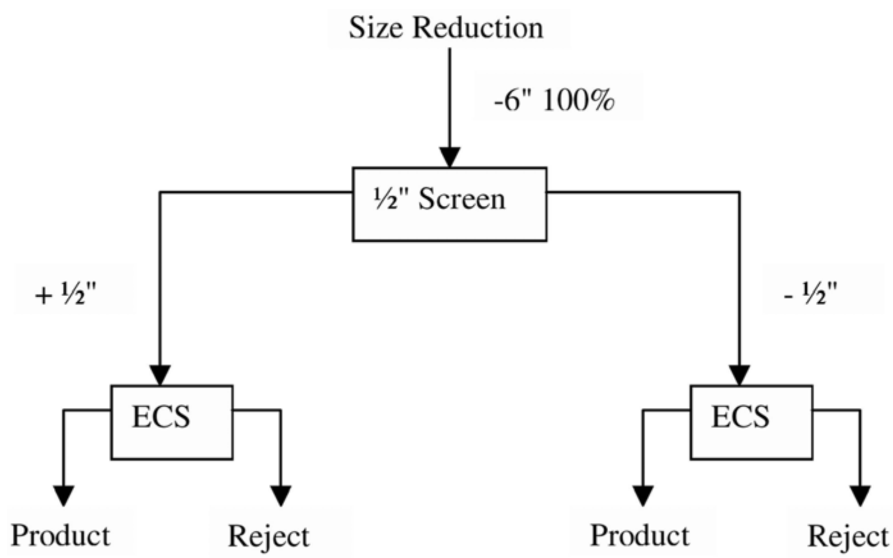

Figure 1. Circuit 1 flowsheet.

Circuit 2 flowsheet

In Circuit 2 (Figure 2), white dross and black dross samples were crushed to -12" and then screened at 3/8", which shifted more material to the coarse fraction for further liberation prior to ECS processing.

Since the top size for crushing was -12, it proved easier to handpick the large aluminum pieces from the 12" x 3/8" fraction than running a mechanical scalping operation. After handpicking, the rest of particles were shredded. The dust and spills were combined with the coarse ECS reject since it was visually observed that the size of the material was below the size of the coarse ECS reject stream and it would serve no purpose to try and reprocess the material on a separate ECS system. The -3/8" fraction was separately fed to an Eddy Current Separator.

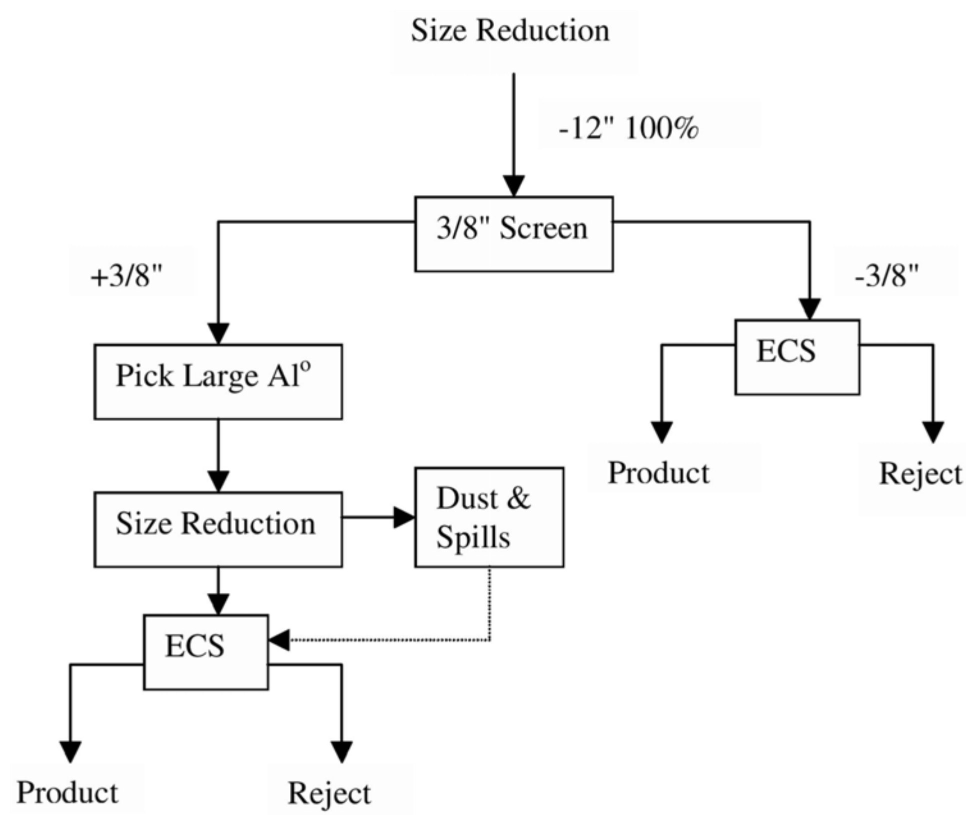

Figure 2. Circuit 2 flowsheet.

RESULTS AND DISCUSSION

Environmental Assessment and Characterization

Table 2 shows the type of aluminum smelting by-product wastes that were received from three project team companies. The samples are here identified by letter designation, i.e. Supplier A, Supplier B, etc., along with the type of material (saltcake, dross, dust, etc.).

TCLP testing on as-received samples

Toxicity Characteristic Leaching Procedure (TCLP) tests were performed on the as-received samples to identify environmental acceptability. The results are displayed in Table 2 along with the concentration limits for acceptability. None of the as-received samples pose environmental concerns for the heavy metals tested under TCLP guidelines.

Gas Generation from aluminum salt cake

The 20-drum salt cake sample received from Supplier A had a distinct odor of hydrogen sulfide (H_2S). A gas analysis study was performed on the material in both a dry and wet state. The results are shown in Table 3. None of the gases generated when the salt cake was wet were found to be hazardous.

Table 2. TCLP Results on As-Received Aluminum By-Product Wastes

Sample	Concentration (ppm)					
	Se	As	Ba	Cd	Cr	Pb
Supplier A						
Salt Cake	0.083	0.124	0.526	0.164	0.262	0.303
Supplier B						
Black Dross	0.154	0.111	0.545	0.211	0.095	0.109
Gray Baghouse Dust	0.039	0.054	0.030	0.009	0.003	0.065
Black Baghouse Dust	0.035	0.039	0.035	0.099	0.041	0.038
Supplier C						
Baghouse Dust	0.027	0.030	0.039	0.010	0.016	0.057
Coarse Black Dross	0.033	0.043	0.008	0.009	0.023	0.054
Fine Black Dross	0.031	0.055	0.006	0.009	0.023	0.068
White Dross	0.033	0.049	0.007	0.009	0.029	0.061
ACA Oxide	0.165	0.251	0.664	0.135	0.272	0.038
Recovered Al Fines	0.173	0.279	0.749	0.134	0.300	0.402
TCLP Limits	1.00	5.00	100.00	1.00	5.00	5.00

No H_2S gas was detected using a GC/TCD and a gas monitor. The concentration of evolved hydrogen sulfide was not high enough to be detected from both wet and dried salt cake, where the limit of detection for GC/TCD is 2.5 % and the H_2S monitor can determine the concentration of H2S in the atmosphere in the range of 0 to 100 ppm with +/- 3ppm accuracy. Hydrogen sulfide gas could be recognized even when it was dry by the characteristic odor. Notice that H_2S gas odor is perceptible in air in a dilution of 0.002 mg/L (2 ppb).

Vigorous H_2 gas evolution was observed when the salt cake is exposed to water. Four percent (v/v) of 2 was detected by the GC method, not exceeding the regulation value, 4.5 % of minimum flammability. During the GC analysis, no methane and ammonia gases were observed from the salt cake by Molecular Sieve 5A, and only trace amounts of methane could be seen by Haysep Q column.

Table 3. Gas Analysis Results with Regulations

Gas	Flammable Limits	OSHA* Limits	Experimental Results
H_2S	4.3 to 45 %	20 ppm	ND**
H_2	4.5 to 75 %	Not toxic	4.2 %
NH_3	15 to 28 %	50 ppm	ND**
CH_4	5.3 to 15 %	Not toxic	ND**

* Occupation Safety & Health Administration; ** Not detected

Characterization Results

Tables 4 and 5 provide a summation of the characterization results for aluminum smelting by-product wastes. From ICP analysis (Table 4), it has been found that these materials contain three major components: water soluble salts (NaCl, KCl), metallic aluminum, and oxides (Al_2O_3, $MgAl_2O_4$). The minor species detected by SEM and X-ray diffraction were Si, SiO_2, $Ca_3Al_2O_6$, $Ca_2Al_2SiO_7$, $CaAl_2Si_2O_8$•H_2O (Table 5).

Table 4. Characterization of Aluminum By-Product Wastes

Sample	Soluble Salts (wt %)	Metallic Aluminum (wt %)	Residual Oxides (wt %)
Supplier A			
Salt Cake	65.00	2.06	32.94
Supplier B			
Black Dross	39.80	22.90	37.30
Gray Baghouse Dust	19.10	1.40	79.50
Black Baghouse Dust	14.90	2.20	82.90
Supplier C			
Baghouse Dust	23.00	18.60	58.4
Coarse Black Dross	43.00	7.13	49.87
Fine Black Dross	34.00	5.83	60.17
White Dross	12.00	43.38	44.62
ACA Oxides	3.80	14.19	82.01
Recovered Aluminum Fines	14.00	10.47	75.53

Table 5. Chemical and XRD analysis of various aluminum smelting by-products.

Sample	Soluble salts	Metallic Aluminum (wt %)	Phases
Black Dross	43% 25% NaCl, 18% KCl	7.1	NaCl, KCl, Al, Al_2O_3, SiO_2, Si, $MgAl_2O_4$, $Ca_3Al_2O_6$
Baghouse Dust	23% 16% NaCl, 7% KCl	18.6	NaCl, KCl, Al, Al_2O_3, SiO_2, Si, $MgAl_2O_4$, Ca3Al_2O_6, $Ca_2Al_2SiO_7$
White Dross	2.7% 1.5% NaCl, 1,2% KCl	43.4	NaCl, KCl, Al, Al_2O_3, $MgAl_2O_4$, $Ca_3Al_2O_6$, $Ca_2Al_2SiO_7$
SPF Fines	34% 20% NaCl, 14% KCl	5.8	NaCl, KCl, Al, Al_2O_3, SiO_2, Si, $MgAl_2O_4$, $Ca_3Al_2O_6$, $Ca_2Al_2SiO_7$
ACA Oxide	0.8% 0.35% NaCl, 0.46% KCl	10.1	Al, Al_2O_3, SiO_2, Si, $MgAl_2O_4$, $CaAl_2Si_2O_8$.H_2O
RAF	2.5% 1.53% NaCl, 0.98% KCl	13.9	Al, Al_2O_3, SiO_2, Si, $MgAl_2O_4$, $CaAl_2Si_2O_8$ .H_2O

Eddy Current Separation

White dross and black dross samples were studied with an Eddy Current Separator to evaluate its capability for recovery of aluminum. Circuit 1, which will be discussed in further detail below, was first tested. A major finding from Circuit 1 was that the coarse fraction aluminum recovery was relatively low. This finding initiated performing a second test where the coarse fraction was further liberated by comminuting prior to receiving ECS processing; this work was performed using Circuit 2. A detailed discussion of this work follows.

Circuit 1 ECS processing performance

White Dross testing on Circuit 1

White dross with a feed composition of 41.05% metallic aluminum (Al^o) was processed first. Combining product streams the process generated a yield of 40.0 wt%. Each stream (product and reject) had a screen analysis performed on it. This was followed by analytical determination of Al^o content for each individual size fraction. The complete by-size analysis is provided in Table 6, including Al^o recovery within size fractions and Al^o recoveries by size fraction, for both the coarse and fine materials.

The coarse fraction (+ 2”) averaged 74.07% aluminum recovery. The recoveries within size fractions ranged from 66.70% to 78.73%, not extremely high, but fairly consistent. The assay for the product fraction averaged 78.85% Al^o with a range of 71.20-88.76% Al^o. A clue that liberation may be a problem can be seen in the product assay where the +1" material showed an assay of 71.20% Al^o and the quality climbed to 88.76% for the +3/4" fraction and remained high for the rest of the fraction. Also, the ½" x 2”size had the highest by size recovery at 22.33% of an overall recovery of 74.07% for the coarse fraction, even though the calculated head assay of that material was not the highest. Again, these results identify potential liberation problems.

The fine fraction (2” x 0) showed that product assay performance dropped off sharply for the -10 mesh fraction. The recovery within the size fraction steadily declined at particle sizes below 6 mesh. Since the +3 mesh fraction shows a 94.12% Al^o recovery at 55.63% Al^o grade, which is higher than the 65.23% Al^o recovery with 35.09% Al^o grade at 3 x 6 mesh, the decline is believed to be related to the equipment capability rather than the liberation.

Overall the Circuit 1 white dross test produced product quality of 69.02% Al^o from feed of 41.05% Al^o, with a total Al^o recovery of 67.25%.

Black Dross testing on Circuit 1

Black dross with a feed composition of 42.44% Al^o was processed on Circuit 1. Combining product streams the process generated a yield of 35.42 wt%. From Table 7, the coarse fraction (+^{2}") performance was consistent with regards to product grade at various particle sizes, maintaining above 50% Al^o . The Al^o recovery within each size fraction declined steadily from a high of 77.59% for +1" present in the coarse fraction. Actually, this is somewhat surprising considering the calculated feed assay for each size fraction was fairly homogeneous with an average of 48.61% Al^o and a range of 40.81 to

58.60% Al^o. In direct comparison to white dross, where the average feed assay for the coarse fraction was 52.55% Al^o, it is fairly close to that of the black dross. However, the white dross Al^o recovery was fairly tight within size fractions, averaging 74.07% with a range of 66.70-78.73%.

In the fine fraction (2” x 0), the product assay drops off below 10 mesh. Al^o recovery within each size fraction drops off below 3 mesh. What was surprising was that the +3 mesh size fraction had a 71.08% Al^o recovery, better than most of the sizes in the coarse fraction, following the pattern established in white dross testing.

Overall, the Circuit 1 black dross test produced product quality of 67.73% Al^o from feed of 42.44% Al^o, with a total Al^o recovery of 56.53%.

The performance of quality was quite similar between black dross and white dross, but it was obtained differently, by processing more coarse material in the coarse fraction, 68.7 wt% for black dross compared to 57 wt% for white dross.

Again, with black dross, based on +3 mesh performance in the fine fraction and somewhat irregular behavior in coarse fraction performance, the question of further liberation needs to be addressed.

Table 6. White Dross Circuit 1 Test Results

Size Fraction	Wt.% Feed	ECS Product	Product Al^o	Rejects Wt%	Rejects Al^o	Calculate Assay	Al^o Recovery	Al^o Recovery
+1/2 inch fraction								
+1"	26.42	13.23	71.20	13.19	29.90	50.58	70.49	17.92
+3/4"	22.76	11.63	88.76	11.12	25.03	57.61	78.73	19.64
+1/2"	27.07	14.95	78.49	12.12	26.21	55.08	78.70	22.33
-1/2"	23.75	9.56	77.92	14.19	26.21	47.02	66.70	14.17
+1/2 inch feed	100.00	49.37	78.85	50.62	26.91	52.55	74.07	74.07
-1/2 inch fraction (mesh)								
3 mesh	15.77	13.12	55.63	2.65	17.21	49.17	94.12	28.28
6	22.05	11.84	35.09	10.21	21.69	28.89	65.23	16.10
10	25.91	1.79	54.14	24.12	17.40	19.94	18.76	3.75
14	10.07	0.84	22.02	9.23	16.81	17.24	10.65	0.72
20	7.37	0.00	0.00	7.37	20.10	20.10	0.00	0.00
28	4.51	0.00	0.00	4.51	21.09	21.09	0.00	0.00
35	2.72	0.00	0.00	2.72	21.20	21.20	0.00	0.00
48	3.88	0.00	0.00	3.88	22.60	22.60	0.00	0.00
-48	7.72	0.00	0.00	7.72	11.65	11.65	0.00	0.00
-1/2 inch feed	100.00	27.59	45.70	72.41	18.24	25.81	48.84	48.84

Table 7. Black Dross Circuit 1 Test Results

Size Fraction	Wt.% of Feed	ECS Product Wt%	Product Assay Al^o	Rejects Wt%	Rejects Assay Al^o	Calc. Assay of Size Fractions	Al^o Recovery w/in Size Fraction	Al^o Recovery by Size Fraction
+1/2 inch fraction								
+1"	62.58	31.53	75.77	31.05	22.22	49.20	77.59	49.15
+3/4"	18.60	8.99	56.38	9.61	26.24	40.81	66.78	10.43
+1/2"	12.00	4.19	51.59	7.81	62.36	58.60	30.74	4.45
-1/2"	6.82	1.14	52.67	5.68	45.70	46.87	18.79	1.24
+1/2” feed	100.00	45.85	69.18	54.15	31.19	48.61	65.26	65.26
-1/2 inch fraction (mesh)								
3	11.55	5.84	53.18	5.71	22.13	37.83	71.08	10.74
6	25.37	5.14	59.61	20.23	29.57	35.66	33.87	10.59
10	29.49	1.54	55.88	27.95	29.36	30.74	9.49	2.97
14	8.77	0.06	39.90	8.71	23.12	23.23	1.17	0.08
20	8.36	0.00	0.00	8.36	22.27	22.27	0.00	0.00
28	5.93	0.00	0.00	5.93	18.26	18.26	0.00	0.00
35	3.19	0.00	0.00	3.19	18.79	18.79	0.00	0.00
48	2.14	0.00	0.00	2.14	18.11	18.11	0.00	0.00
-48	5.20	0.00	0.00	5.20	9.20	9.20	0.00	0.00
-1/2” feed	100.00	12.58	56.07	87.42	25.02	28.93	24.38	24.38

Circuit 2 ECS processing performance

White Dross testing on Circuit 2

White dross from a different batch with a feed composition of 60.27% Al^o was processed using Circuit 2. Combining all product streams, the process generated a yield of 75.87 wt%. A breakdown of the by size performance is provided in Table 8.

As seen in Table 8, the product assays for the coarse fraction were in the 45-55% Al^o range down to 10 mesh, but the Al^o recovery within size fractions was outstanding, being in the 90% level down to 10x14 mesh. The Al^o recovery within the 14x20 mesh size was 78.28%, comparable to the best coarse fraction recoveries from Circuit 1. By including the additional liberation step, the coarse fraction material obtained higher recoveries at approximately the same quality. In addition the ECS was able to effectively perform on slightly finer material than experienced under Circuit 1 conditions.

The fine fraction (3/8" x 0) showed that product assay by size maintained quality down to the 20x28 mesh size, however, the recoveries within each size fraction were extremely good for the +3 mesh size (94.13%) and 3x6 mesh size (83.06), but dropped off significantly at 10x14 mesh size. In general, reducing to a 3/8" size changed the weight distribution to the fine ECS unit, but pretty much maintained performance compared to the ² inch split of Circuit 1. Overall Circuit 2 produced better product quality (73.49% Al^o) with a remarkably high aluminum recovery of 92.51%. This may be somewhat misleading because the feed assay of the Circuit 2 white dross was 60.27% Al^o, up considerably from the material tested on Circuit 1 (41.05% Al^o). For true comparison the performance has to be normalized with regards to feed quality, which will be addressed later.

Black Dross testing on Circuit 2

Black dross with a feed composition of 15.44% Al^o was processed using Circuit 2. Again there is a disparity in feed quality between black dross material in Circuit 1 and Circuit 2 and this will have to be normalized for fairness of comparison. A breakdown of the by-size performance is provided in Table 9.

Because of the low feed grade quality, considerably lower product qualities were experienced than expected. For the coarse fraction the quality drops off below 10 mesh, and the recovery within size fractions also experienced significant deterioration below 10 mesh. For the fine size fraction (3/8" x 0), product quality was fairly consistent down to 20 mesh, but Al^o recoveries within size fractions were small below 10 mesh. Overall the Circuit 2 black dross test produced a product quality of 30.16% Al^o from a feed of 15.44% Al^o, with a total Al^o recovery of 56.81%.

Comparisons of the ECS

The efficiency of separation for two ECS processing circuits was compared, by including normalization because of variations of feed quality. To provide a basis for comparison, we know that if we produced 100% Al^o at 100% recovery a perfect 100% efficiency of separation would be obtained. Secondly, to compensate for feed quality variations between tests, the ratio of Assay of Product over Assay of Feed ratio can be used for normalizing. Combining these aspects, an efficiency index value can be obtained from the following equation.

$$[[(\%\ Al^o \text{ in Product})/ (\%\ Al^o \text{ in Feed})] \times \text{wt\% recovery}]/100 = \text{Efficiency Index Value}$$

Based on the equation the higher the index value, the more efficient the separation. Table 10 displays the efficiency of separation index values as determined for Circuit 1 and Circuit 2 white and black dross tests.

Table 8. White Dross Circuit 2 Test Results								
Size Fraction	Wt.% of Feed	ECS Product Wt%	Product Assay Al^o	Rejects Wt%	Rejects Assay Al^o	Calc. Assay of Size Fractions	Al^o Recovery w/in Size Fraction	Al^o Recovery by Size Fraction
12 x 3/8 inch fraction (mesh)								
3	30.47	30.47	55.77	0.00	0.00	55.77	100.00	40.90
6	20.44	20.30	49.68	0.14	29.50	49.54	99.59	24.28
10	16.38	15.86	45.95	0.52	24.75	45.28	98.26	17.54
14	5.44	4.85	38.12	0.59	22.18	36.39	93.39	4.45
20	4.52	3.19	32.92	1.33	21.91	29.68	78.28	2.53
28	4.25	1.98	27.15	2.28	20.12	23.39	53.96	1.29
35	1.40	0.41	24.27	0.99	19.33	20.78	34.21	0.24
48	6.24	0.96	15.53	5.28	16.60	16.44	14.54	0.36
-48	10.85	0.78	13.95	10.07	12.57	12.67	7.92	0.26
12 x 3/8" feed	100.00	78.81	48.43	21.20	15.97	41.54	91.85	91.85
-3/8" fraction (mesh)								
3	4.77	3.82	45.02	0.95	11.29	38.30	94.13	6.26
6	13.82	9.29	49.14	4.53	20.56	39.77	83.06	16.62
10	17.07	7.14	53.08	9.93	25.57	37.08	59.88	13.80
14	7.20	1.71	50.37	5.49	28.24	33.50	35.71	3.14
20	8.11	1.04	51.43	7.07	27.97	30.98	21.29	1.95
28	9.80	0.62	43.62	9.18	24.27	25.49	10.82	0.98
35	3.33	0.13	25.29	3.20	24.73	24.75	3.99	0.12
48	12.33	0.28	20.12	12.05	19.32	19.34	2.36	0.21
-48	23.57	0.39	11.90	23.18	13.55	13.52	1.46	0.17
-3/8" feed	100.00	24.42	48.64	75.58	20.63	27.47	43.23	43.23
Products		Wt% of feed		Al^o assay			Al^o Recovery	
SK12		58.08		81.15				
SK4		4.60		48.64				
SK14		13.18		48.43				
Subtotal		75.87		73.49			92.51	
Rejects								
SK5		14.24		20.63				
SK15		3.55		15.96				
Baghouse		6.35		15.96				
Subtotal		24.13		18.71			7.49	
TOTAL		100.00		60.27			100.00	

Table 9. Black Dross Circuit 2 œ By size Performance Analysis								
Size Fraction	Wt.% of Feed	ECS Product Wt%	Product Assay Al^o	Rejects Wt%	Rejects Assay Al^o	Calc. Assay of Size Fractions	Al^o Recovery w/in Size Fraction	Al^o Recovery by Size Fraction
12 x 3/8 inch fraction (mesh)								
3	22.87	22.02	34.06	0.85	5.70	33.01	99.36	45.61
6	11.91	6.54	24.06	5.40	8.85	17.16	76.62	9.53
10	17.87	5.01	20.68	12.86	9.57	12.68	45.71	6.30
14	7.85	1.36	14.06	6.49	12.41	12.70	19.19	1.16
20	10.43	0.72	13.67	9.71	9.38	9.68	9.75	0.60
28	7.25	0.31	12.06	6.94	9.51	9.62	5.36	0.23
35	4.89	0.13	10.60	4.76	8.61	8.66	3.25	0.08
48	4.51	0.03	12.80	4.48	8.58	8.61	0.99	0.02
-48	12.42	0.05	7.10	12.37	8.61	8.60	0.33	0.02
12 x 3/8" feed	100.00	36.14	28.92	63.86	9.38	16.44	63.56	63.56
-3/8" fraction (mesh)								
3	6.69	3.33	26.99	3.36	11.10	19.01	70.67	7.90
6	15.82	5.02	23.96	10.80	9.24	13.91	54.65	10.57
10	16.46	2.24	30.15	14.22	9.83	12.60	32.58	5.93
14	8.33	0.37	32.37	7.96	10.48	11.45	12.55	1.05
20	8.85	0.16	30.88	8.69	9.55	9.94	5.62	0.43
28	10.21	0.21	10.34	10.00	9.25	9.27	2.29	0.19
35	8.56	0.00	0.00	8.56	9.63	9.63	0.00	0.00
48	7.04	0.00	0.00	7.04	10.27	10.27	0.00	0.00
65	5.27	0.00	0.00	5.27	10.00	10.00	0.00	0.00
100	4.40	0.00	0.00	4.40	9.20	9.20	0.00	0.00
-100	8.36	0.00	0.00	8.36	6.90	6.90	0.00	0.00
-3/8" feed	99.99	11.33	26.19	88.66	9.49	11.38	26.08	26.07
Products		Wt% of feed		Al^o assay			Al^o Recovery	
BD4		1.54		26.19				
BD14		26.86		28.92				
BD12		0.68		88.32				
Subtotal		29.08		30.16			56.81	
Rejects								
BD5		12.05		9.49				
BD15		47.46		9.38				
Spills		11.41		9.38				
Subtotal		70.92		9.40			43.19	
TOTAL		100.00		15.44			100.00	

Table 10. Efficiency Index Values from ECS Testing		
	Circuit 1	Circuit 2
White Dross	1.131	1.128
Black Dross	0.90	1.11

CONCLUSIONS

Based on the Eddy current separation tests, the following conclusions can be made from the test work:

- White dross performed equally well with either circuit.
- Black dross processing was more efficient with Circuit 2, realizing the effect of liberation on the coarser fraction.
- Both circuits were more efficient using white dross than black dross or white dross is easier to upgrade.
- ECS technology is effective processing down to 6-10 mesh size material.

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