THE DEVELOPMENT AND ADVANTAGES OF XSTRATA'S PREMUS PROCESS

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ABSTRACT

Xstrata has modified and improved on the solid state reduction of chromite (SRC) process that was pioneered by Showa Denko in Japan and previously used at Xstrata's Lydenburg plant. The history of pre-reduction is a long one, with the SRC process being the first and only commercially successful one prior to Premus. Krupp developed the chromite direct reduction and the rotary hearth for the pre-reduction of chromite. However, these processes have not been successfully commercialised.

The are a number of significant differences between Xstrata's patented Premus and the original Consolidated Metallurgical Industries (CMI) process. These include, the use of lower cost anthracite fines as the reductant source together with the use of unactivated bentonite as the binding agent. In addition the use of oxygen as an energy source is used in Premus but not in the original CMI process. There was a fundamental change in the operational philosophy of the process in that while the original CMI process aimed to maximize metallization of the pellets, the Premus process seeks to maximize the energy output from the kiln while still achieving the required efficiencies and hence increasing furnace output. Premus is designed to reduce electrical energy consumption, provide high recoveries of metallic oxides, and utilizes low cost reductant and energy sources such as anthracite and oxygen respectively.

Due to the fact that Premus is one of the most technologically advanced and competitive processes used today in the production of ferrochrome it was the process selected for Xstrata's new ferrochrome facility, Project Lion, that is due to be commissioned in the third quarter of 2006 in the Steelpoort Valley in Mpumulanga, South Africa.

1. INTRODUCTION

The history of pre-reduction is a long one, with the pre-reduction of iron ore being a more common process. The pre-reduction of chromite ore however has not been widely used commercially. Various experimental test-work has been documented and papers written on the solid state reduction of chromite ore using various reductant sources including hydrogen, methane, carbon monoxide and coke. There are only two commercial plant facilities where the solid state reduction of chrome ore had previously proved successful, the Shunan Denko Plant in Japan and the CMI Plant in Mpumulanga South Africa. Both of these plants had employed the Showa Denko Solid-State-Reduction of chromite ore (SRC) process and proved to be the most energy efficient plants in the world. Upon Xstrata's acquisition of CMI from the Johannesburg Consolidated Industries (JCI) group it sought to bring down the cost structures at the Lydenburg plant. Between 1998 and 2001 the Premus process was developed largely by in-plant trials. The patent was filed in 2002 and finally granted in February 2006.

2. THE DEVELOPMENT OF PREMUS

2.1 Rationale Behind the Change

The primary factors that influenced the decision to modify the original CMI process that was operational at the Lydenburg Works were:

- Increasing cost of coke breeze
- Reduced availability of coke and char breeze
- The increase in furnace capacity warranted a higher kiln capacity
- Change in operating philosophy from that of maximizing metallization levels to that of maximizing energy output from the kiln

2.2 Choice of Reducing Agent

Previously coke breeze served as the primary reductant source in the pre-reduction process. Later char breeze was also introduced as a reductant source due to its lower cost. However, the fixed carbon content of char breeze is significantly lower than that of coke, having fixed carbon levels of between 70 – 75%. This resulted in a higher reductant requirement and reduced the chrome output from the kiln, effectively reducing kiln capacity at a time when all effort was placed on maximizing the kiln capacity. Raw anthracite breeze which has a fixed carbon content of >82% was then identified as a potential reductant source. Initially lab-scale tests where conducted, whereby pellets were produced using increasing percentages of anthracite breeze as a replacement for coke and char breeze. The main difference in the chemical analysis between coke breeze and anthracite breeze was in the volatiles content as illustrated in table 1. As a result, the greatest risk that was foreseen was that the pellets would burst in the preheating process as the combustion of the volatiles would cause the temperature to rise uncontrollably before the pellets are dried. Lab as well as small scale plant trials indicated that the pellets would not burst in the kiln. However, as a precautionary measure, the first full scale plant trials were conducting using calcined anthracite. Raw anthracite was then introduced as a blend with coke breeze.

Table 1: Chemical Analysis of Various Reductant Sources Used

Reductant Source	*%Fixed Carbon*	*%Ash*	*%Volatiles*
Coke Breeze	81.8	15.4	2.8
Char Breeze	76	19.3	4.7
Calcined Anthracite	84.3	13.8	1.9
Raw Anthracite	81.8	13.5	4.7

2.3 Initial Plant Trials

The percentage of anthracite as a reductant source was progressively increased. The pellets produced by the pan pelletisers prior to drying and preheating are termed green pellets. The main parameters that were monitored during the plant trials were green pellet strength, green pellet appearance, uniformity in green pellet sizing and level if any of pellet bursting in the grate kiln. Green pellet strength was measured via drop tests and compression strength tests. Pellet strength is vital due to the fact that after drying and preheating in the grate kiln, the pellets are fed directly into the rotary kiln where pre-reduction takes place. The rotary action can result in the disintegration of weak pellets resulting in fines formation, increase in kiln build-up and operational difficulties. On-line moisture analyzers were used to gauge the moisture content of the pellets and the tendency for the pellets to burst in the grate kiln, before actual moisture results are obtained from the laboratory. Green pellet sizing was monitored by taking a representative sample and measuring the diameter of the pellets. Small pellets can result in over-roasting and too large pellets will lead to lower metallization levels. Previous experimental test-work had indicated that the ideal pellet diameter in terms of reaction efficiency and pellet strength is about 20mm. Practically the diameter should be controlled from 10 to 30mm. Variability in pellet size can reduce gas permeability through the grate kiln affecting the initial drying process and resulting in pellets bursting and is therefore a key parameter to be monitored.

As the anthracite trials progressed increasing steadily from 0% to 100%, it became clear that the pellet quality deteriorated as the anthracite contribution increased to 60% and above. There was a large degree of variability in terms of pellet sizing with the diameter varying from 5mm to 35mm without any adjustments to the pan pelletizer. The surface appearance of the pellets was also poor. During this stage of the trial 4% soda ash (Na_2CO_3) activated bentonite was used as the binding agent.

Adjustments to the pan angle, pelletizer depth and water addition did not yield significant improvements in pellet quality at contributions of greater than 60% raw anthracite. The main factors influencing the pelletizing process such as particle size and shape, the influence of the binder used and the pre-wetting effect was then considered.

The particle sizing was measured and found to be within the normal range. Raw anthracite is less porous and less crystalline in comparison to coke and char which could have an influence on the pre-wetting process. Further research and test-work was then done on the binder used and bentonite at different activation levels was tested. It was found that the use of 0 – 1% soda ash bentonite produced the best quality pellets at high anthracite levels. The use of 100% raw anthracite together with unactivated bentonite produced excellent quality pellets and became the standard pellet mix.

Trials conducted later indicated that attapulgite could also be successfully used as a binding agent in the production of pellets containing chromite and anthracite fines.

During processing through the grate and rotary kiln it became apparent that the maximum volatile content that was acceptable which did not result in pellets bursting was 7%. This process change has been patented by Xstrata and has been termed Premus (meaning first in Greek).

2.4 Theoretical Explanation of Results

Bentonite is a widely used binder in the pelletizing process. The main constituent of Bentonite which is a determining factor in the clays properties is the clay mineral montmorillonite. Bentonite presents strong colloidal properties and its volume increases several times when coming into contact with water, creating a gelatinous and viscous fluid. In the pelletizing process a high swelling type of bentonite is desirable, a property associated with sodium-type bentonites, whilst calcium-type bentonites are characterised by low swelling. Calcium bentonites are converted to sodium bentonites by the addition of suitable sodium salts corresponding to the base exchange capacity.

$$Ca\ Montmorillonite + Na_2CO_3 \lozenge Na\ Montmorillonite + CaCO_3$$

The addition of soda ash (Na_2CO_3) to the bentonite results in what is termed activated bentonite. Traditionally the use of activated bentonite in the pelletizing of ores has resulted in good quality pellets while the use of unactivated bentonite resulted in poor quality pellets.

The results obtained from the plant trials with anthracite were in contradiction to this theory and therefore warranted further investigation. The use of unactivated bentonite with coke or char resulted in poor quality pellets while the use of unactivated bentonite with carbonaceous material such as anthracite, coal and the like resulted in good quality pellets. The conclusion that was reached was that, owing to the shape of the anthracite particles as well as its wettability properties, lower quality calcium bentonite produced the best quality pellets. Good quality pellets at 100% anthracite usage could not be produced using activated bentonite except when the level of activation was very low. Calcium type bentonite is more readily available and cheaper to produce. As a result the project reduced costs both in terms of reductant usage as well as binder usage.

The use of reductant with a high volatile in pellets would require a redesign of the drying process so as to ensure the correct energy balance. This was not seen to be critical as anthracite with a volatile content of <7% was readily available and no further test-work on increasing the volatility of the reductant used was performed.

2.5 Change in Operation Philosophy

The energy content of the pellets produced from the rotary kiln has an intrinsic energy value derived from the metallization level of the pellet and the temperature of the pellet. Therefore the higher the metallization levels, the higher the energy content of each individual pellet produced. The higher the pellet output, the higher the total energy produced by the kiln. There is a direct relationship between metallization levels in the pellets and pellet output, whereby metallization levels increase as the pellet out decreases and vice versa up to a minimum throughput level below which carbon burn-off from the kilns increases resulting in oxidation of the pellets.

Traditionally in the CMI process, the aim has been to maximize the metallization levels in the pellets produced. The rotary kilns at the Lydenburg plant were each designed to produce 20 tons per hour (tph) of roasted pellets. The aim was to increase pellet throughput at the kilns and ensure that the net energy output from the kilns increased. The rationale behind this was that the higher the energy produced from the kilns, the lower would be the specific energy requirements during the smelting process. As such the operating philosophy at the plant was changed and although metallization levels were still monitored, the total energy produced by each kiln was monitored and controlled on a daily basis.

The output from the kiln was increased to 30 tph and although the reduction rate dropped the total energy produced by the kiln increased by 17.5%. Thereafter pellet output was increased further to 35 tph. The increase in net energy output from the kiln was 6.6%. The smaller change was due to the fact that the metallization level dropped to a level that also affected furnace recoveries resulting in a higher consumption of pellets per ton of ferrochrome metal produced. Oxygen injection into the kiln was used as an additional energy source that resulted in higher temperatures and hence higher metallization levels in the reaction zone of the kiln. The use of oxygen injection further increased metallization levels to such an extent that the total energy output from the kilns increased by a further 7%. Therefore the net increase in energy output from the kiln was 31%. This in turn led to an increase in ferrochrome production. There was a 54% increase in ferrochrome production resulting from a combination of the above process changes and an increase in furnace energy input.

3. THE ADVANTAGES OF PREMUS OVER OTHER PROCESSES USED IN THE PRODUCTION OF FERROCHROME

3.1 Brief Description of Various Technologies Available for the Production of Ferrochrome

There are four primary processes that are currently in use for the production of ferrochrome. These include the conventional process, the Outokumpu process, the DC Arc route and the Premus process. Each of these is discussed briefly below:

Conventional Process

In the conventional process, a mixture of chrome ore, reductants and flux is fed cold with minimum preprocessing directly into open submerged arc furnaces. The furnace off-gases are cleaned in a bagplant before being vented into the atmosphere. The metal and slag are then tapped from the furnace for further processing. The primary advantages of this process are that it requires the lowest capital investment and is very flexible in terms of raw materials that can be used in the process. The main disadvantage of this process is that it is increasingly being perceived as being less environmentally friendly than other available processes and it has the lowest efficiencies.

Outokumpu Process

Fine chrome ore is wet milled and then pelletized using a binder such as bentonite. The pellets are then sintered and then air cooled and stockpiled. The pellets together with fluxes are then heated in a preheater located above the furnace bins. Reductants consisting primarily of coke is added to the preheated raw materials and fed into closed submerged arc furnaces. The furnace off-gas is cleaned in wet scrubbers and used as an energy source in the preheating process. The main advantages of this process are that the sintered pellets and preheating results in reduced specific energy consumptions and improved chromium recoveries.

DC Arc Furnace

The furnace uses a single solid carbon electrode, and produces a DC arc to an anode in the bottom of the furnace. The arc is normally an open or semi-submerged one. Raw materials can be charged either directly into the furnace, or by using a hollow electrode. The primary advantages of this process are that the process can utilise any of the available raw materials including 100% chromite fines with minimum or no pre-processing required. Chromium recoveries obtained using this process is very high.

Premus Technology

Fine chrome ore, bentonite and a reductant such as anthracite fines are dry milled, pelletized and preheated before being fed into rotary kilns where partial pre-reduction of the chrome and iron oxides take place. The metallized pellets are then hot charged into closed submerged arc furnaces. The furnace off-gas is cleaned in venturi scrubbers and used throughout the plant as an energy source. Initial capital costs for this process are high and the level of operational control required to ensure smooth operation of the process is very high.

3.2 Primary Advantages of Premus Over Other Processes

Xstrata has improved and modified the original CMI process and equipment and changed the raw material requirements to a mix that is more suitable, cost effective and available. Xstrata uses anthracite with great success to replace the expensive and increasingly more difficult to source coke in the furnace, which is a reductant required by almost all ferrochrome production units.

While the Premus capital cost is higher than the capital for a conventional process, it is still the lowest capital cost per annualised ton of alloy of the alternative environmentally acceptable processes available. It will also result in the lowest cost of production for the foreseeable future. Not only does it result in significantly better efficiencies than conventional operations, but it also addresses critical issues such as low coke consumption, 100% agglomeration and produces a low silicon product. Traditionally South African charge chrome has a silicon content of around 4%. It also has a very low energy consumption, high efficiencies, high recoveries and excellent industry best practice environmental results.

Xstrata is today the only Ferrochrome producer in the world to make use of this technology, and is the only company equipped with knowledge and experience to embark on this process with all its advantages and believe that the change to anthracite will be a continuous benefit. Electricity consumption is a key factor in the advantages that Premus offers in that the cost of electricity is increasing continuously and will continue to form a large cost component to a ferrochrome producer.

3.3 Premus Process Description

Ferrochrome is produced using the solid-state reduction of chromite ore. A flow diagram illustrating the process is given in Figures 4 and 5. Raw materials, including chromite ore, reductants and binder clay, are weigh-fed into a rotary dryer to remove excess moisture. The material is milled to a fine mesh, pre-wetted and fed into maturing bins. The wet material is transported to inclined disc pelletizers, which produces pellets of between 15-30mm. Pellets are dried and pre-heated in a travelling grate kiln before entering the rotary kilns. Solid-state reduction in the rotary kilns is obtained with energy supplied by pulverised coal and furnace off-gas at the discharge end of the kilns, as well as carbon contained within the pellets. The carbon source in the pellets is anthracite fines which significantly reduces the cost of producing the pellets.

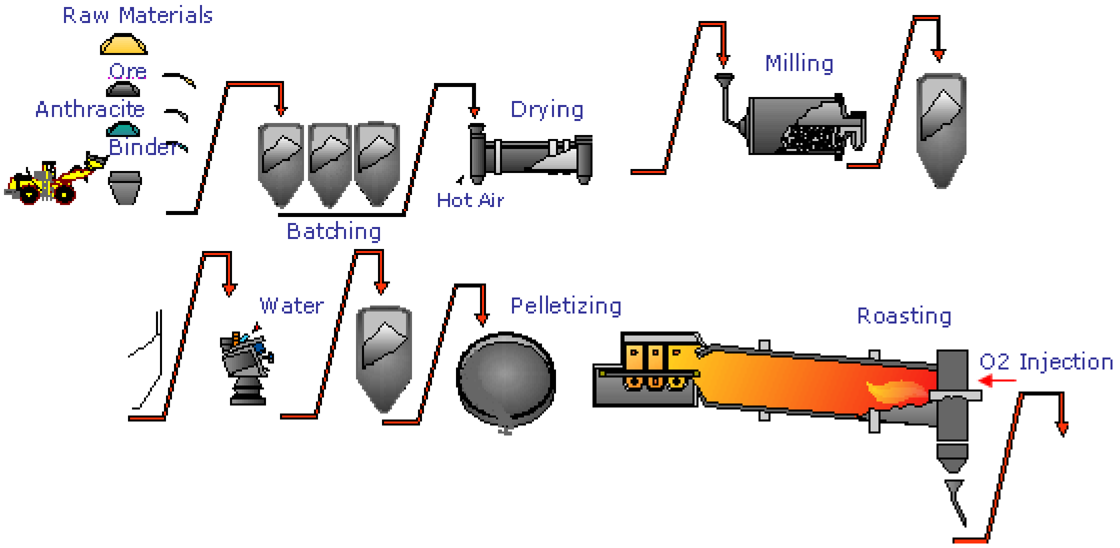

Figure 4: Premium Process – Pelletizing and Pre-reduction

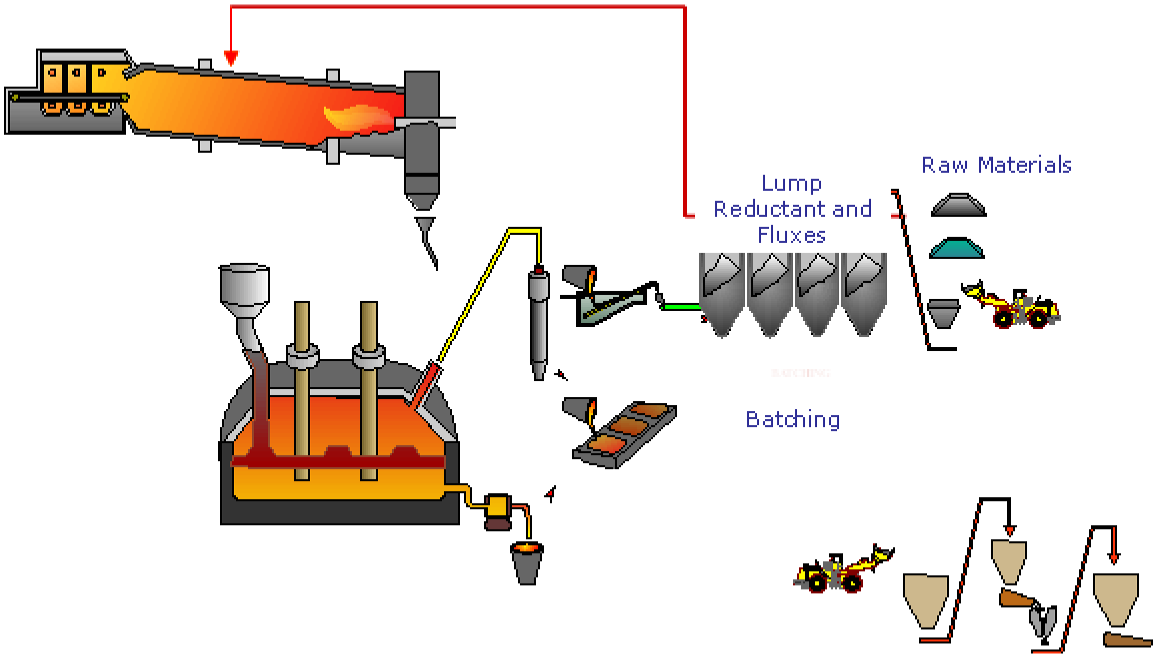

Figure 5: Premus Process – Smelting

Hot sintered pellets (HSP) are discharged into hot-charge containers from where they are lifted and discharged into the feed bins of the submerged arc furnaces. Closed furnaces are used to ensure a reducing environment, which also limits the production of toxic hexavalent chromium. Off-gases are cleaned through a water scrubbing system and recycled to the plant as a source of energy. Therefore unlike a conventional open furnace where the carbon monoxide produced is burnt in the atmosphere to carbon dioxide, the carbon monoxide produced in the furnace is cleaned and reused throughout the process resulting in reduced electrical and other externally sourced energy requirements.

Pre-reduction of pellets encapsulates a significant amount of energy, while loading these pellets hot to the furnace further contributes to reduced electrical energy requirements during the smelting process. The Premus process utilizes approximately one third less electrical energy than the conventional process. Therefore approximately one third less greenhouse gases are produced per ton of ferrochrome than with the conventional process. The consumption of electrical energy is increasing in world-wide placing pressure on supply.

Metal collected from all furnaces can either be cast into ingots, or granulated in granulation dams. Cast ingots are crushed and screened into different saleable products in a crushing and screening plant. Due to the type of process employed, low silicon ferrochrome which is regarded as a prime product will be produced. The low production cost coupled with the production of prime low silicon material increases the sustainability of a plant using the Premus process.

The slag which is a solid waste by-product produced during the process is approximately one third less than that produced in a conventional process.

4. PROJECT LION

In its bid to remain the number one producer of ferrochrome in the world in terms of both capacity and cost competitiveness, Xstrata took the decision to increase its capacity in order to keep pace with the forecast increase in stainless steel demand. The primary challenges influencing growth in the South African ferrochrome industry include the following:

- A large portion of the chromite generated in South Africa requires agglomeration.
- The increased demand in electricity will result in electricity price increases in excess of inflation that will be required to fund the additional capacity.
- The growth in the base metals and steel industry has precipitated worldwide volatility in the price of metallurgical reductants.
- Logistical infrastructure is increasingly being strained by stronger demand.
- The increased strength of the rand against major currencies has resulted in the driving need for improved cost structures.

The different technologies available for the production of ferrochrome including the conventional process, Outokumpu process, DC arc process and the Premus process were evaluated to determine which would be the most advantageous for a new facility. Considering the advantages and disadvantages of each of these processes as discussed earlier, it is believed that the implementation of the Premus process addresses all of the challenges facing the South African producer. Due to the success of the Premus process at the Lydenburg plant, it was decided that this process would be used at the Lion facility.

Pre-feasibility studies were completed to determine the number of kilns and furnaces as well as the optimum furnace tonnages that would be required to ensure the targeted return on capital. At the completion of the pre-feasibility study it was concluded that two rotary kilns feeding two closed submerged are furnaces each with a MVA rating of 63MVA would be constructed in phase 1. The ferrochrome capacity in phase 1 would be 364 000 tons per annum. Phases 2 and 3 will be duplications of phase 1, resulting in a final capacity of 1.09 million tons of ferrochrome per annum at the end of phase 3.

The key parameters of the Lydenburg kiln including kiln output and degree of metallization together with kiln diameter, length, slope, angle of repose of the material and the kiln rotational speed were used to develop an in-house simulation that adequately matched the actual output at the Lydenburg plant with its design parameters. This simulation program was used to obtain the initial design parameters of the kiln. FFE Minerals Vecor were contracted to construct both the mills and the kilns for the new plant. Further test-work was conducted at FFE's test facilities in the United States to enable the completion of the detailed design of the kiln.

The furnaces were designed with the aid of the Pyromet group. Pyromet also supplied the electrode columns and the slipping system. Some of the benefits that the Pyromet electrode and slipping system offer include the following:

- the contact shoes and pressure rings are protected by a water-cooled copper heat shield section,
- The configuration of the pressurizing bellows provides better pressure and is on a separate water circuit.
- Each electrode is carried on four hydraulic cylinders which provide a stable support base with much better lateral stability than electrodes using two jacks.
- Fail-safe slipping system with both upper and lower clamps.

The major equipment was designed in-house with expert advice sought as needed. Project Lion was successfully commissioned during the third quarter of 2006 and is expected to reach full phase 1 production capacity by mid 2007.

5. CONCLUSIONS

The main conclusions that were reached from the in-plant trials that were conducted was that owing to the shape of the anthracite particles as well as its wettability properties, lower quality calcium bentonite produced the best quality pellets. Good quality pellets at 100% anthracite usage could not be produced using activated bentonite except when the level of activation was very low. The philosophy of maximizing energy output from the kiln resulted in positive production increases and lower costs of operation.

Although the Premus process is the most capital intensive it is the most competitive technology available for the production of ferrochrome today. Due to its ability to ensure a long term sustainable competitive advantage this was the process chosen for Xstrata's new ferrochrome facility, Project Lion, that is due to be commissioned in the third quarter of 2006 in the Steelpoort Valley in Mpumulanga, South Africa.

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