Energy Recovery Opportunities in Pyroprocessing of Nickel Laterites

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Abstract

Energy recovery measures are increasingly being adopted in nickel laterite smelters. The typical nickel laterite smelter involves significant energy inputs in the order of hundreds of megawatts into large rotary kilns and high-powered electric furnaces. Some plants have been constructed with energy recovery as part of the original design while other smelters have added equipment to improve economy of production, reduce emissions or improve carbon footprint. Energy recovery measures such as preheat of combustion air have been in use for many years and are considered mature and relatively low risk while opportunities such as dust insufflation or slag heat recovery are in varying stages of development. This paper reviews energy recovery precedents and presents a technical and economic review of energy recovery opportunities for a typical nickel laterite pyroprocessing facility.

Introduction

Since the 1950's, production of ferronickel from laterites has predominantly been achieved using the Rotary Kiln - Electric Furnace (RKEF) process. The RKEF process was first developed by Elkem for treatment of garnieritic (a serpentinized ultramafic laterite) ore in New Caledonia [1]. In the RKEF process, the ore is screened, crushed, partially dried and fed with a solid reductant (typically bituminous or sub-bituminous coal) into a rotary kiln. In the kiln, the remaining free moisture in the ore is driven off, crystalline water is gradually eliminated and iron and nickel oxides are partially reduced to minimize energy consumption in the subsequent electric furnace smelting step. The calcined solids leave the kiln at temperatures ranging from 700°C to 900°C and are fed into an electric furnace where final reduction and phase separation occurs. In the electric furnace, the slag phase floats on top of the denser, metallic phase, which is removed through tap holes located below the slag level. Depending on the ore composition, grade of ferronickel and the composition of the fuels and reductants used in the dryer and reduction kiln, crude ferronickel contains varying levels of carbon, silicon, chromium, phosphorous and sulphur. Crude ferronickel impurities are removed in a batch ladle refining process. A typical RKEF block flow diagram is shown in Figure 1.

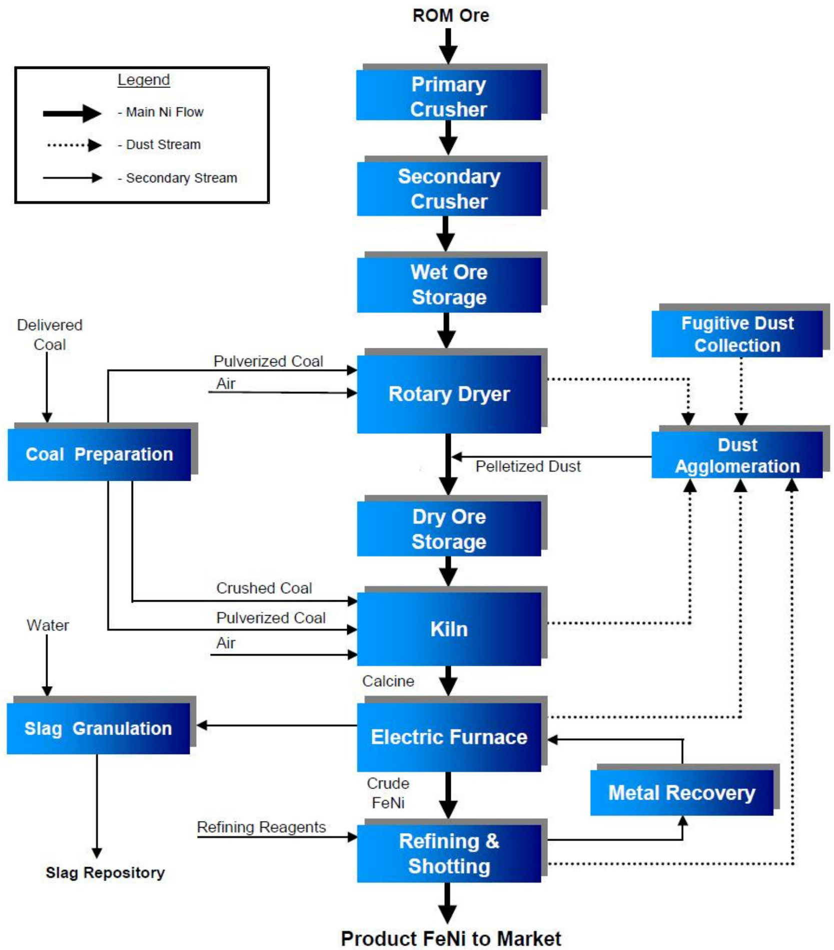

Figure 1. Typical RKEF Block Flow Diagram

RKEF is an energy intensive process because, unlike sulphide processing, there is little or no opportunity to upgrade the ore. Consequently, material containing only around 2% nickel must all be dried, calcined and smelted. This requires consumption of significant amounts of a hydrocarbon fuel (coal, heavy fuel oil or natural gas) in the dryer and kiln, and electric power in the electric furnace. Typical energy consumptions of ore drying and calcining operations are approximately 520 and 4,000 MJ/dry tonne of ore, respectively. Typical power consumption of the electric furnace is approximately 460 kWh/dry tonne of ore [2]. RKEF operations also produce several significant thermal waste streams.

Figure 2 shows the breakdown of energy inputs and outputs to major operating units of a representative RKEF operation. Although the RKEF line only consists of the rotary kiln and electric furnace, the ore dryer has been included to provide a relatively complete energy balance (excluding refining). The output streams have been divided into two groups: those that cannot be recovered because they are chemical reactions and evaporation energies, and those that can be considered as wasted energy that could potentially be harvested (Clearly, there are necessary wastes - it is not possible to make ferronickel without also making slag). As shown, furnace discard slag is the largest single waste energy stream in a typical RKEF plant. Kiln off-gas and furnace off-gas are the next most significant sources of energy loss.

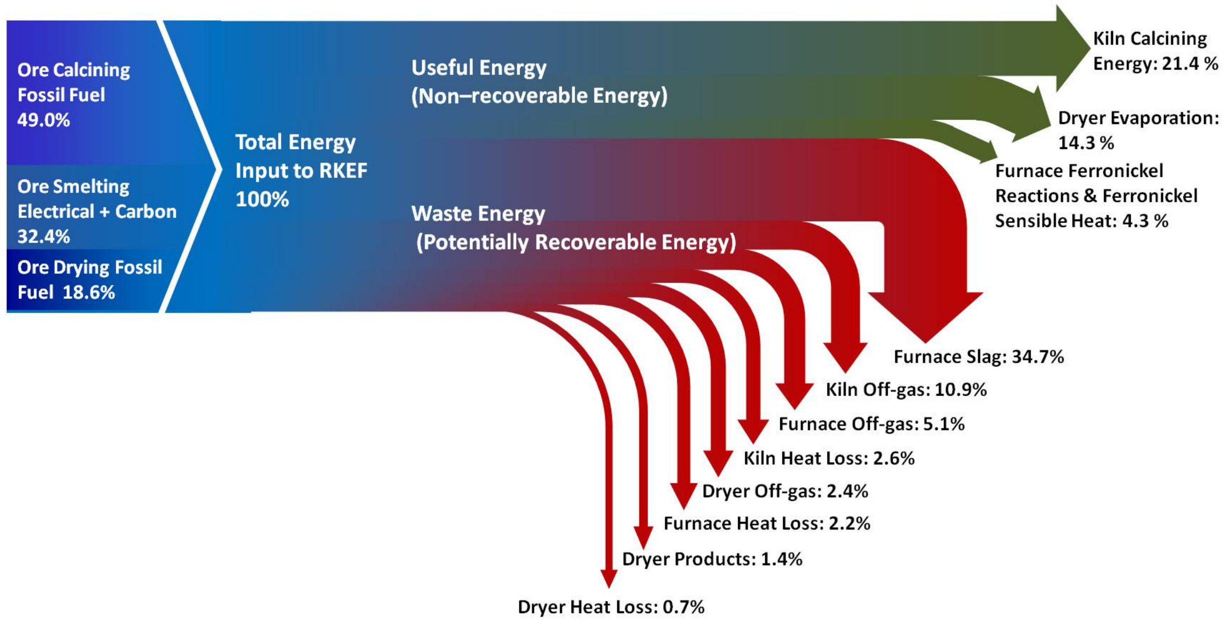

Figure 2. Typical Distribution of Energy Loss

There would appear to be ample opportunity to improve the overall energy efficiency by harvesting some of these waste energy streams. Motivations for energy recovery include improving the financial performance of the operation (through fuel savings and production of marketable granulated slag) and reducing the carbon footprint of the operation by decreasing Greenhouse Gases (GHG) emissions, with the potential for substantial carbon tax savings.

Although some of the energy recovery options have been in use for years and are considered fully developed and relatively risk free, they have not found widespread application in the RKEF flowsheet. Some of these are proprietary developments and are not commercially available. Some have integration issues and others are not economically justifiable for every operation. As a result, project developers, operators and engineers have been reluctant to adopt these measures due to upfront costs, start-up and operational issues and potential impact on the plant operating factor. This paper first reviews an array of different energy recovery options for the most significant sources of heat loss in a typical RKEF smelter. The paper then presents a preliminary technical and economic analysis of these options.

Review of Energy Recovery Options

Recovery Options for Furnace Thermal Waste Streams

In a typical RKEF plant, furnace freeboard gas enriched in carbon monoxide is fully combusted with use of infiltration/post-combustion air. The resultant high temperature (approximately 900^{o}C) off-gas is sent to gas cooling (e.g., spray chamber) followed by an ESP or baghouse prior to release to atmosphere. The molten slag is either water granulated or transported by slag haulers to a dump site and discarded. As shown in Figure 3, Almost 75% of the total energy input (including calcine sensible heat) to the electric furnace is lost to molten discard slag. The energy loss to off-gas accounts for approximately 10% of the energy input.

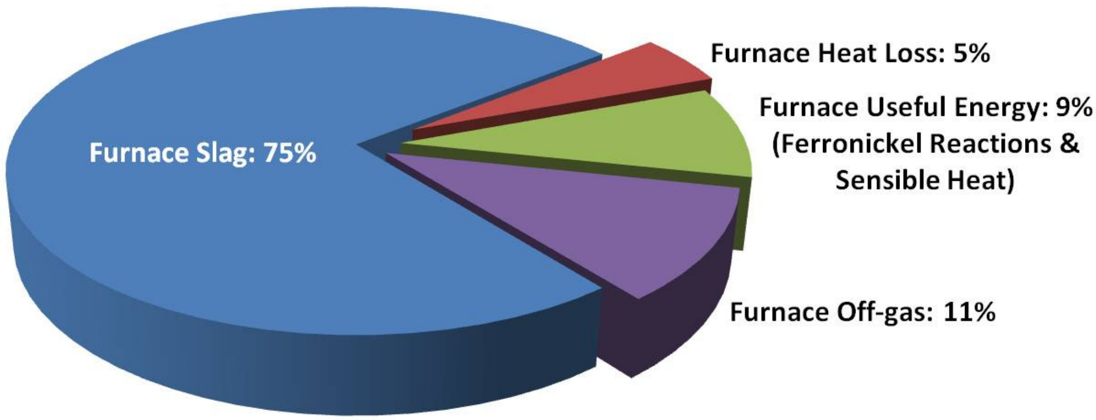

Figure 3. Distribution of Furnace Energy Consumption

Table 1 summarizes energy recovery options for the electric furnace thermal waste streams. These are also briefly reviewed in the following sections.

Table 1. Electric Furnace Energy Recovery Options

Heat Loss Source	Recovery Option	State of Development
Furnace Slag	Air Granulation	Demonstrated in one RKEF smelter; commercially practiced in a number of steel plants.
Furnace Off-gas	Recycle to Ore Dryer	Proven - Practiced in at least two RKEF operations
	Recycle to Kiln as Preheated Secondary Air	Proven - Practiced in at least one RKEF operation
	Use as Supplementary Fuel	Proven - Practiced in at least one RKEF smelter
	Waste Heat Boiler	Not proven in RKEF smelter
Furnace Shell	Recycle to Kiln as Preheated Secondary Air	Proven - Practiced in at least one RKEF smelter

Heat Recovery from Slag

For a number of years the Japanese nickel laterite smelter Pacific Metals (Pamco) air granulated electric furnace slag in a rotary granulator followed by a counter-current heat exchanger to produce preheated air for use in the ore dryer [3]. Controlled granulation of slag can recover heat in the form of saturated steam and hot gas, and produce structurally stable (safe for disposal) and marketable slag by-product. Although relatively expensive, the economic viability of this heat recovery option can be greatly improved if there is a demand for steam, a local market for the granulated slag or carbon taxes. It is also important to note that although several slag granulation technologies are commercially available, a complete recovery system would require project specific design development.

Furnace Off-gas Recycle to Ore Dryer

In at least two RKEF operations furnace off-gas is directly recycled to the dryer air heater and used as preheated tempering air. Ore drying is a relatively simple low temperature operation, and can accommodate fluctuations in the recycled stream conditions (temperature and flowrate). The air heater combustion system can quickly respond to changes in the furnace operating conditions by either adjusting the air heater burner input or by manipulating tempering air flowrate. Despite high temperature gas and dust related maintenance issues, furnace off-gas recycle to dryers has been in use for many years and is considered a relatively low cost and fully developed option. Locating the dryer closer to the electric furnace in new facilities together with proper design of the hot gas line can greatly improve the cost benefits of this heat recovery system. Retrofitting this option in an existing operation requires particular attention to the design and operating conditions of the dryer ESP or baghouse.

Furnace Off-gas Recycle to Rotary Kiln

At the Eramet SLN facility in New Caledonia, dusty furnace off-gas is directly recycled to rotary kilns as preheated secondary air [4]. In contrast to the dryer operation, the kiln operation is sensitive to fluctuations in the recycled hot gas conditions. When calcine is charged to the furnace the release of volatile matter and residual carbon burn-out in the freeboard can result in fluctuations in furnace off-gas conditions. Although a properly designed kiln combustion system can quickly adapt and compensate for these changes, this type of recovery system is likely too difficult to operate with a single furnace to single kiln configuration. Preferably, to alleviate potential impact on the kiln operation, the recycle system should collect off-gases from several furnaces in a common header and direct them to the kilns as required. In addition, many modern kiln operations increasingly rely on tertiary air supplied by onboard fans and the extent of secondary air utilization could be limited. Compared to the furnace off-gas recycle to dryers, this is a more technically challenging option. On the other hand, the kilns are close to the electric furnaces, so that long duct runs normally associated with recycle to dryers are not required.

Supplementary Fuel

At one ferronickel smelter, furnace freeboard off-gas containing carbon monoxide is combusted in the kiln as a supplementary fuel. This heat recovery system requires specific furnace design and operating conditions in order to ensure a CO-rich off-gas. To minimize ingress air, the furnace should be well sealed and operated under suppressed combustion mode. This option is also sensitive to the furnace operation and requires a versatile kiln combustion platform capable of co-firing several fuels separately or in combination. Changes in the furnace off-gas conditions typically require replacing the recycled gases in full or in part with another fuel without compromising burner operation and the heat release pattern in the kiln. This heat recovery option has several precedents in other ferroalloy production facilities (ilmenite and chromite processing).

Waste Heat Boiler (WHB)

This heat recovery system utilizes a waste heat boiler to recover steam to a distribution system for use in various process units either for direct use or to produce electric power using a steam turbine. Although this option is relatively capital intensive and does not have any reference installation in the nickel laterite industry, it could be economically justifiable for operations using high cost thermal power in remote off-grid locations. There is commercial precedent in smelters in other industries.

Heat Recovery from Furnace Shell

In at least one RKEF operation an attempt has been made to recover a portion of the furnace shell heat loss. Warm gases from a hygiene canopy over the furnace (used for CO containment) is directed to the kiln secondary air supply. The value of the energy recovered in this system is low due to the low temperature of the hot gas (50-60^{o}C) but it is also a relatively low cost energy efficiency measure.

Recovery Options for Kiln Thermal Waste Streams

Figure 4 shows that nearly a quarter of the energy input to the rotary kiln in the RKEF process is lost to off-gas. Shell heat loss accounts for approximately 5% of the energy input.

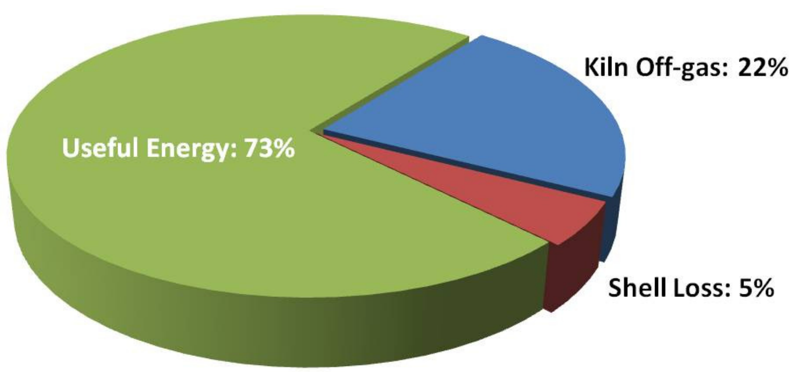

Figure 4. Distribution of Kiln Energy Consumption

Table 2 summarizes energy recovery options for the rotary kiln thermal waste streams. These are briefly reviewed in the following sections.

Table 2. Rotary Kiln Energy Recovery Options

Heat Loss Source	Recovery Option	State of Development
Kiln Off-gas	Preheat Kiln Secondary Air	Proven - Practiced in at least two RKEF smelters
	Preheat Kiln Feed	Proven - Practiced in at least one RKEF smelter
	Preheat Recycled Dust	Not Proven in RKEF smelter
Kiln Shell	Recycle to Kiln as Preheated Secondary Air	Demonstrated

Preheat Secondary Air

At two nickel laterite smelters, kiln off-gas is either passed through a multiclone or ESP and then a heat exchanger to preheat kiln burner secondary air. Unlike other off-gas heat recovery options, this system does not suffer from high temperature gas and dust related maintenance issues. An optimized kiln operation is typically stable without short term fluctuations in off-gas conditions. In the event of a kiln process upset, the combustion system can quickly adapt and compensate for changes in preheated air conditions. This heat recovery option is relatively simple and has several reference installations in the mineral and metal (particularly iron ore) industry.

Preheat Kiln Feed

One RKEF smelter uses kiln off-gas to preheat the kiln feed. Mini balling of partially dried ore enables preheating of the ore with a travelling Lepol grate. Although this option would be difficult and costly to retrofit into an existing plant, it presents an alternative way to recover a considerable portion of the kiln off-gas heat content and may be an economic option in a new smelter.

Preheat Recycled Dust

In most nickel laterite smelters dust is agglomerated with water and recycled to the dryer or kiln. The dust agglomerates have high moisture content (typically 20-25% H_2O). As these agglomerates heat-up in the kiln steam generation can break apart the agglomerates resulting in re-dusting and increased kiln dusting rates. Several nickel laterite operations have investigated the use of a conveyor (belt) dryer for drying of dust agglomerates with the kiln off-gas. Controlled heating in the different conveyor dryer heating zones results in near complete drying (approximately 5% residual moisture content) of dust agglomerates without excessive decrepitation. The conveyor dryer is equipped with a dedicated combustion system to compensate for any process upset in the kiln operation. Conveyor dryers can also accommodate gases with high dust loading. As a result, they can be installed ahead of the kiln ESP providing potential for even higher heat recovery. These dryers are relatively capital intensive and may have a large footprint.

Kiln Shell Cooling

In several smelters attempts have been made to recover a portion of the kiln shell heat loss. Primary or secondary air intakes have been placed right over the hottest part of the shell near the discharge end. In one plant, a hot air collection hood has been placed over the kiln discharge end to collect and send hot air to the coal mill.

Kiln Energy Conservation Options

The following sections review options which are not directly for the recovery of heat from kiln thermal waste streams. These technologies, however, improve energy utilization and avoid wasting thermal energy.

Metal Lifters

A rotary kiln is a heat transfer device. The bed shape and effective area of the charge available for heat transfer by radiation, convection and conduction from the burner combustion gases and hot refractory lining are important factors in improving heat transfer in the kiln. The effective area is greatly increased by the use of metal lifters. The heated surfaces of the lifters provide regenerative heat transfer between the solid and the gas and mitigate the segregation of materials in the bed, which together substantially increase the heat transfer rate and thermal efficiency of the kiln operation [5]. Several nickel laterite smelters have used metal lifters for many years. Recent designs with optimized lifter shape, configuration, density and metallurgy have been proven to considerably increase kiln thermal efficiency without causing excessive dusting (although this can be of concern). A typical lifter installation is shown in Figure 5.

Figure 5. Lifter Installation (Courtesy of FLSmidth)

Coal Scoops

In the majority of nickel laterite operations, reductant coal is fed together with partially dried ore through the kiln feed end. As coal travels through the kiln, it heats-up and releases volatile matter. The temperatures at which volatiles are released are not high enough to support complete combustion and significant fuel value is lost to off-gas. The scoop feeder is a mechanical device that allows coal to be picked up from a trough running underneath the kiln and dropped into the high temperature zone. This results in near complete combustion of volatile matter and substantial energy saving [5]. A typical coal scoop installation is shown in Figure 6.

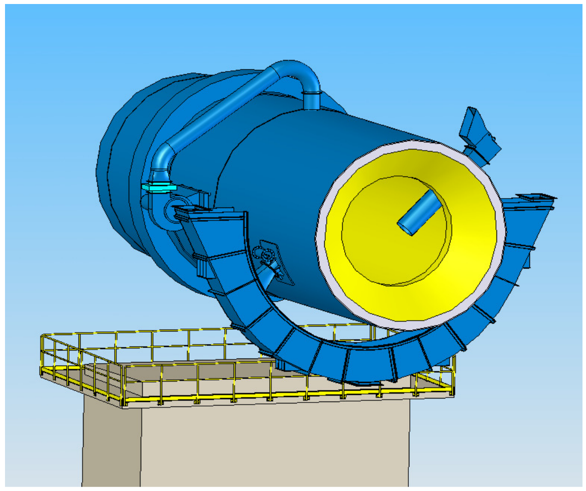

Figure 6. Typical Coal Scoop Installation (Courtesy of FLSmidth)

Several RKEF plants have operated coal scoops with varying results. The operation of coal scoops is strongly dependant on the type of coal used (particularly volatile matter composition), coal granulometry, distribution of tertiary air along the length of kiln, and burner heat release profile.

Dust Insufflation

Nickel laterite operations generate significant amounts of dust at several points in the process, the largest source being dust reporting to the kiln off-gas system which can amount to as much as 25-30% of the feed. Different plants handle the dust in different ways, but broadly speaking the dust is agglomerated by addition of water in some manner and fed back to the kiln. Usually, these agglomerates re-dust to a significant extent, further contributing to the recirculating load. Two laterite smelters have investigated insufflation of the kiln ESP dust either through the burner or a dedicated nozzle installed on the firing hood. Both operations have reported high dust fixation rates. The direct recycle of dust into the kiln removes a portion of the water evaporation load from the kiln process duty (since no water is added for agglomeration), increases kiln productivity and reduces overall dust processing requirements. Dust insufflation has many reference installations in the cement industry ("Cement Kiln Dust" (CKD) injection).

Technical Evaluation

Selection of the most advantageous energy recovery option requires a detailed technical and economic analysis. There are many technological options and system arrangements. In addition, there are several general and specific considerations which should be taken into account.
The following sections present a review of these issues.

General Considerations

Linking two operating units could impact the plant operating factor. Even a slight decrease in the plant operating factor could result in a substantial financial loss. Utmost care should be taken to avoid potential impact on operating factor. Plant layout could also be a determining factor in the selection of an energy recovery option. Layout and equipment arrangement of an existing operation could render adoption of a certain heat recovery option impractical. Layout considerations should also be addressed in the development of a Greenfield project.

Heat Recovery from Furnace Off-Gas

Furnace off-gas is at high temperature and has relatively high dust loading. Furnace off-gas recovery systems may operate at 600-650°C or 400-450°C. While fan operation with gas at 600-650°C is proven within the nickel laterite industry, it is not a common practice. These temperatures are beyond the capability of carbon steel fans and a specialty alloy fan would be required. As a result, recovery systems operating at 400-450°C are more favored. This ensures that the use of carbon steel for both fans and ductwork is appropriate and refractory lining is not necessary. The other concern is dust. Recycle of dirty furnace gases could degrade mechanical equipment and result in build-up and plugging issues.

Furnace Off-Gas Direct Recycle to Kiln

Although recycling furnace gases to rotary kilns has been demonstrated in the nickel laterite industry and kilns are in close proximity to the furnace, this recovery system has several potential issues. Recycling furnace off-gas to the kilns links the two unit operations and may consequently lower the overall plant operating factor. This arrangement also features a high temperature fan and requires a very versatile kiln combustion system. In addition, rotary kiln operations increasingly rely on tertiary air supplied by onboard fans and therefore have less capacity for recycled gas.

Furnace Off-Gas as Supplementary Fuel

This option requires furnace operation in suppressed combustion mode which would need better furnace seals with potentially higher maintenance requirements. Furnace gas evolution is highly variable and furnace pressure control would be critical. This option could also increase risk of explosion with handling flammable gases or risk of carbon monoxide leaks, requiring additional safety equipment to operate and maintain.

Furnace Off-Gas Recycle to Dryer

While kiln operation is sensitive to fluctuations in heat input, a properly designed dryer combustion chamber can accommodate recycle of dirty furnace gases.

Heat Recovery from Kiln Off-Gas

Among the heat recovery options from kiln off-gas, preheat of kiln burner secondary air has been successfully used in the nickel laterite industry. This is a relatively simple and low cost option which operates at low temperatures and does not suffer from dust related issues.

Slag Heat Recovery

There are many slag heat recovery options. Some feature energy recovery in the form of superheated steam for power generation while others recover heat in the form of hot gas. Slag heat recovery systems are relatively expensive. Power generating options feature a boiler and a turbine generator, and hot gas systems include one or two reactors to first granulate the slag and then recover energy from hot solidified slag. These options could be viable if the operation is affected by high power cost or slag disposal issues. In addition, their financial performance would be aided by sale of granulated slag and assuming a contribution from carbon credits [6]. Site specific considerations such as demand for steam either for power generation or other applications should also be considered. It is also important to note that adopting a slag heat recovery option requires technical development (some more than others) and is not risk free.

Process Modeling of Selected Options

Noting the above considerations, three options were selected for analysis,

- Option A - Furnace off-gas recycle to ore dryer
- Option B - Preheat of kiln burner secondary air with kiln off-gas
- Option C - Air granulation of furnace slag and sending hot gas to ore dryer and rotary kiln

For Option A, after cooling, the furnace off-gas is taken directly to the dryer combustion chamber.

Option B uses an air-to-air heat exchanger.

For Option C, since in a typical RKEF operation furnace slag is the largest single stream of energy loss and there is a significant renewed interest in slag heat recovery, this analysis evaluated slag heat recovery to ore drying and rotary kiln as preheated combustion chamber tempering air and burner secondary air, respectively. Compared to power generating options, this is a simpler and less costly system. The system features slag air granulation in a rotary reactor followed by energy recovery from hot solidified slag in a counter-current rotary reactor. The generated hot gas is divided between dryer and kiln to enable highest possible energy recovery.

Using the METSIM® software package, mass and energy balances were developed for selected options. The process modeling assumed the following:

- Production: 27,500 t/y
- Fuel: Coal, Natural gas and Heavy Fuel Oil
- Ore Grade: 2.3% Ni
- Ore SiO_2/MgO: 1.6
- Wet Ore Moisture: 35 wt%
- Kiln Calcine Discharge Temperature: 900˚C
- Kiln Off-gas Temperature: 250˚C
- FeNi Grade: 35%
- FeNi Temperature: 1,510˚C
- Slag Temperature: 1,585˚C
- Furnace Off-gas Temperature: 950˚C
- For Options A & C, hot gas temperature at dryer combustion chamber inlet was 300˚C
- For Option B kiln secondary air was preheated to 150˚C

- For Option C kiln secondary air was preheated to 350˚C

Table 3 summarizes process modeling results. It is important to note that with the exception of Option A, only a fraction of waste energy (after gas conditioning and allowing for air infiltration and duct cooling) can be recovered at the dryer and kiln. For Option A, furnace off-gas can replace dryer tempering air without compromising dryer operation. Recycle of furnace gas to dryer combustion chamber results in less fuel and combustion air requirements without changing hot gas conditions (flowrate, temperature). For Option B, only 14% of the initial waste energy is recovered in the heat exchanger. As noted in previous sections, rotary kiln operations increasingly rely on tertiary air supplied by onboard fans and secondary air share in the overall kiln aeration is limited. Recycle of preheated secondary air results in less demand for fuel and primary air and slightly changes the primary air to secondary air ratio. For Option C, hot gas from slag air granulation system was divided between dryer and kiln to maximize energy recovery. Table 3 also shows that although Option A has the highest energy recovery efficiency, Option C recovers the highest amount of energy. This is due to significant slag sensible heat.

The analysis highlights an inherent impediment to energy recovery; the waste gas streams tend to be large in volume and low in temperature and difficult to accommodate. More recovery could be possible at higher temperatures, but this brings with it greater technical challenges and likely higher costs.

Table 3. Option Comparison

Description	Item	Unit	Case		
			Option A	Option B	Option C
			Electric Furnace Off-gas to Dryer	Kiln Off-gas to Preheat Burner Secondary Air	Slag Air Granulation Hot Gas to Dryer and Kiln
Thermal Waste Stream at Source	Flowrate	Nm^3/h	33,826	303,219	-
	Temperature	^{o}C	950	250	1,585
	Heat Content	MW	13.8	29	93.7
Thermal Waste Stream after Conditioning*	Flowrate	Nm^3/h	43,826	95,395	318,555
	Temperature	^{o}C	300	150	350
	Heat Content	MW	4.7	4.1	37.9
Energy Recovered at Destination	Flowrate	Nm^3/h	43,826	95,395	69,757 (Dryer), 99,738 (Kiln)
	Temperature	^{o}C	300	150	300 (Dryer), 350 (Kiln)
	Heat Content	MW	4.7	4.1	18.8
Energy Recovery from Conditioned Stream		%	100	100	50
Overall Energy Recovery vs. Source		%	34	14	20

*e.g., cleaning, cooling, heat exchanger as appropriate

Economic Evaluation

Table 4 shows CO_2 emission saving, estimated order of magnitude capital cost, preliminary operating costs, Net Present Value (NPV), and simple payback for each option. Figure 7 plots NPV values. The economic analysis was based on the following assumptions:

- Unit coal cost: 150 USD/tonne
- Unit natural gas cost: 0.25 USD/Nm^3
- Unit heavy fuel oil cost: 655 USD/tonne
- Unit power cost: 0.10 USD/kWh
- Clean Development Mechanism (CDM) credits of USD 20 per tonne of CO_2
- 50%, 75%, 90% and 100% of production capacity achieved at Month 6, Year 1, Month 18, and at Year 2 (a Greenfield project was assumed for the analysis)
- Nickel price of 7 $/lb
- Granulated slag credit : none
- Project's life-of-mine of 25 year
- Discount rate: 10%

Table 4. Option Comparison

Fuel	Case	CO_2 Saving (tonne/year)	Capital Cost (Million USD)	Operating Costs Difference (Million Δ USD/y)	NPV	Simple Payback (year)
Coal	Option A	17,102	9.0	-2.02	10,993,897	3.8
	Option B	12,588	6.6	-0.86	2,804,334	5.9
	Option C	53,723	50.0	-3.67	-9,825,925	10.5
Natural Gas	Option A	9,456	9.0	-2.07	10,118,828	4.0
	Option B	7,164	6.6	-0.95	2,661,510	6.0
	Option C	31,171	50.0	-4.14	-9,659,657	10.5
Heavy Fuel Oil	Option A	13,428	9.0	-3.57	23,513,957	2.3
	Option B	10,648	6.6	-2.18	13,717,487	2.8
	Option C	46,369	50.0	-9.52	38,512,521	4.8

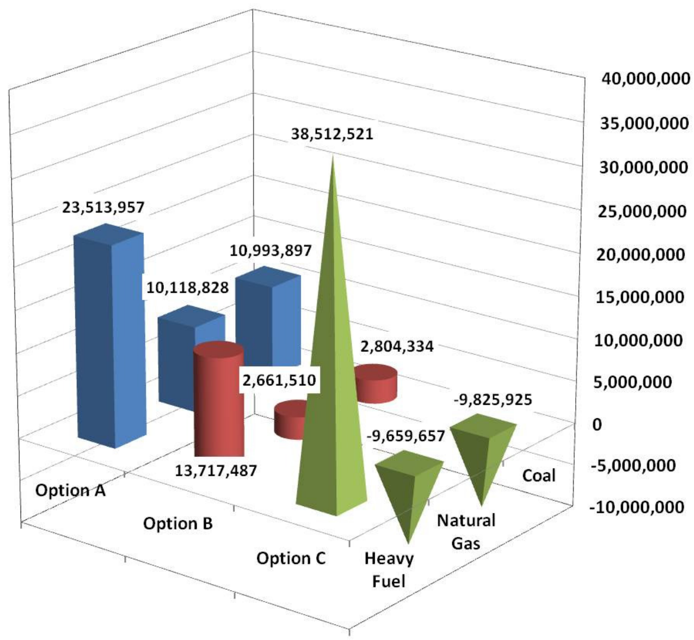

Figure 7. Net Present Value of Energy Recovery Options

Concluding Remarks

There are a variety of opportunities for energy recovery in pyrometallurgical nickel laterite plants. They tend to manifest as high volume gas streams that, if not already at low temperature, may have to be cooled to facilitate handling. The high volumes make it difficult to make use of a large proportion of the available energy, particularly for Brownfield installations and because of the need to revert to normal operation when the recycle stream becomes unavailable.

Three energy recovery scenarios were selected for analysis. A process model of a hypothetical single-line RKEF plant was developed and used to see how the recovery scenarios would work. A set of economic assumptions was made to assess the financial benefit of the three options for plants operating with oil, gas or coal as their primary fossil fuel.
Recycling electric furnace off-gas to the dryer combustion chamber makes most efficient use of the waste stream and appears to be the most robust option financially, with good returns even for plants operating with coal.

Using kiln off-gas to preheat kiln secondary air via a heat exchanger only uses a small portion of the available energy and appears to be significantly more beneficial for plants operating with oil.

Electric furnace slag is by far the largest potential source of recycle energy. However energy recovery from slag is notably more capital intensive than the other options and for the scenario selected (supplying relatively cool air to the dryer and kiln), the financial benefit appears to be highly sensitive to the fuel type. Furthermore, only a small portion of the original energy is recovered. Capturing the energy in another form, e.g., as a higher temperature air stream, steam or electrical energy may be more attractive depending on the circumstances, but these routes incur further technical challenges and higher capital costs.

It should be noted that the results shown above are for a specific set of circumstances and assumptions. The outcomes will be influenced (in some cases quite strongly) by factors such as:

- Local power costs
- Shipping costs
- Carbon taxation
- Target IRR
- Markets for sale of slag
- Brownfield vs. Greenfield projects.

It is therefore important to assess energy recovery options in the light of the specific and unique circumstances of each project. By way of example, the above analysis did not assume any credit for the sale of air-granulated slag. If a market could be found and the slag sold for $8 per tonne (net), then the $10M negative NPV shown for a coal-fired plant would turn into positive $60M.

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