MEETING THE CHALLENGE OF SUSTAINABILITY THROUGH TECHNOLOGY DEVELOPMENT AND INTERGRATION IN FERROALLOY SUBMERGED ARC FURNACE PLANT DESIGN

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ABSTRACT

The development of a sustainable and environmentally responsible business model is becoming an increasingly important aspect of the minerals processing industry. The power shortage in South Africa with its associated cost and loss of production and the increased international focus on global warming is having a significant impact on how engineering companies and producers approach the design of new ferroalloy plants. The effective use of energy and the reduction of emissions will be critical to remaining cost effective and competitive in the global market of the future.

In the context of a growing worldwide drive to reduce industrial energy consumption and green house gas emissions this paper reviews the ferrochrome production process from the view point of energy conservation and carbon dioxide reduction. The paper identifies and describes initiatives and technologies that have been or may be used in the future to improve the sustainability of the ferrochrome process with respect to these areas and investigates the benefits of these technologies. Where competing technologies exist, a summary allowing the reader to get a broad understanding of the differences between the equipment and/or processes is presented. The initiatives undertaken by Tenova Pyromet in facing the issue of sustainability through a strategy of in-house technology development and partnerships with other leading technology providers is discussed and a number of process areas are explored. These include upstream material processing, downstream material processing and also the core furnace itself.

1 INTRODUCTION

"The era of 'abundance' is over"[1]. This statement highlights the reality of the environment that many companies worldwide and particularly in the South African ferroalloy industry are facing. One only need look back a few years in the case of South Africa to find low electricity costs, profuse electrical supply, substantial demand for metals due to economic growth and little in the way of environmental constraints. With the advent of the global financial crisis and the considerable increase in concern worldwide over global warming and related environmental issues, businesses have had to re-evaluate how they operate in order to remain sustainable, profitable and environmentally accountable.

The pyrometallurgical processing of ores in particular imposes a significant footprint in the area of resource consumption, predominantly with respect to water and electricity. In South Africa, both these resources are receiving high levels of attention from government and society at large due to their scarcity and cost. Specifically, the National utilities electrical load shedding programme during 2008 and subsequent cost increases amounting to over 30% on an annual basis have negatively impacted the Ferroalloy industry. Capacity constraints will remain for the foreseeable future and the cost of electricity will continue to increase [2], [3]. A prediction made on the cost of electricity by a leading company in the area of energy recovery, Biotherm Energy, is shown in Table 1 [4]. It is clear that, should these predictions materialise, the producers of ferroalloys in South Africa will be severely impacted from a operational cost point of view.

Table 1: Predicted cost escalation of electricity in South Africa

Year	Megaflex (Low) Nominal	Megaflex (High) Nominal
2009/2010	31.4%	31.24%
2010/2011	30%	60%
2011/2012	30%	60%
2012/2013	30%	30%
2013/2014	30%	7%
-> 2034	6%	7%

The proposed introduction of the Power Conservation Programme (PCP) could have an even greater impact on the industry. The two key components of the programme include the Energy Conservation Scheme (ECS) which will target the reduction of energy consumption by an average of 10% and the Electricity Growth Management (EGM) strategy which will aim to manage new electrical connections in line with the available electrical supply capacity [5]. The potential revenue loss from the ECS in particular increases the urgency to explore energy recovery and conservation.

In addition, significant amounts of green house gasses are emitted either directly through the smelting process or indirectly as a function of the electricity that has been generated from non-renewable sources such as coal or gas. Table 2 highlights the increase in CO_2 emissions in the ferroalloy industry in South Africa from 1990 to 2004 [6] as a direct consequence of production. The total CO_2 emission has more than doubled in the 14 years under review.

Table 2: Ferroalloy production 1990 and 2004 (1990 inventory and DME 2006)

	1990		**2004**	
Commodity	**Production (tpa)**	**CO_2 emission (Gg)**	**Production (tpa)**	**CO_2 emission (Gg)**
FeCr	1,076,000	1,399	2,900,000	3,770
FeMn	390,000	624	575,000	865
FeSi	60,000	234	106,000	413
FeSiMn	233,000	396	300,000	510
Si	37,700	45	50,000	60
	Totals	2,698		5,618

Further, due to the availability of low cost coal, South Africa generates more than 90% of its electricity from coal fired power stations and hence, by using this energy, producers are indirectly adding to their environmental footprint. Table 3 shows the generation of emissions by the local electrical utility per MWh of electricity consumed in South Africa [7].

Table 3: Emissions from the production of 1 MWh of electricity

Component	**Amount (Unit)**
Particulate emissions	0.27 kg
Water consumption	1350 Litres
CO_2	1.032 tonnes
SO_2	8.72 kg
NO_x	4.45 kg

If one were to use the values detailed above in the hypothetical comparison between a 45 MW ferrochrome furnace using a combination of pellets and lumpy feed, an operation that managed to replace 10% (for example) of its electrical off take through energy recovery and one that was capped by the proposed PCP, the yearly impact would be as follows:

Table 4: Comparison of a 45MW Submerged Arc Ferrochrome furnace with 10% energy saving and 10% PCP cap

	Typical 45 MW Furnace (pa)	**45 MW Furnace with 10% electrical recovery (pa)**	**45 MW Furnace with 10% PCP Cap (pa)**
Metal Production	102,279 tonnes	102,279 tonnes	92,050 tonnes
Income (0.75 USD/lb)	$169 million	$169 million	$152 million
Availability	96%	96%	96%
Electricity Usage (annum)	378,432 MWh	340,588 MWh	340,588 MWh
Electrical Cost (Rate @ 34c/kWh)	R 128,666,880	R 115,799,920	R 115,799,920
Emissions associated with Electricity (per annum)			
Particulates	102 tonnes	91 tonnes	91 tonnes
Water	511,000 m^3	459,793 m^3	459,793 m^3
CO_2	390,541 tonnes	351,487 tonnes	351,487 tonnes
SO_2	3,300 tonnes	2,970 tonnes	2,970 tonnes
NO_x	1,684 tonnes	1516 tonnes	1516 tonnes

It is clear that from both an environmental and commercial perspective, the implementation of energy reduction and recovery projects needs to be seriously considered in order to ensure the ongoing sustainability of smelter operations.

2 FURNACE ENERGY LOSSES

Daavittila et al [8] state that electricity can account for approximately 30% of operational costs within the ferrochrome industry. The efficient use of energy is therefore a critical component of any smelting operation. Electrical energy is used to heat up the raw materials and to allow for smelting to occur. Energy is however lost firstly through operations such as tapping and extraction of off-gasses and secondly through the cooling that is required due to the thermal limitations of furnace equipment. The bulk of the energy loss from the furnace (typically between 60-85% depending on the size and design of the furnace) is attributable to the operational processes whilst energy loss from cooling accounts for the balance. Figure 1 and Figure 2 give a basic overview of the heat losses that are typically witnessed on submerged arc furnaces and show some of the typical values that could be expected for cooling in various furnace areas.

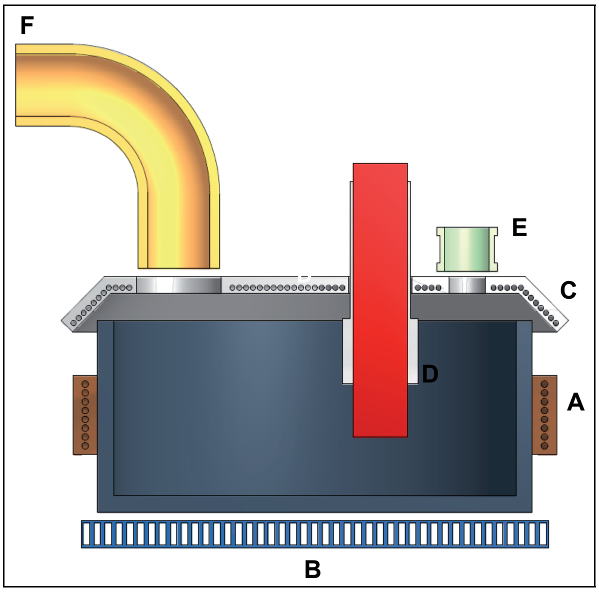
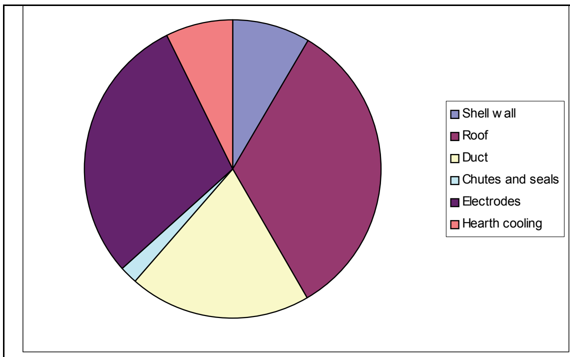


Figure 1: Heat loss points from a typical SAF



	Description	Coolant	Overall Percentage Heat Loss %
A	Shell wall	Air	9
B	Hearth	Air	7
C	Roof	Water	33
D	Electrodes	Water	30
E	Roof seals & chutes	Water	2
F	Off-gas duct	Water	20

Figure 2: Typical Cooling Heat losses from semi-closed Si furnace

3 OPTIONS FOR ENERGY RECOVERY

What then are the options available to organisations to recover this lost energy? Broadly speaking, there are two main areas that cover the various options available for energy recovery. These are the direct application of recovered energy and electrical power generation. The type and combination of technology used varies from process to process and is dependant on the specific requirements of the organisation.

3.1 Direct Application of Recovered Energy

The most efficient manner of utilising lost heat energy is in its direct application in heating something else. A typical example of this is the use of waste heat to generate steam which may then be used within the plant or sent off site for use by other parties. The pre-heating of raw materials entering a furnace is another example of this application. Pre-heating allows producers to reduce their electrical consumption while sustaining production levels or increasing production while maintaining electrical consumption levels. The total capital cost for equipment used in these processes is also generally lower than that for electrical power generation. In addition, the available energy is more effectively utilised as inefficiencies associated with electrical generation are avoided. For these reasons, this form of energy recovery should always be one of the first options considered by organisations embarking on either energy efficiency or energy reduction projects.

3.2 Electrical Power Generation

Three of the most common power generation systems used in industry include combustion engines, gas turbines and Rankine Cycle Systems. The Rankine Cycle Systems can further be divided into steam and organic systems. Electricity generated from these units can be used internally or sold back to the power grid depending on the prevailing economic conditions and plant requirements. A basic overview of each system is shown in Figure 3, Figure 4 and Figure 5. It is also common practice in power generation to link two of these processes in series. This gives rise to what is known as co-generation, which increases the energy utilisation efficiency of the process. An example of this would be the use of a Brayton Cycle followed by a Rankine Steam Cycle. In this example, the gas turbine generates electricity and the steam generated from the exhaust of the gas turbine is used to generate steam for a steam turbine, which in turn generates additional power.

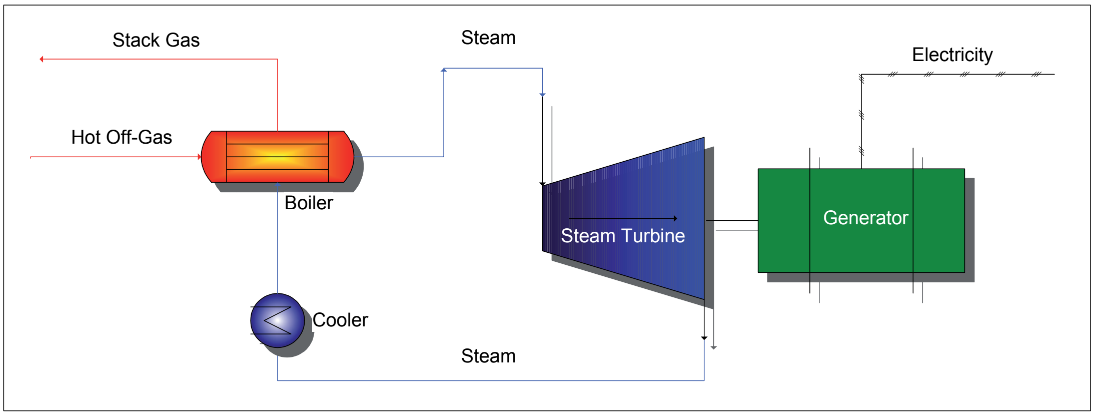


Figure 3: Basic Overview of Rankine Cycle (steam turbine)

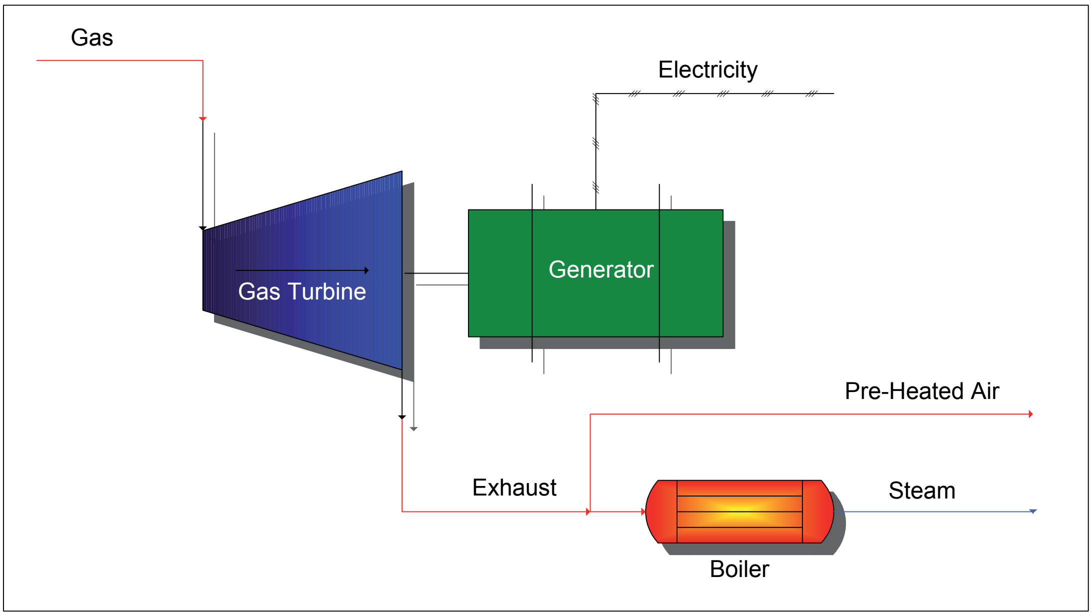


Figure 4: Basic Overview of Brayton Cycle (gas turbine)

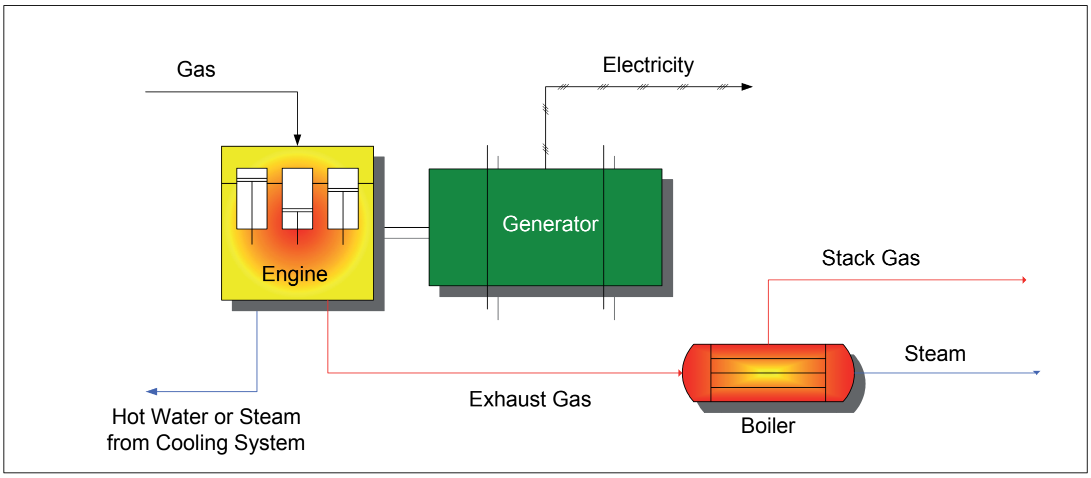


Figure 5: Internal Combustion Engine

A brief summary of the combustion engine, gas turbine and Rankine Steam Cycle technologies is detailed in Table 5.[9] The Organic Rankine Cycle technology is not as well known as the others listed above and will be discussed under section 3.3

Table 5: Comparison of common co-generation technologies

	IC Engine	**Gas turbine**	**Steam Rankine**
Process			
Fluctuations in gas flow	Fair	Fair	Good
Fluctuations in gas composition	Fair	Fair	Good
Need for buffer gas holder	Yes	Yes	No
Turn down ratio	50%	30%	20%
Gas cleaning	Critical	Critical	Less Critical
Nett efficiency	37%	43%	27% - 35% [10]
Furnace Type	Closed Only	Closed Only	Semi-closed and Closed
Financial			
Total Plant Cost	Lowest Cost	Highest Cost	Intermediate Cost
OPEX (per MWh)	Highest	Intermediate Cost	Lowest
Life of plant (years)	15 to 20	20 to 25	25 to 40

3.3 Other Options

3.1.3 Organic Rankine Cycle

The Organic Rankine Cycle (ORC) operates in fundamentally the same way as the Rankine Steam Cycle. The main difference between the two systems is the use of an organic fluid rather than steam. The lower boiling point of the organic fluid allows for lower grade heat streams to be utilised. ORC systems have several advantages over the Rankine Steam Systems which include:

- a lower boiling point requirement, thus allowing for low grade heat streams (120^{o}C to 500^{o}C) to be used
- the potential to use saturated steam as the heating medium
- the fact that system runs at lower pressures and that
- no treatment of the working fluid is required.

Typical electrical efficiencies for ORC systems run at between 10-20%.

3.2.3 Absorption Chillers

Absorption chillers utilise heat to produce a chilled medium, such as water, that can be used in various refrigeration or cooling applications. Two main types of chillers are commonly used. A lithium bromide-Water system supplies chilled water in the range from 6^o to 12^o Celsius. Ammonia-water systems can be used for applications requiring cooling down to as low as -60^o Celsius. Efficiencies of 70% are typical with single stage indirectly heated absorption machines of a suitable design [11].

4 OPPORTUNITIES FOR ENERGY RECOVERY / REDUCTION

4.1 Feed Systems

In many operations, raw materials entering a ferroalloy furnace are often near ambient in temperature and therefore negatively affect the overall energy input requirement. In addition, depending on the materials storage practices employed at the site, the materials may contain significant amounts of moisture which further affect the energy requirements. Pre-heating and drying of the ores offers a solution to these problems and has been successfully implemented in several ferrochrome furnaces. The single pre-heater system from Outotec is a well established technology in the industry and more recently Tenova Pyromet and Outotec have jointly developed a multiple pre-heater system which offers several advantages over the original single pre-heater design. An elevation view of the two systems side by side is shown in Figure 6.

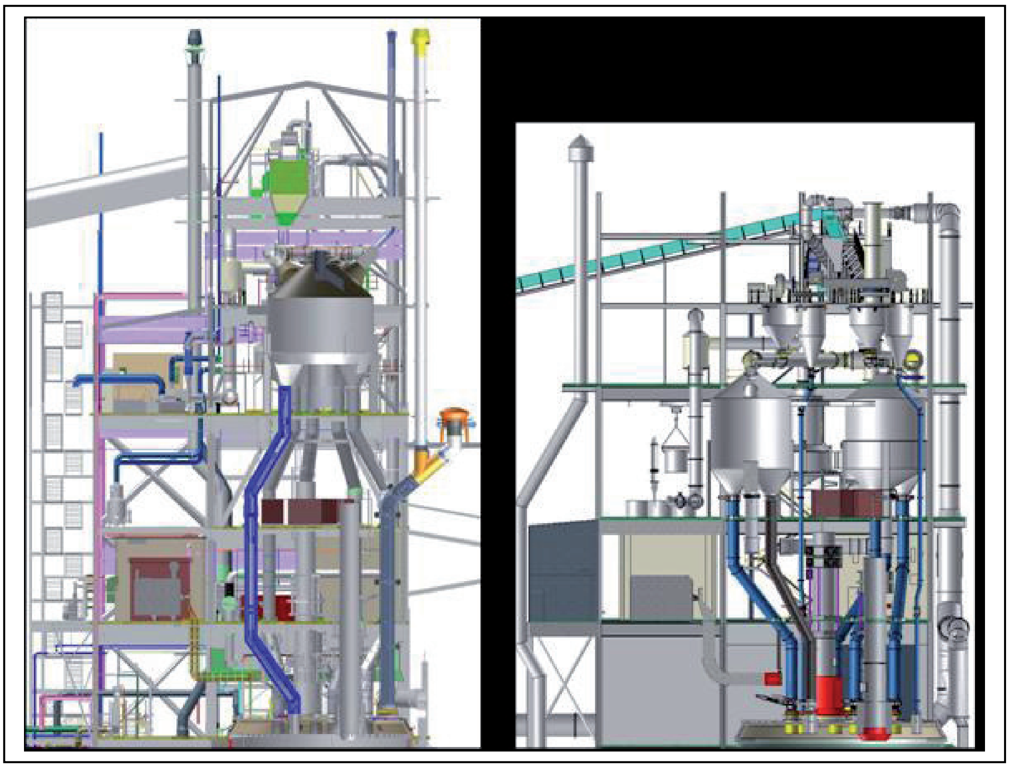


Figure 6: Elevation view of a single and multiple pre-heater systems in a ferrochrome plant

Benefits of the Multiple Pre-heating system are as follows:

- All the recycle gas is combusted in a combined combustion/mixing chamber which improves control
- Power input (gas volume) is controlled by MPH gas exit temperatures i.e. it is reactive to the feed rate change
- The furnace building is lower by 10 – 15m
- Feed chutes are shorter, resulting in less heat loss and lower replacement costs, leading to lower operational expenditure
- The configuration allows for good maintenance flexibility
- The system is more reactive to differential furnace conditions
- One can feed different raw material mixes to each unit
- The system can be retrofitted to existing furnaces

Challenges in using the Multiple Preheating system are as follows:

- Potential safety implications related to the MPH units being located adjacent to the electrode casing welding and paste addition area
- Potential maintenance problems due to multiple control & isolation valves
- Unknown effects on the furnace operation when one or more units are not heating

The area of pre-reduction also offers significant benefits with regards to energy reduction in processing ores. The process of pre-reduction aims to selectively reduce certain components in the ore feed which reduces the electrical input requirement of the submerged arc furnace or allows for increase in throughput at the same electrical input. Various companies have developed this technology for the ferrochrome industry with varying levels of success [8]. A recent example of pre-reduction application may be seen in the Xstrata Premus process, which is a proprietary technology used exclusively by Xstrata Alloys. The Premus process has a claimed energy requirement of 2.4 MW/tonne of metal [12]. The main challenges for these existing technologies include the hot charging of material in the submerged arc furnaces, re-oxidation of feed material and control of the pre-reduction process. Tenova Pyromet in co-operation with its technical partners, Paul Wurth and Tenova LOI Italimpianti, has recently developed a pre-reduction process for ferrochrome ores based on using Rotary Hearth Furnace technology fired with closed furnace off-gas. This process is known as the ChromeRed process and is illustrated in Figure 7.

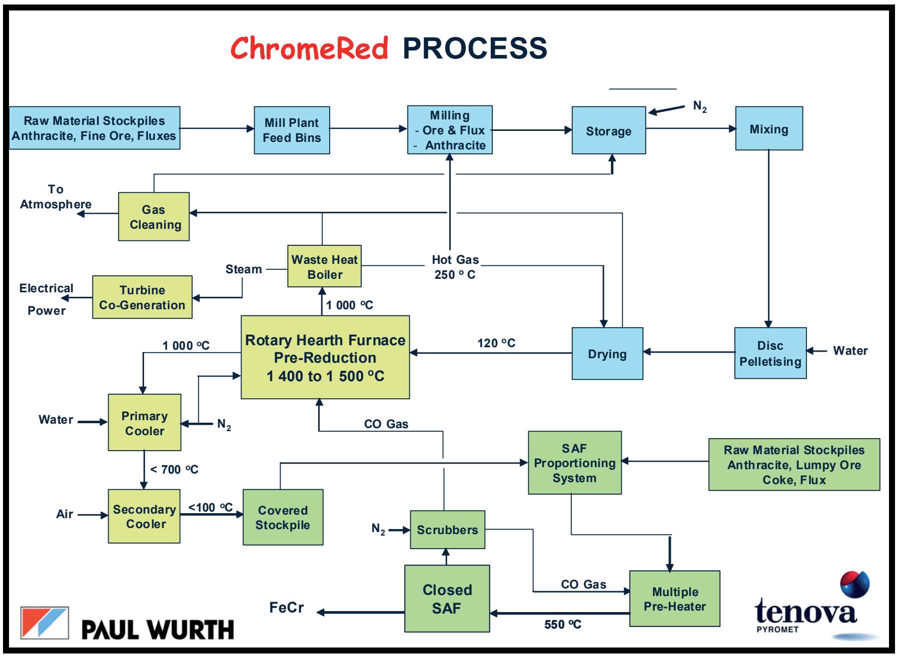


Figure 7: ChromeRed Process Diagram

Benefits of the ChromeRed Pre-Reduction Process are as follows:

- A higher percentage of Cr reduction can be achieved (94% vs. 87% for the conventional process)
- Reduced power consumption (PC) by approx 1,000kWh/t
- Coke usage reduction from 600 to approx 160 kg/t FeCr
- Si in the FeCr decreases from 4 – 5% to 2 – 2.5%
- Furnace production increases by approximately 40%
- Operational expenditure reduces by 10 to 12 USc/lb Cr
- Minimal additional electrical power is required
- RHF technology allows for tight control of the process resulting in good pre-reduction control
- The process can be easily combined with energy recovery systems

A comparison of the expected energy consumption per tonne of metal at the taphole for the various processes is shown in Table 6 [13]

Table 6: Comparison of expected energy consumption for different Ferrochrome Furnaces

Feed Materials	Expected Energy Consumption (MW/tonne metal at the taphole)
Fines and Lumpy Feed	4.2
Pellets and Lumpy Feed	3.7
Pre-heating	3.25
Pre-heating and Pre-Reduction	2.25

4.2 Furnace

Various opportunities are available to be explored within the furnace area. The most obvious is the reduction of heat losses associated with cooling around the furnace. Tenova Pyromet is currently working with Tenova ReEnergy on the design of evaporative cooling for furnace hoods, side skirts and doors. The evaporative cooling system will be tied into a steam turbine system allowing for energy to be converted to electricity rather than ejecting the energy to the atmosphere as is currently the case in many furnaces. A recently completed project by Tenova ReEnergy on a DC electric arc furnace in Germany was designed to operate with off-gas temperatures up to 1800 ^{o}C which highlights the large temperature ranges that can be accommodated. Depending on the design, it is anticipated that between 0.5-1.5 MW can be recovered from a semi-closed furnace hood running off-gas temperatures of around 700 ^{o}C. An alternative to the evaporative cooling approach would be the cooling of the furnace (hood, skirts, doors and sidewalls) using thermal oils thereby eliminating the need for water around the top of the furnace. The oil could then be pumped through an Organic Rankine Cycle system in order to recover the energy. The thermal oils are however still combustible at high temperatures and adequate design and operational measures are required to ensure that oil does not come into contact with the furnace environment.

The use of high emissivity coatings on the upper walls and hoods of furnaces is also being investigated by Tenova Pyromet. The coating absorbs and then re-radiates the energy resulting in lower heat losses to the cooling water. This process is illustrated in Figure 8 [14]. Reported benefits of the use of the coating include:

- Energy savings and/or production increases of 3-6%
- More uniform heat distribution on the surface of the refractory
- Lower heat losses and lower temperatures on un-cooled walls (which results in improved personnel safety)
- Improved refractory life

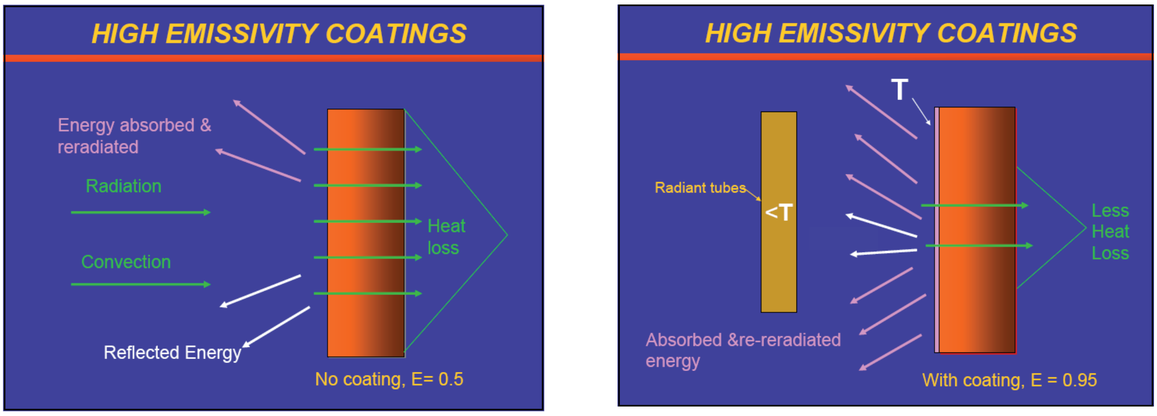


Figure 8: A comparison of the energy flows though a refractory with and without a high emissivity coating

4.3 Off-gas Systems

The furnace off-gas represents one of the main areas where energy may be recovered and is ideally suited to electrical generation applications. In closed ferroalloy furnaces, the gas usually contains a high level of carbon monoxide and hydrogen, which can be used to supply energy for the purposes of preheating (as discussed in section 4.1) or for electrical generation in either internal combustion engines, gas turbines or Rankine Steam Systems. In open or semi-closed furnace applications, the carbon monoxide and hydrogen are combusted above the freeboard and hence internal combustion engines or gas turbines are not options for recovery of heat within these processes. Tenova Pyromet is working closely with sister company Tenova ReEnergy and with local and international energy experts on the supply of complete heat recovery and electrical generation projects both in South Africa and internationally.

4.4 Products

A significant amount of sensible heat is available in the metals and slags that are tapped from ferroalloy furnaces. Research into this area is still ongoing with teams in various parts of the world investigating how to unlock this energy potential. Corder et al [15], who are based in Australia, are investigating heat recovery from molten slag through a process of dry granulation. The main advantages of this system over a wet granulation system include reduced water consumption, no formation of acid mist and no need to dewater the granulated slag. In Japan, Akiyama et al [16], [17] have been investigating the recovery of waste heat using a chemical recuperator. The process is based on the concept that an endothermic reaction can use high temperature waste heat to convert thermal energy into chemical energy. Most of the research has revolved around using a methane-steam reforming system which produces carbon monoxide and hydrogen. It is hoped that commercially viable options for recovering heat from slag and metal will be available in the near future.

5 CONCLUSIONS

The ferroalloy industry in South Africa is currently facing an increasingly challenging environment where electricity scarcity, electrical costs and environmental pressures are going to significantly affect the competitiveness of these industries into the future. With these challenges come opportunities that offer competitive advantages to those organisations that are ready and willing to embrace those initiatives. The recovery and saving of energy very clearly represent some of these opportunities and Tenova Pyromet is optimally placed to support customers in these areas through our own in-house technology and our network of partners both in the worldwide Tenova group and other specialist technology companies.

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