THE DEVELOPMENT OF INTEGRATED ORE PRE-REDUCTION AND DC TRANSFERRED ARC PLASMA SMELTING TECHNOLOGY FOR IRON AND FERRO-ALLOYS PRODUCTION

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ABSTRACT

An extensive programme of investigation and development of both plasma furnace technology, based on the Noranda furnace design, and particulate ore pre-reduction by plasma smelting product gas, has been carried out by Davy McKee. It has been concluded that the Noranda furnace design has unique advantages in smelting particulate ores and that the integrated process has a wide application for the production of iron and ferro-alloys.

1. INTRODUCTION

The future use of the plasma technology for iron and ferro-alloys production depends on exploiting (i) the ability of the process to treat particulate ore, (ii) the use of coal as reductant, (iii) the high efficiency of electrical energy usage in the plasma furnace, (iv) the efficient use of the plasma furnace product gas, and (v) the use of non-consumable electrodes.

Davy McKee have developed process and equipment design knowhow in an integrated ore pretreatment/plasma smelting process in which plasma furnace product gas is used to preheat, pre-reduce and calcine particulate feed ore and flux. Ore pretreatment is based on established FIOR [1] type fluid-bed ore reduction technology while the plasma furnace is based on a design principle developed by Gauvin and Kubanek of Noranda Research [2].

2. PLASMA FURNACE DESIGN PRINCIPLES

The plasma furnace design investigated and being developed by Davy McKee is based on the Noranda furnace development [2]. The furnace design principles are illustrated in Figure 1. A direct current (dc) transferred plasma arc (1) is directed from the cathode (2) down the axis of the sleeve reactor (3) to the furnace hearth (4) containing molten product which acts as the anode. Pre-reduced particulate ore, flux and coal are injected using a carrier gas into the reaction sleeve via tangential inlet ports (5) at a sufficiently high velocity to form a uniform covering of the inner wall of the reaction sleeve. Melting occurs in the reaction sleeve, using the radiant heat of the arc which also provides the enthalpy for some ore reduction to take place. The molten material then falls into the hearth zone (4) where the reaction is completed. The return path electrode (6) is located in the base of the furnace. Metal fines melting may also be carried out using the sleeve reactor.
3. THE DAVY MCKEE PLASMA FURNACE

A plasma furnace pilot plant based on the Noranda configuration was designed and constructed at the Davy McKee Research and Development facility in Teesside, England.

A flexible dc power supply provides a maximum power of 1 MW in the range 500 to 2000 amps and 500 to 2000 volts. The plasma furnace has a nominal capacity of 250 kg which enables 2 hours continuous operation to be achieved. The plasma gun is movable in the vertical axis of the reaction sleeve to operate with arc lengths up to 60 cm. The furnace is provided with viewing and sampling ports.

The charge of cold, premixed, particulate feed is stored in a weighed hopper and a gas injection feeder with a capacity of approximately 3 kg/minute transports the feed mixture to the furnace.

The product gas handling system consists of gas cooling, water scrubbing and venting. The gas scrubber water is collected over each run and product dust recovered. A facility for gas sampling and on-line analysis is also provided.

4. INVESTIGATION OF FURNACE CHARACTERISTICS

4.1. Arc Characteristics and Power Distribution in the Transferred Arc

The preliminary programme was carried out using an argon arc together with argon carrier gas injected into the reaction sleeve, with and without iron ore, in order to investigate the distribution of heat radiated along the length of the plasma column. Investigations up to 1500 A showed that arc voltage is relatively insensitive to arc current but is strongly dependent on arc length. Voltage gradients are in the range 1.5 to 2.6 volts/cm and the intercept on the volts axis for zero arc length lies between 35 v and 56 v. Similar findings have been reported elsewhere [3] [4]. The intercept voltage and corresponding power value are related to (i) the resistances in the external circuits, (ii) the voltage drop in the immediate vicinity of the cathode and anode and (iii) the resistance of the anode bath. The balance of the power is therefore associated with the arc column.

Further tests were carried out with zero feed addition using a cold furnace chamber to minimise the effect of heat radiation from the furnace. A low power arc was used (400 amps) and the arc voltage and power were measured as the arc length was increased by withdrawing the plasma gun up the reaction sleeve. The heat radiated within the sleeve was measured by the increase in temperature of the sleeve cooling water. The arc power calculated within the sleeve was almost completely accounted for by the power passing to the sleeve cooling water, thus indicating that the arc energy is available mainly in the form of radiation. The results are summarised in Figure 2. It is clearly seen that as the arc length increases the proportion of the power to the anode decreases whereas the proportion of the power radiated to the sleeve increases.

At a total arc length greater than 20 cm approximately 80% of the arc power is radiated and as the arc length within the reaction sleeve increases, the proportion of this power radiated within the sleeve increases.
The study was continued with feed injection tests. Hammersley fine ore was used without flux or carbon additions to avoid the generation of gas product and to provide a melting system. It was possible to determine the power available for heating and melting the feed at selected cathode positions within the sleeve by deducting the sleeve cooling water power losses from the arc power within the sleeve, Figure 3. The power required to melt the feed (at 1 kg/min) and the position at which this would occur is indicated for cathode positions A and B and coincides within 1 cm of the position at which the film was seen to form. The consistency of these results provides further evidence that the arc energy is mainly transferred as radiation and that the proportion of arc power which is in the form of radiant energy increases with increasing arc length. It is concluded that the sleeve reactor is an ideal system for utilising the radiant energy of long arcs to heat the incoming feed. In the absence of the reaction sleeve the radiant heat is dissipated to the furnace refractories.

4.2. Arc Characteristics in a Smelting System

Arc voltage characteristics for an argon arc are compared for a series of tests with and without iron ore, coke and flux injection in Figure 4. The voltage gradient is low without feed but increases to about 10 V/cm during feed injection due to dust and product gas entrainment in the argon arc. The curves are drawn to intercept the voltage axis at 50 V which corresponds to the sum of the voltage drops as described above. The balance of the power is in the form of radiant arc power and may be as high as 90% for a 50 cm long arc. Sleeve reactor tip positions are indicated in Figure 4 and it is apparent that the reactor configuration is capable of utilising a significant proportion of the radiant power which is generated during extended arc operation.

4.3. Power Utilisation in Smelting Reactions

The effectiveness of power utilisation in smelting (carbothermic reduction of oxide ore) reactions was examined using iron ore, coke and flux. This system was selected for the reactor study as the chemistry of the process is simple and well understood. There is in addition considerable commercial potential for the integrated pre-reduction and plasma smelting process for iron making in small units in suitable locations. Details of the power consumption for three tests are given in Table 1 expressed as a percentage of the total input. In each test the arc power was selected to provide the sensible heat and endothermic reaction requirements of the feed at the specific feed rate assuming complete reaction.

The furnace gas was analysed by GLC at intervals during the test and the product gas flow rate was determined using argon as a tracer since the selected plasma and feed gas flow rates were known. Product samples were retrieved at the end of each test and chemically analysed. The measurements were used as a basis for establishing the metallic yield and power consumption during smelting.

Power utilisation in the smelting reaction is seen to be in the region of 75 to 83% (after subtracting the power surplus) on this scale of operation. Sleeve cooling water losses were highest in Tests 2 and 3 where the reactor protruded into the furnace chamber. As the reactor was unshielded the contribution to the losses from furnace radiation was greater than in Test 1. The highest losses are also seen to be experienced in Tests 2 and 3 in which there was an excess of power. In the developed furnace design the reaction sleeve is shielded from the furnace radiation and losses would
decrease. In addition when total power input is balanced by feed input, and therefore by power demand, the heat losses to the sleeve cooling water would be reduced. The resulting efficiency of utilisation of electrical energy will be 85% to 90%.

The power demand in these tests was calculated from the analysis of all the products collected including dust carry-over. Metallisation, based on the molten metal and slag production, was approximately 97% in Tests 2 and 3 in which sufficient energy was available for reaction.

5. INTEGRATED ORE PRETREATMENT AND SMELTING PROCESS

Significant reductions in both power and fossil fuel consumption over conventional processes result from the use of the chemical energy of the plasma furnace product gas to pre-reduce ore feed, the residual calorific value of the gas being used to calcine and preheat both ore and flux. In the Davy McKee Integrated Process particulate ore and flux are fed to a FIOR [1] type multistage fluid bed unit where ore pretreatment takes place. Mixed ore, flux and coal, or coke, are then injected into the Noranda Plasma Furnace, via the reaction sleeve and the reaction to metal is completed with co-production of a reducing gas. Fluid bed ore pretreatment leads to good contact between gas and ore and both heat transfer and reaction are fast in finely divided material. Fluid bed equipment is therefore efficient, compact and low cost.

Plasma smelting in the Noranda type plasma reactor eliminates the need for ore agglomeration and the preparation of metallurgical coke from coal. The capital and operating costs of the Integrated Process using particulate feeds are therefore significantly reduced over blast furnace and submerged arc electrical processes. The size of the cost savings will vary with ore type, plant location and scale of operation. Finely divided ores are produced in a large number of beneficiation processes and ore fines are also generated during mining and handling. Particulate ores therefore represent a large proportion of those currently treated and the Integrated Process has a wide range of potential applications.

6. CONCLUSIONS

Although optimisation of the furnace design and operation is required it may be concluded that a plasma furnace design based on the Noranda concept, which efficiently utilises the radiant heat of the long plasma arc, provides an effective means of smelting oxide ores.

The use of electrical energy in metals production is competitive with other processes in locations with low power costs. Iron and steel production using the integrated process will be competitive with the blast furnace and direct reduction processes in locations such as North East Canada which has indigenous iron ore, produced as a concentrate, and low cost hydro-electric power [5] [6]. Manganese ore mining, beneficiation and handling produces large quantities of ore fines which may be used in the integrated process to produce ferro-manganese metal [7]. Capital and operating costs for the integrated process are significantly less than in conventional processes which also use electric power.
REFERENCES


Table 1  Power Utilisation in Smelting Reactions

<table>
<thead>
<tr>
<th>Test No</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<tbody>
<tr>
<td>Input power kW</td>
<td>157</td>
<td>187</td>
<td>224</td>
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<tr>
<td>Total feed blend rate kg/min</td>
<td>2.2</td>
<td>2.4</td>
<td>2.4</td>
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<td>Basis of calculation, power input kW</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<tr>
<td>Measured cooling water losses kW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- cathode</td>
<td>0.3</td>
<td>0.6</td>
<td>0.9</td>
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<tr>
<td>- reaction sleeve</td>
<td>7.9</td>
<td>12.6</td>
<td>16.8</td>
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<tr>
<td>Furnace wall losses (calculated)</td>
<td>8.8</td>
<td>7.2</td>
<td>6.8</td>
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<tr>
<td>Total Losses kW</td>
<td>17.0</td>
<td>20.4</td>
<td>24.5</td>
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<td>Smelting requirements (calculated from products)</td>
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<tr>
<td>Sensible heat kW at 1500°C</td>
<td>41.8</td>
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<td>Reaction (250°C) kW</td>
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<td>35.0</td>
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<td>Total Heat Required kW</td>
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<td>71.4</td>
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<td>Total power demand kW</td>
<td>100.6</td>
<td>96.7</td>
<td>95.9</td>
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<td>Power surplus %</td>
<td>-0.6</td>
<td>3.3</td>
<td>4.1</td>
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<tr>
<td>%Metallisation, based on metal plus slag (All products had low Carbon content)</td>
<td>94.3</td>
<td>97.1</td>
<td>96.9</td>
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</tbody>
</table>
Figure 1  Diagram of the Noranda Plasma Furnace

Figure 2  Power Distribution to Furnace without Feed Injection

Figure 3  Arc Power Available for melting iron ore

Figure 4  Arc characteristics during iron ore smelting

Feed rate 1 kg/min
Current 400 A