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DROSRITE EXTENSIVE ON-SITE HOT DROSS TREATMENT TESTS

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Abstract

DROSRITE is a salt-free process for the recovery of metal from dross. In addition to producing a salt-free residue, it does not produce any CO_2 or NO_x gases. The process is highly energy efficient, extracting heat from energy in the residue and, thus, it does not require an external heat source such as a plasma torch, an electric arc or a gas or oil burner.

A DROSRITE pilot unit built by PyroGenesis was used for an extensive series of 50 tests on the site of an aluminum smelter.. Hot dross, charged into the DROSRITE furnace, was treated without any external heat input (1, 3, 4, 5 and 6xxx alloys).

Results of this industrial trial are presented. The *absolute* metal recovery efficiency was found to be 94% on the average. The input dross metal content, determined for each of the 50 skimmings, was found to vary widely; it is proposed to use that knowledge to improve the skimming practices. The economic analysis is also presented.

Introduction

Dross, a major byproduct of all processes involving molten aluminum, forms at the surface of the molten metal as the latter reacts with the furnace atmosphere. It generally represents 1 to 5 wt% of the melt, depending on the process, and typically contains about 50% free aluminum dispersed in an oxide layer. Since aluminum production is highly energy-intensive, dross recycling is attractive from both the energy and economic standpoints.

Dross is produced both at primary smelters where aluminum is obtained by electrolysis of alumina and also at remelt plants where aluminum scrap and used beverage cans are recycled.

The conventional dross treatment process, using gas or oil-heated rotary salt furnaces (RSF), is thermally inefficient and environmentally unacceptable because of the salt slag produced. In the past several years, a number of salt-free processes have been developed and some of these have found limited commercial use. One of these uses a plasma torch as the energy source and it has been implemented at Alcan's plant in Jonquière, Quebec (1). Another approach makes use of a graphite arc (2, 3), with the advantage (over the torch technology) of not requiring water cooling and not producing additional nitrides and burning recoverable metal.

In all existing dross treatment processes, heating of the cold dross in a rotary furnace requires an external energy input that varies between 375 and 2,500 kWh per tonne of dross (4-6). Molten metal separated during processing of the heated dross is tapped, and the remaining solid residue is discharged from the furnace.

The novel process developed by PyroGenesis (7), named DROSRITE, does not require any external energy input. Process energy is extracted from the solid residue, stored in the furnace refractory wall, and released to the next batch of fresh dross. Furthermore, the process is operated online with the molten aluminum holding furnace where the dross is generated. Thus, the hot metal can be returned to the furnace immediately after tapping, still in its molten form.

Energy savings in comparison with conventional processes can exceed 2,500 kWh per tonne of dross.

The differences between the conventional RSF method and the DROSRITE method are illustrated in Figure 1. The RSF process is characterized by five unit operations while, with DROSRITE, only a single step is required. In addition, the RSF-produced metal must be reheated, which is not the case for the hot metal returned to the holding furnace when using the DROSRITE process.

A further and critical advantage of DROSRITE over conventional dross treatment processes is that no fluxing salt is used. Thus, the residue is not contaminated by as much as 50% salt, as in the case of the RSF process. The salt-free residues of the DROSRITE process are suitable for production of calcium aluminate or for other value-added use (8).

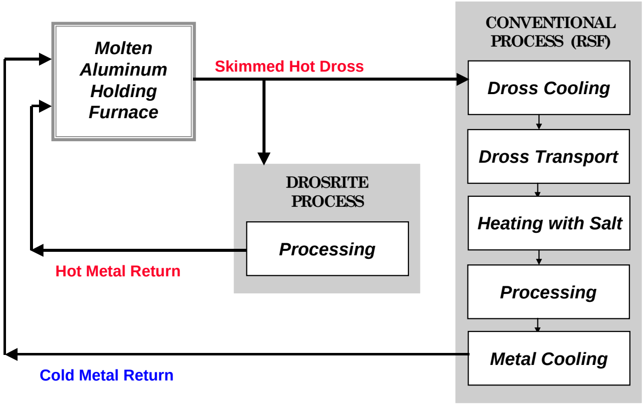

Figure 1 – The Conventional Rotary Salt Furnace (RSF) Process and the DROSRITE Process

Separation of Aluminum from Dross

The separation of metallic aluminum from aluminum dross is not well understood. In spite of the lack of understanding of the phenomenon, separation fortunately *does* occur and most of the metal contained in the dross is recovered. The mode of heating (fuel burner versus plasma torch versus electric arc) does not seem to be a dominating factor, as long as the charge is heated above the melting point of the metal.

In fact, for all of the heating modes considered, most of the energy provided by the heat source is picked up by the furnace wall and then transferred by contact to the charge as the furnace rotates. Very little energy is transferred directly to the charge, as this is covered by a thick insulating layer of dross.

In the case of DROSRITE, the source of heat during processing is also the wall of the rotary furnace. Thus, DROSRITE does not differ significantly from earlier technologies in terms of the mode of transferring energy to the dross or the separation phenomena at work. The major difference is in the novel way in which energy is released into the furnace.

The DROSRITE Process

With DROSRITE, hot dross is charged to a refractory-lined rotary furnace, immediately after skimming from the aluminum holding furnace. The DROSRITE furnace is sealed and maintained under an argon atmosphere. The only heat source for the furnace is the controlled reaction of oxygen with residual aluminum contained in the dross residue, after the recoverable metal has been tapped.

The process operates in five distinct steps:

Step 1: Charging

The furnace, having been preheated at the end of the previous batch to between 800 and 900 °C, is flushed with argon. The furnace door is opened and the dross is charged. The furnace door is then tightly closed.

Step 2: Processing

The furnace cavity is purged with argon. The furnace is rotated as necessary to gently tumble the charge, for roughly 15 to 30 minutes. Duration of this tumbling is as required to achieve transfer of energy from the refractory walls of the furnace to the charge.

Step 3: Metal Tapping

The tap hole is opened, and the metal is poured into the receiving vessel or ladle.

Step 4: Furnace Heating

A controlled amount of oxygen is injected into the furnace cavity, burning some of the non-recoverable aluminum contained in the residue. The temperature inside the furnace is monitored. When the temperature reaches the target value, typically in the range of 800 to 900 °C, oxygen injection is stopped.

Step 5: Discharging the Residues

Purging with argon is repeated. The furnace door is opened, and the residue is discharged into a suitable pan. The door is closed. The furnace is ready for the next cycle.

An Industrial DROSRITE Unit

An industrial DROSRITE unit will typically be installed in close proximity to the casting department of the aluminum plant. The furnace unit will be sized according to the operating characteristics and total treatment requirements of the particular installation.

As an example, consider an aluminum plant producing 6,000 tonnes of white dross per year, with approximately one furnace skimming of 700 kg each hour. A suitable DROSRITE configuration in this case would comprise two furnace units, each having a capacity of 2.1 tonnes. Up to three pans containing 700 kg of dross could be charged into the standby unit as dross became available. The furnace in this case could have an internal diameter of two meters and a length of 2.5 meters. One furnace would be on standby while the second was processing.

Mass and energy balances for such a 2.1 tonne unit are presented in Figures 2 and 3 respectively, with the assumption that the process will in this example recover 600 kg of aluminum from each tonne of dross.

Figure 2 indicates that 15.6 kg of oxygen are required in this case to “burn” a sufficient amount of the aluminum remaining in the residue to return the furnace to its initial temperature of 850 °C at the conclusion of a run. The quantity of aluminum that is burned in this case corresponds to 0.8% by weight of the original dross charge, and this percentage has been found to be quite insensitive to detailed operating parameters.

The energy balance of Figure 3 illustrates quantitatively how the energy generated by the controlled reaction of oxygen with residual aluminum balances the other energy inflows and outflows in a process cycle.

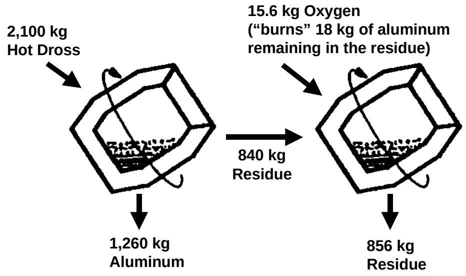

Figure 2 – Mass Balance for an Industrial DROSRITE Installation

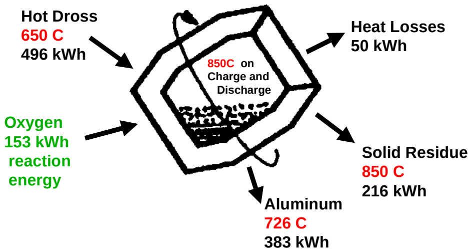

Figure 3 – Energy Balance for an Industrial DROSRITE Installation

Industrial Demonstration of DROSRITE

The Pilot Unit

A small rotary furnace was constructed for use in demonstrating the feasibility of the DROSRITE process in an industrial environment. The unit, illustrated in Figure 4, has overall dimensions of 5-ft x 7-ft x 7.5-ft and weighs approximately two tonnes.

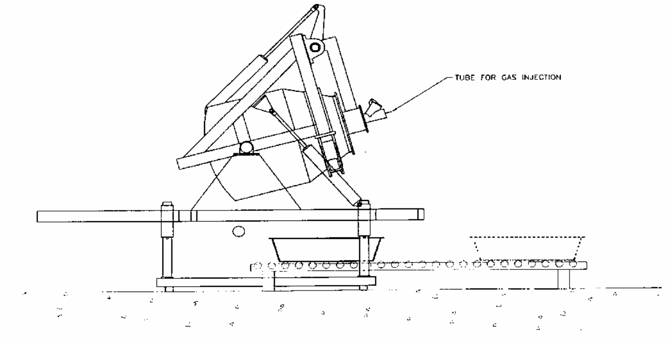

Figure 4 – Processing of the Dross
Under Inert Argon Atmosphere

Industrial Trials

Trials were conducted at a large aluminum recycling plant and at the pilot plant of a second aluminum producer, both in the U.S.A. Various charges of hot white and black drosses were treated. A third series of 50 tests (Aluminum alloy 1,3,4,5 and 6xxx) were conducted at a smelter plant in Europe. At the beginning of a series of runs, the cold furnace was preheated using either natural gas or propane. In Europe, no heating gas was used, the furnace being heated to 800 °C using hot dross alone, with oxygen injection.

The test results obtained at both the recycling plant and the pilot plant have been published previously (9). The dross, both black and white, which was tested at the aluminum producer pilot plant was quite different from that tested previously at the recycling plant, most notably being much “wetter” or richer in aluminium. It was found that the processing recipe could be adjusted readily to achieve successful processing.

A typical processing test is illustrated in Figure 5. In this test, preheating of the furnace was stopped at 18:40 and 66 lb of hot white dross was charged when it arrived from the melt shop. The temperature of the process was monitored with a thermocouple embedded in the refractory, approximately 0.13-in from the inner surface.

The tapping yielded 49 lb of aluminum, corresponding to 74% of the initial charge.

Injection of 0.5 m^3 of oxygen following tapping raised the temperature of the vessel to 860 C in a controlled manner. Note that the temperature rise, and thus the thermiting reaction, stopped as soon as the oxygen flow was switched off. Controlling oxygen intake controls the thermiting process.

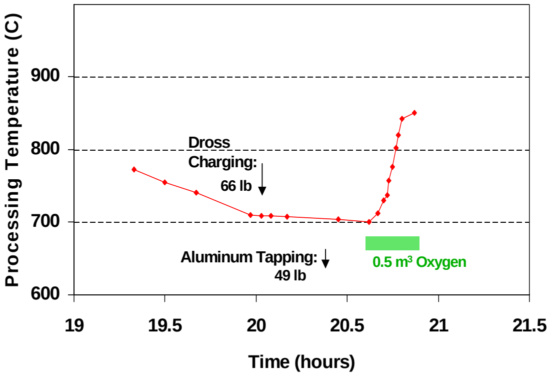

Figure 5 – Temperature Variation in a Typical
DROSRITE Test Processing White Dross

A total of 1 m^3 of argon was used in this test, for purging on charging and discharging, and during tapping. It is noteworthy that, when argon was injected to the furnace, a small amount of smoke was always visible in the furnace exhaust. By contrast, when oxygen was injected there was no visible exhaust. This supports the conclusion that essentially all of the oxygen reacts with the charge.

Figure 6 presents the results of three consecutive DROSRITE white dross runs. The first of these is the same as was presented in Figure 5. Good aluminum recovery was achieved in each case, and oxygen addition successfully reheated the furnace following tapping. Processing temperatures were quite different in each of the three runs, indicating the robustness of the process.

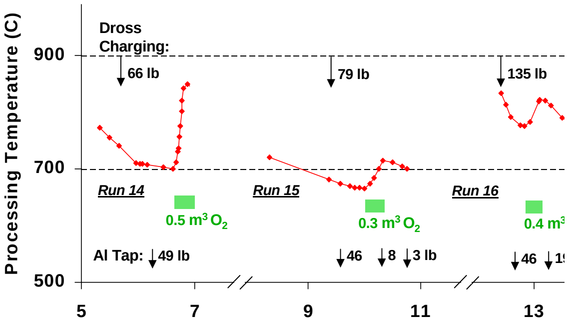

Figure 6 – Three Consecutive Runs, Treating White
Dross by the DROSRITE Process

During operation, the furnace assembly was mounted on a scale to allow monitoring of the charge weight, the weight of aluminum tapped, and the weight of residue produced. Weighing accuracy was within 1 to 3 pounds. In each case, overall weight increase during processing corresponded to the weight of oxygen injected.

Figure 7 presents the results of seven consecutive DROSRITE runs processing black dross. In this campaign the charges of black dross, varying between 140 and 172 lb, were much heavier than the lighter density white dross charges used in earlier trials. Furthermore, it was found necessary to inject some oxygen into the furnace before tapping in order to heat the charge and promote separation. As noted in figure 7, metal recovery from the black dross varied between 18% and 40%.

Table I – Chemical Composition of Residue from Three DROSRITE Runs

	Al (as metal)	Al (other)	F	Na	Mg	Si	Cl	Ca	Mn	Fe
Sample 1	0.8	51.8	0.7	0.28	5.57	0.16	0.84	0.8	0.46	0.71
Sample 2	13	56.2	0.5	0.28	6.6	0.29	0.59	0.54	0.43	0.35
Sample 3	6.2	45.1	0.56	0.28	9.73	0.21	1.81	0.67	0.33	0.35

Analyses of the chemical composition of residue from three different DROSRITE runs with white dross are presented in Table I. All figures are percentage by weight. Given the very low salt content, each of these materials would be suitable for use in production of calcium aluminate or of other value-added products.

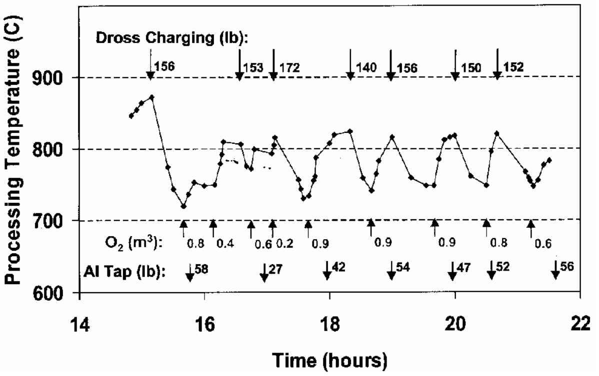

Figure 7 – Seven consecutive Runs, Treating Black Dross by the DROSRITE Process

Analysis and Discussion

The results presented in Figure 5 support a useful qualitative confirmation of the principle of operation of the DROSRITE process. In this case, addition of 0.5 m^3 of oxygen resulted in a temperature increase of 160 °C at the refractory wall, from 700 °C to 860 °C. Further, thermocouples embedded in the refractory 1 inch and 2 inches from the inner surface indicated corresponding temperature increases of 100 °C and 50 °C respectively.

The thermiting reaction at approximately 800 °C is

$$2Al + \frac{3}{2}O_2 = Al_2O_3 + 1{,}700\ kJ/mole.$$

The amount of heat generated is 8.7 kWh per kg of Al reacted or 9.8 kWh per kg of O_2.

Addition of 0.5 m^3 (0.72 kg) of oxygen in the case of Figure 5 would have generated approximately 0.72 x 9.8 x 3600 = 25,400 kJ of energy. This energy served to heat the 16 lb (7.7 kg) of residue <u>and</u> the refractory wall of the crucible.

The specific heat of alumina at 800 °C is approximately 1.1 kJ/kg-°C. Thus, energy consumed heating the residue in this example was on the order of 1.1 x 7.7 x 160 = 1,350 kJ. For the refractory wall, the data indicated that approximately 2.3 inches of the alumina refractory (200 kg) were heated to an average temperature increase of 100 °C, consuming 1.1 x 200 x 100 = 22,000 kJ. Heating of the wall and the residue (23,350 kJ) thus accounts for 92% of the energy contributed by the controlled thermiting reaction.

Within the uncertainty of the estimate, this calculation supports the claim that DROSRITE can successfully separate aluminum from dross using only the energy content of aluminum contained in the residue, energy that would otherwise be lost. Most if not all of the injected oxygen is consumed by this heating.

Process Efficiency

The ***absolute*** process efficiency defined as the ratio of the amount of metal recovered and cast over the metal content in the initial dross charged is usually difficult to determine for lack of knowledge of the initial metal content. However, the ***relative*** efficiencies between different processes have been determined and reported. This is the case for the plasma torch (Alcan) and the graphite arc (Hydro-Quebec / DROSCAR) processes which were both compared to the RSF process.

1) Comparing DROSCAR and RSF

   One half of a 40 tonne lot of white dross was treated in the DROSCAR furnace at LTEE Hydro Quebec and the other half was treated at the RAQ facility in Bécancour (2).

   It was found that the amount of metal recovered by the DROSCAR furnace was 7% higher than the amount recovered by the RSF. This was attributed to the fact that the DROSCAR treatment being under Argon atmosphere, no metal was burned during processing.

2) Comparing the Plasma Torch Process and RSF

   It was found that the RSF gave about 10% more metal than the plasma torch process. This was attributed to the fact that while the metal is partially protected by salt in the RSF furnace, the plasma gas being air is highly oxidizing and is burning aluminium.

   The combustion of aluminium by the air plasma flame was also reported by Alcan (1). The amount of metal combusted was determined by Alcan knowing:

   - The torch power 1MW and its efficiency 67%
   - The torch air flow rate 3m^3/mn
   - The amount of aluminium combusted by 3m^3/mn of air is 0.96kg Aℓ/mn
   - The electrical input is 475 kW. h / tonne dross

The required heating time is: 475 kW. h / 670kW = 43 minutes

The maximum amount of aluminium burned * by the oxygen in the air plasma is 0.96 kg/mn x43 mn = 41kg.

With Alcan, assuming a 50% metal content in the 1 tonne charge, this metal loss of 41kg corresponds to 8% of the metal content. This result is in fair agreement with the 10% loss observation made during the W. Virginia trial and support the interpretation made at the time that the oxidizing air plasma is responsible for the reduction in metal recovery.

*Contrary to the assumption made by Alcan, oxidation will occur as soon as the plasma flame comes in contact with the sponge dross. In fact sponge dross burns more readily than molten metal because of the much larger surface and the alumina thermally insulating support.

3. DROSRITE ***Absolute*** Process Efficiency

As the DROSRITE furnace weight is monitored continuously during the process, it is possible to determine accurately the ***absolute*** efficiency: Let's call A, the weight of the dross, B, the amount of metal recovered and C the weight of the residue.
The A, B and C values are used to calculate the initial metal content in the charge which is obtained as follows:

- First calculate the amount of metal oxidized:

  $$(C+B-A) \times 54 / 48$$

- Then the initial metal content is:

  $$(B + (C+B-A) \times 54 / 48)$$

- The average DROSRITE process efficiency determined for the 50 tests conducted in Europe was found to be:

$$\frac{\textit{Metal recovered and cast}}{\textit{Metal content in charged dross}} = 94\%$$

Furthermore, the DROSRITE treatment being conducted under Argon, as is the case for the Hydro-Quebec process, its metal recovery should be comparable, i.e. higher than RSF by at least 7% and higher than the plasma Alcan process by at least 15%.

Economic Analysis

Treatment Cost Analysis

The detailed cost analysis for a particular DROSRITE installation will depend very much on the scale and on the manner in which the system is to be integrated into existing facilities. Only an indication will be included here of the possible savings in operating costs that can be realized with DROSRITE.

Consider a plant producing 10,000 tonnes of dross per year. Treatment cost paid to a dross treater is typically on the order of \$200 U.S./tonne. In-house treatment using DROSRITE may require an additional operator on all shifts. Argon and oxygen consumption are respectively 5 m^3 and 10 m^3 per tonne (although this argon requirement may displace argon currently used for inert-gas cooling of dross prior to shipping). Thus, annual operating cost can be estimated at \$335,000 annually, as follows:

Additional operator per shift (5x)	$200,000
Relining furnace each two years	35,000
Other maintenance costs	35,000
Argon, oxygen gases	60,000
Power cost	5,000
TOTAL	$335,000

This operating cost must be compared with the alternative tolling cost of \$200 x 10,000 = \$2.0 million. The corresponding operating cost benefit is approximately \$1.7 million annually or \$170/tonne.

Several other factors can impact this analysis, all of them favourably :

- Aluminum separated from dross by DROSRITE can be returned directly to the holding furnace, without remelting. Assuming that 6000 tonnes of metal is recovered per year, annual savings can be on the order of 6,000 tonnes x 400 kWh/tonne x 4.5 ¢/kWh = \$110,000.
- Some companies would give substantial credit for the sharp reduction in in-process aluminum inventory.
- The need for cover salt during dross cooling is eliminated, corresponding to annual savings of approximately \$65,000. If inert gas cooling is currently used, a corresponding saving will result from elimination of this operating cost.
- There could be a cost for disposal of the 4,000 tonnes per year of DROSRITE residues. For example, at \$75/tonne this would correspond to \$300,000 annually. However, DROSRITE residues are particularly clean, with no added salt or nitrides. Thus, its is likely that cost-neutral or value-added outlets can be found.

As discussed earlier, metal recovery is expected to be superior by 7 to 15% to recovery obtained with processes where hot dross is exposed to air, such as the RSF process and the plasma process. This results in a substantial further cost advantage.

Dross Metal Content Control

As indicated earlier the metal content corresponding to each skimming was determined for each of the 50 skimmings tested during our five week trial at the aluminium smelter plant in Europe. Although the average metal content was only about 40%, much less than the value of 50% quoted in the industry, the metal content values, determined for each skimming, were found to vary very widely from 15% up to 87%.

These variations are illustrated in figure 8 where the metal content is plotted versus the day of the week when the dross was skimmed; day 1 corresponds to Monday, day 2 to Tuesday, etc. The trend line for the average value for each week day is also shown as a dotted line in figure 8.

The following observations can be made bearing in mind that the results correspond to only a fraction of the content of each dross pan and not to its full content:

a. The trend line shows an increase in metal content of approximately 5% from Monday to Friday. If this trend can be extrapolated to the full dross pan content, then for the aluminum smelter plant where the test were conducted and which produces 20 000 tpa of dross, this 5% increase in dross metal content correspond to a loss of metal valued at approximately:

   2.5% x 20 000 tpa x $2000 / t = $ 1 million

b. This 5% increase in the trend can be attributed to an increase in the metal content of most skimmings from Monday to Friday.

c. The low metal value observed can be attributed either to careful skimming or possibly to a pan full of hot dross not sent immediately from the cast house to the test area and, on the contrary, left to burn, thus loosing metal content.

In figure 8, an operator's name can be associated with each data point. Therefore, the performance of each skimming operator can be monitored on a continuous basis and measures taken to reduce metal content in the dross by changing the skimming practices.

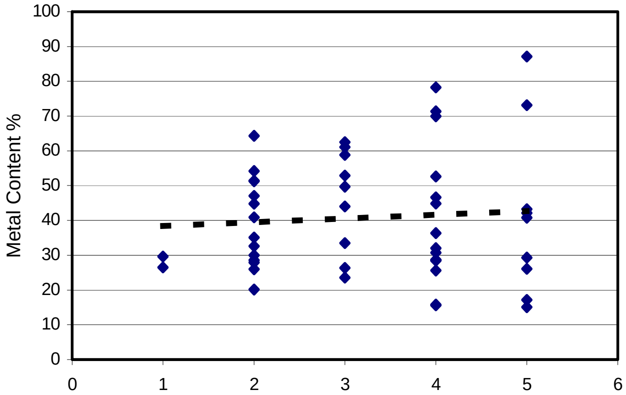

Figure 8 - Metal Content % in the Skimmed Dross vs. Day of Week

Summary and Conclusions

The new industrial trials presented here have further demonstrated that DROSRITE can successfully treat aluminum dross, on-line with the melting furnaces of an aluminum plant. The results demonstrate the viability of batch-to-batch heating with energy stored in the refractory of a DROSRITE furnace, with heating based on "burning" of some of the residual aluminium contained in the residue of the process. Thermiting is effectively controlled and efficient aluminum separation results.

Compared to existing technologies, DROSRITE offers economic advantages due to elimination of the need for salt, high metal recovery, hot metal return, low capital and operating costs and reduced residue disposal costs.

Environmental advantages are even more marked. There is no salt cake requiring disposal. No carbon dioxide or NO_X gases are produced. No nitrides are formed. The process has little off-gas and produces a residue that is suitable for production of calcium aluminate or for other value-added use.

Furthermore, in addition to providing better metal recovery from dross, at much lower cost and much higher energy efficiency, DROSRITE also provides information for the control and follow-up of the dross skimming practices.

Thus, DROSRITE not only treats the ***dross right*** but also allows you to ***skim right*** for added savings.

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