AN IMPROVED DC-ARC PROCESS FOR CHROMITE SMELTING

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ABSTRACT

Mintek together with Middelburg Steel & Alloys, developed the DC arc furnace process for the production of ferroalloys with the expressed objective of smelting ore fines (<1mm) without the need for agglomeration. In the case of ferrochrome production, the DC arc furnace, being a semi-open bath operation, loses radiant energy directly from the bath to the furnace roof and sidewalls above the melt. This energy loss is reflected in a higher electrical energy usage per ton of alloy than for a submerged-arc operation smelting lumpy ores or sintered pellets. The difference increases still further when pre-heated sintered pellet feed is used in a submerged-arc operation. This shortcoming of the DC arc furnace can however be overcome by preheating the feed to the furnace in a fluidized bed or flash reactor fuelled by cold furnace off-gas.

In addition to fluidization and preheating testwork, various preheating flowsheets with associated mass and energy balances have been developed and compared from a techno-economic viewpoint. The three major advantages identified were: a) fluidized beds can preheat ores and fluxes up to 950°C without sticking and defluidizing, b) the open bath DC arc furnace does not require expensive coke or char to maintain the burden porosity and, c) the capital cost associated with the milling, pelletising and sintering plant falls away since ore fines are used directly.

1. INTRODUCTION

Mintek and Middelburg Steel & Alloys developed the DC arc furnace process for the production of ferroalloys with the expressed objective of smelting fine ores without the need for agglomeration. This technology has been successfully implemented commercially in ferrochromium, titania slag and stripping of cobalt from copper process slags and is being considered for the production of ferronickel.

In the case of ferrochrome production, the DC arc furnace, being a semi-open bath operation, loses radiant energy from the molten bath to the furnace roof and sidewalls above the melt. This energy loss is reflected in electrical energy usage higher than for a submerged arc operation smelting sintered pellets and preheated raw materials [1]. This shortcoming of the DC arc furnace may, however, be overcome by preheating the feed to the furnace in a fluidized bed or flash reactor.

At present, the leading process for ferrochrome is that offered by Outokumpu [2]. This process essentially involves firstly the agglomeration (pelletizing) of the smelting recipe, followed by sintering, cooling, and screening. This sinter is thereafter reheated to 600-700°C and hot charged to a closed submerged electric arc furnace. The off-gas from the furnace is utilised in the sintering and preheating units.

The objective of this study was to develop various DC arc furnace preheating flowsheets with associated mass and energy balances, select the best, and compare it from an economic viewpoint with the Outokumpu route.

2. PREHEATING TESTWORK

2.1 Lurgi tests

Preheating and charring tests with chromite ores and coals were carried out at the Lurgi test facilities in Frankfurt. The objective of these tests was to investigate the suitability of a flash type preheating system to pre-heat chromite ore as well as fluxes and coal/anthracite. A 50mm laboratory fluidized bed reactor (Figure 1) was used to give a first indication of the behaviour of the different materials charged.

Eleven tests were carried out to determine the behaviour of each of the components. Ore and coal were treated individually and in the form of material mixtures at the pre-heating temperature of 950°C. Three different chromites and three different reductants were tested. The analyses of the materials tested are given in Tables 1 and 2.

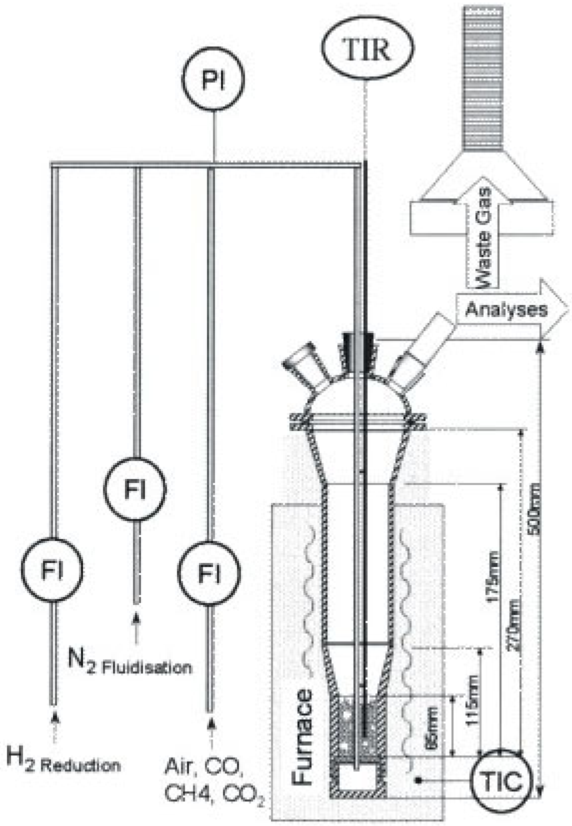

Figure 1. Diagram of the 50mm Fluidized Bed Test Facility (Courtesy Lurgi Outokumpu).

The 50mm laboratory fluidized bed reactor is a batch reactor without circulation, used predominantly for qualitative assessment of material behaviour under fluidizing conditions.

The test results proved to be very promising, as all materials could be heated up to ~950°C individually as well as in mixtures with low decrepitation and fines formation. Agglomeration of the fines did not occur.

Table 1. Chemical analysis of test materials.

Test Material	**Chromite ore 1**	**Chromite ore 2**	**Chromite ore 3**	**Anthracite**	**Coal 1**	**Coal 2**	**Lime stone**	**Quartzite**
Moisture %	0.20	0.19	0.21	5.77	0.71	1.21	0.2	0.23
Volitiles %				11.4	25.7	26.4	43.4	
Ash %				14.2	18.7	15		
Chemical analysis % by mass								
MgO	7.0	6.4	7.1	0.11	0.09	0.24	0.66	0.025
Al_2O_3	9.6	10.4	10.5	4.22	4.94	4.51	0.13	0.43
SiO_2	4.9	2.33	1.9	6.69	7.82	10.4	0.6	98.8
CaO	0.54	0.2	0.05	0.55	0.74	0.69	53.4	0.025
Cr_2O_3	45.8	44.3	53.7		0			
Fe total	19.6	21.9	13.8	0.87	0.16	0.81	0.2	0.37
Fe^{2+}	0.66	0.88	0.44					
Cr/Fe								
C fixed				74.4	59.3	54.9		
C total	0.13	0.04	0.05				~11.8	0.10

Table 2. Screen analysis of test materials.

Test Material	**Chromite ore 1**	**Chromite ore 2**	**Chromite ore 3**	**Anthracite**	**Coal 1**	**Coal 2**	**Lime stone**	**Quartz**
Screen analysis, %								
>0.5 mm	4.3	0	0.7	33.1	39.2	18.3	26.7	228.8
0.500 to 0.315 mm	21.3	0.5	5.5	20.3	26.7	19.4	12.2	20.9
0.315 to 0.200 mm	28.6	10.1	18.2	14.3	15.9	18.7	8.5	14.8
0.200 to 0.100 mm	31	58.5	38.1	15.3	13.2	24.6	7.7	14
0.100 to 0.063	12	27.8	25.2	4.6	2.9	9.3	7	7.5
0.063 to 0.045	2	2.3	7.9	3	0.9	4	4.4	3.5
0.045 to 0.032 mm	0.5	0.7	2.9	3.7	0.6	2.5	4.4	2.3
<0.032 mm	0.3	0.1	1.5	5.7	0.6	3.2	29.1	8.2
Total	100	100	100	100	100	100	100	100

In the ore preheating tests that were carried out under nitrogen fluidization, the ores were calcined and a small carry over of material was observed varying from 0.3 to 3.9 percent for the finest ore.

Coal was also preheated under nitrogen and produced a good char with a carry over of 0.9 to 4.3 per cent depending on the grading.

The tests with ore/coal/fluxes were aimed at determining the behaviour of a multi-component solid bed in a fluidized bed reactor paying special attention to decrepitation or agglomeration. The proportion of materials was as normally batched to a DC arc furnace for ferrochrome production. Neither decrepitation nor agglomeration occurred. In the case of ore in a reducing atmosphere a slight reduction of iron oxide was observed.

2.2 POLYSIUS AG POLCAL PILOT PLANT TESTS

As a result of the encouraging results obtained by Lurgi, a pilot-scale test was arranged at the Polysius test centre at Neubeckem. The test regime was dictated by a simple flowsheet in which only chromite would be preheated using the DC arc furnace. Chromite ore types 1 and 2 were preheated to 950°C by thermal treatment in a 4-stage cyclone preheater with an integrated calcining loop (Figure 2). The tests were carried out at a continuous feed rate of 37 kg/h. In order to reach and maintain material temperatures of ~950°C, hot gas temperatures of approximately 1100°C in the calcining duct were required. The ores showed good flowability characteristics and again showed that there was little propensity to agglomerate or sinter at the test temperatures.

The hot gases required for preheating were generated in a combustion chamber and directed to the cyclones via a calcining duct (C3 to C6). To achieve constant temperatures in the calcining section natural gas was injected. The thermal process of the POLCAL plant [3] was monitored with the aid of thermocouples and pressure-measuring points distributed in the equipment. The exhaust gas was cleaned in a bag filter. The calcined material was collected below cyclone 1. The fine dusts from the filter (~5% of feed) and the calcined material were weighed hourly.

The outcome of the tests was:

- The material can be calcined and heated to a temperature of approximately 950°C in the POLCAL without problems.
- Up to a gas temperature of approximately 1100 to 1150°C, the chromite can be thermally treated in the POLCAL plant without sintering and coating of the unit's interior.
- The loss of ignition of the product was 0.5 to 1.3%.

- The calcined material could be transported from the underflow of cyclone 1 by a rotary airlock feeder without problems.

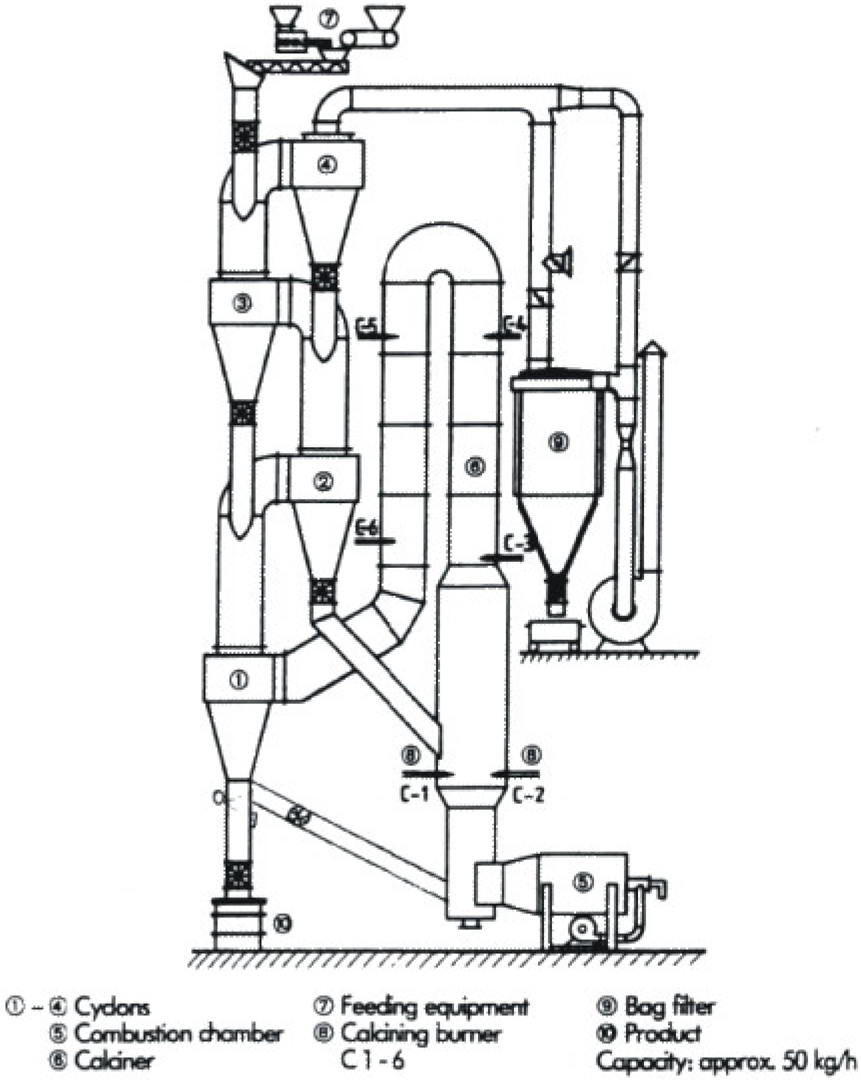

Figure 2. Diagram of the POLCAL pilot-plant (Courtesy Polysius AG.)

3. FLOWSHEETING

3.1 Development

Mintek's Pyrosim computer simulation software package was used throughout to generate the mass and energy balances for each flowsheet option. As seen in Figure 3, three types of unit operation were set up, namely, a DC arc furnace, a preheater, and a gas plant or scrubber. The basic assumptions associated with each of these unit operations are summarised as follows:

3.1 1 DC arc furnace

For this unit an empirical model was used based on Mintek's DC arc ferrochrome experience. Raw materials were assumed to be LG6 chromite fines, duff anthracite and coal, limestone, silica, electrodes, and air. Slag, metal, gas, dust, and solids form the basis of the furnace product streams. The solid stream has been incorporated in order to provide for excess carbon fed to the unit and is assumed to leave the furnace with the slag. Slag is assumed to be at the operating temperature of 1650°C, while metal and gas, dust are assumed to be 50°C and 100°C lower at 1600 °C and 1550°C, respectively. The reason for this is than in practice the metal temperature is usually lower due to a thermal gradient across the slag and the offgas and dust lose energy to the cooler freeboard and roof.

3.1.2 Gas plant

In all cases for this unit a simple heater/drier model was used. This model assumes that no chemical reaction takes place and effectively separates the products into solid and gaseous streams.

3.1.3 Preheater

Energy to this unit is assumed to be via the combustion of either coal or recovered furnace off-gas (plant gas). In all cases for this unit an equilibrium model has been chosen and thus chemical reactions do take place. Product gas and dust are assumed to pass through a venturi scrubber where energy is removed from the unit in order to cool the products. Hot material flowing to the furnace is assumed to lose 100°C of preheat temperature during transportation.

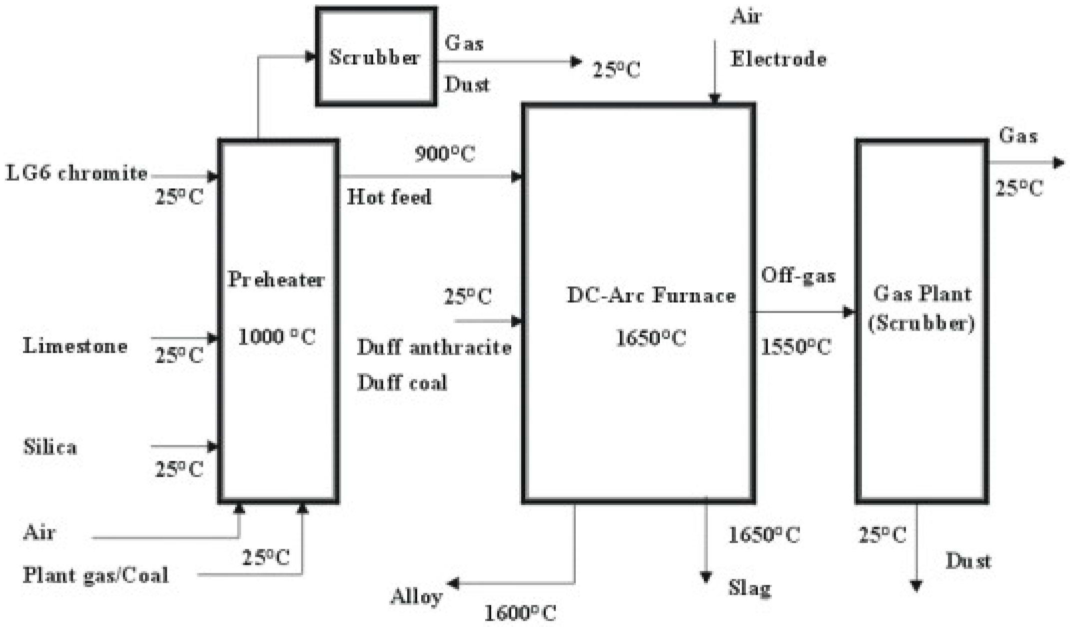

Figure 3. Flowsheet example.

3.2 Results

Five flowsheets processing 250kt chromite per annum were evaluated against a baseline of cold feed as follows:

Option 1: Gas preheating of chromite and flux tranferred at 900°C, ambient temperature anthracite as reductant.
Option 2: Gas preheating of chromite and flux tranferred at 1200°C, ambient temperature anthracite as reductant.
Option 3: Gas preheating of chromite and flux tranferred at 900°C, ambient temperature coal as reductant.
Option 4: Coal fired preheating of chromite and flux tranferred at 600°C with char formation as the furnace reductant.
Option 5: Coal fired preheating of chromite and flux tranferred at 900°C with char formation as the furnace reductant.

A summary of the various flowsheet options is given in Table 3. Here gas-fired preheating of chromite and fluxes to 1200°C, utilising coal at ambient temperature as a reductant, appears to be the most favourable in terms of furnace power and energy requirements. As is to be expected, the higher the temperature of the preheated material the better, provided the chromite does not sinter. Coal-fired preheating of chromite and fluxes in excess of 600°C is costly due to inefficient burning of coal to produce both preheat energy and solid reductant (char) for the downstream furnace.

Although coal is seen to be the more economic reductant, blending of coal and anthracite is reputed to be of practical benefit in process control. The additional benefit of simultaneously preheating the fluxes, although not shown here, is small (~5% energy saving) and therefore the added complexity introduced by preheating these materials would have to be weighed up against the economics.

Table 3. Flowsheet summary, 250kt/a LG6 Chromite.

Operating Parameter	**Base case (all feed at 25°C)**	**Gas-fired Preheater**			**Coal-fired Preheater**	
		Option 1	**Option 2**	**Option 3**	**Option 4**	**Option 5**
Furnace power (MW)	62.4	51.7	48.7	47.8	51.7	49.0
Process energy (MWh/t alloy)	3.97	3.11	2.91	2.87	3.10	2.92
Silica (kt/a)	25	25	25	22.5	20	8
Limestone (kt/a)	28	28	28	30.5	30.5	40
Anthracite (kt/a)	85.2	79.3	79.3	-	-	-
Coal (kt/a)	-	-	-	99.2	142.7	361.2
Plant gas (kt/a)	-	56.3	92.5	92.0	-	-
Furnace off-gas (kt/a)	130.4	115.2	115.2	130.8	100.0	100.9
Preheat off-gas (kt/a)	-	201.7	322.4	330.3	266.3	1035.6

3.3 Technical Evaluation

While preheating of the furnace feed, or part thereof to varying degrees, indicates significant potential downstream energy savings, this can only be realised if equipment and control issues are addressed. Materials of construction will be a restriction in the maximum temperature that can be obtained and thus the suitable choice of preheater is dependent not only on its ability to preheat but also on the unit's availability (physical wear etc.) and controllability. Feed attrition and fines generation is an additional consideration.

The higher the operating temperature the greater the likelihood of mechanical failure and also the need for improved furnace control. DC arc furnace smelting of ferrochromium is an open bath process, which relies heavily on the balance between feed and energy input to ensure containment. As feed is preheated to greater temperatures the furnace energy requirements decrease and thus the margin for error per ton of feed becomes more critical. The introduction of both preheating and pre-reduction would exacerbate the situation even further.

Considering the above it is felt that the use of furnace off-gas to pre-heat the chromite and fluxes to 1000ºC (furnace charge at 900°C), charging the reductant at ambient temperature to the furnace, is the more prudent option.

4. ECONOMIC EVALUATION

The flowsheet selected for economic evaluation was that of gas-fired preheating of chromite only at a temperature of 1000°C (charged at 900°C to the furnace) with reductant charged at ambient temperature to the furnace. The incorporation of the flux into the preheater feed stream and the possibility of increasing the preheat temperature, were allowed for as future developments.

4.1 Operating Costs

Table 4 summarises the operating cost comparison between a typical AC Furnace process flowsheet and the improved DC flowsheet. As can be seen here, the operating costs are similar with lower reductant cost for the DC operation (anthracite vs. metallurgical coke or char) being offset by increased furnace consumables and maintenance costs.

Table 4. Operating cost summary.

		ZAR/t FeCr Advantage of DC Furnace Process
Feedstock:	Chromite Ore	15
	Reductants	114
	Fluxes	0
Consumables:	Pellet/Sinter	17
	Preheater	-12
	Furnace	-105
Utilities:	Pellet/Sinter	21
	Preheater	-1
	Furnace	-37
Labour:	Pellet/Sinter - Shift	19
	Preheater	-13
	Furnace - Shift	3
	Other	0
Maintenance and Spares:	Pellet/Sinter	34
	Preheater	-10
	Furnace	-39
Other		1
TOTAL		**7**

4.2 Capital

Based on the flowsheet requirements a comparison summary of the capital requirements for a typical AC process flowsheet and the improved DC flowsheet is shown in table 5. The DC option consists of a 60MW furnace linked to a four-stage suspense heater based on the Polysius POLCAL process.

Here the capital costs of the AC operation far exceed those of the improved DC alternative primarily due to the pelletizing and sintering requirements.

Table 5. Capital cost summary.

	ZAR '000 Advantage of DC Furnace Process
Pre-Investment Expenditure	0
Mining	0
Site Preparation	0
Raw Materials Receipt and Stockpiling	0
Raw Materials Conditioning and Proportioning	-40,000
Pelletising and Sintering	222,000
Furnace and Preheating	-42,000
Hot Metal Handling	0
Slag Handling and Removal	0
Final Product Handling and Storage	0
On-Site Auxiliary Facilities	0
On-Site Facilities	0
TOTAL	**140,000**

5. CONCLUSIONS

Of the five flowsheets evaluated, the preferred option from an economic viewpoint is to use furnace off-gas to pre-heat the chromite and fluxes to 1200ºC, charging the reductant at ambient temperature to the furnace. While coal is seen to be the more economic reductant, in practice blending of coal and anthracite is reputed to be of benefit in process control. Coal-fired preheating of chromite and fluxes in excess of 600°C is costly due to inefficient burning of coal to produce both preheat energy and solid reductant (char) for the downstream furnace.

The higher the temperature of the preheated material the better, provided the chromite does not sinter. Although preheating of the furnace feed, or part thereof to varying degrees, indicates significant potential downstream energy savings, this can only be realised if equipment and control issues are addressed. Materials of construction will restrict the maximum temperature that can be obtained; therefore the choice of a suitable preheater is dependent not only on its ability to preheat but also on the unit's availability (physical wear etc.) and controllability.

The cost comparison between a typical AC process flowsheet and the improved DC flowsheet reveals a significant capital saving for the DC process for similar operating costs.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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