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THE EFFECT OF FEED PRETREATMENT ON THE EFFICIENCY OF A PLASMA-ARC FURNACE

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ABSTRACT

Experiments in a plasma-arc furnace operated at 120 kW showed that the efficiency of utilization of electrical energy increased from 44.4 to 61.3 per cent when the feed was preheated to 700°C in a fluidized-bed reactor. It is also demonstrated that the rate of energy loss from a plasma furnace is independent of both the power and feed fluxes (subject to thermodynamic constraints).

INTRODUCTION

The Council for Mineral Technology (Mintek) has been engaged in the development and evaluation of direct current (d.c.) open-bath transferred-arc plasma technology for the past decade. The applications under investigation include iron, steel, ferro-alloys, and stainless steel because of the abundance of the requisite raw materials in South Africa. A major objective has been the scale-up of plasma furnaces to an economically viable commercial size(1); maximization of the throughput and efficiency of such furnaces has naturally formed an integral part of the effort to attain this goal(2).

ADVANTAGES AND LIMITATIONS OF PLASMA FURNACES

In the South African context, the capability of the plasma furnace to accept fine feed materials without prior agglomeration is an attractive advantage, not only because of the friable nature of many ores, but also because the beneficiation of lower-grade deposits invariably delivers a fine product. Together with the high recoveries that are typical of plasma furnace operation, the direct processing of fines enables this furnace to compete favourably with submerged-arc furnaces, particularly in the production of ferro-alloys.

Other advantages of the plasma-arc furnace include greater flexibility of operation because the power input to the furnace is largely unconstrained by the resistivity of the materials smelted or remelted, and because the furnace can respond to changes in a relatively short period.

A noteworthy feature of the plasma-arc furnace is that, given the same throughput rate and power flux, its thermal efficiency is lower than that of a submerged-arc furnace. Two factors are responsible for this:

(1) some energy is lost by radiation from the open arc to the walls and roof of the furnace, and
(2) the sensible energy of the gases evolved is not utilized.

IMPROVING THE EFFICIENCY OF A PLASMA FURNACE

Since the energy supplied to a plasma furnace is in the form of expensive electrical energy, its thermal efficiency has a direct bearing on its operating costs.

The direct approach in efforts to improve the thermal efficiency of a process is to lower the rate of energy loss but, for a given furnace, the application of this approach is severely limited in scope. This is because the rate of energy loss is usually determined by the operating temperature required for the process, the type and thickness of the refractories, and the external surface area and geometry of the furnace.

However, an improvement can be achieved by an indirect approach in which the throughput rate is increased without a simultaneous increase in the rate of energy loss. Curr *et al.*(2) have shown that, when an open-bath d.c. transferred-arc plasma furnace was operated at higher power fluxes (and concomitantly increased feed fluxes), the resulting improvement in thermal efficiency was in accordance with the assumption of a constant rate of energy loss.

A knowledge of the independent effects of variations in power and feed rate would contribute to an improved understanding of the mechanisms of energy loss, e.g. whether an increased feed rate would lower the off-gas temperature by virtue of improved gas-solids contact. The work of Backer and Szekely(3) indicates that a substantial proportion of the energy dissipated by an arc in a furnace environment is transported away from the arc region by convection, and therefore gas-solids contact may have a significant effect upon the rate of energy loss.

THE ROLE OF FLUIDIZED-BED REACTORS

The fluidized-bed reactor is complementary to the plasma furnace in that both are well suited to the processing of fine feeds without prior agglomeration, and both are high-throughput reactors with relatively short response times. Several potential applications have been identified at Mintek(4).

A portion of the specific electrical energy required in the furnace can be replaced by the utilization of cheaper energy sources such as furnace off-gas or coal, including duff coal, to preheat or prereduce the feed to the furnace. Pre-treatment also permits a greater production rate to be attained without upgrading of the transformer. Both of these factors contribute to a reduction in the total operating cost per ton of product.

MINTEK'S PLASMA FURNACE WITH A FLUIDIZED-BED PILOT PLANT

Mintek has established several different plasma-furnace pilot-plant facilities with ratings ranging from 50 kVA to 3.2 MVA. Details of these pilot plants have been given elsewhere (5-7).

One of these furnaces, rated to operate at 200 kW, has an internal diameter (i.d.) of 0.5 m. A fluidized-bed reactor was recently installed on this furnace to allow the combined operation of the two units to be investigated. The pilot plant is depicted in Figure 1. The single-stage fixed fluidized-bed reactor has an i.d. of 280 mm and a freeboard i.d. of 450 mm. The bed depth is controlled at 350 mm by virtue of the location of the overflow pipe, leaving a 1,3 m freeboard. A pair of sealed tubular vibratory feeders deliver material onto the surface of the bed in the reactor; separate feeders deliver materials that are not to be processed in the fluidized bed direct to the furnace.

The small amount of material elutriated from the bed is collected in a cyclone separator and introduced to the furnace along with the particles that overflow from the bed. Under steady conditions, the flowrate of material to the furnace is constant, and equal to the feed rate to the bed.

EXPERIMENTAL WORK

In the experimental work reported here, the effect of feed flux on furnace efficiency was measured at constant electrical power. For this to be accomplished, it is necessary to vary the specific thermodynamic energy requirement of the process being conducted in the furnace because the feed and energy inputs must be balanced at all times if the furnace is to be operated at a constant temperature. Different feed flux levels can be attained by preheating or prereduction of the feed material.

In the present investigation, cold and preheated hematite were smelted, and cold and preheated direct reduced iron (DRI) were remelted in the plasma furnace. An operating power set point of 120 kW was selected, and the feed rate was set to correspond to this in each case. The fluidized-bed reactor was employed as a tool to preheat the feed materials, and no attempt was made to optimize its operation. Liquefied petroleum gas (LPG) was combusted in the bed to provide the required energy. When DRI was preheated, an excess of LPG was admitted to the bed to maintain the CO/CO_2 ratio at approximately 1.3 to 1.4 so that re-oxidation of the DRI would be minimized.

The experiments were conducted in a continuous campaign that lasted 110 hours. The feed material was fed to the furnace in batches, and after each batch, the furnace was switched off and tilted to allow the slag and the metal to be tapped. During tapping the fluidized bed was slumped. The energy lost during the downtime associated with tapping was made up by adjustment of the feed rate for the following batch so that the furnace temperature remained relatively constant. In practice, the downtimes are fairly consistent so the feed rate remains essentially constant for a given recipe.

The volume of the furnace constrains the size of the batch, and hence the period between taps is shorter at higher feed rates. Consequently, the availability of the furnace decreases. To allow a fair comparison to be drawn between the different operations, the effect of downtime was eliminated when the reported efficiencies were calculated.

RESULTS AND DISCUSSION

The principal parameters describing the periods of stable operation on which the mass and energy balances were based are shown in Table 1. Owing to the excessive segregation and defluidization of the coarse fraction of the hematite, operation with preheated hematite could not be sustained for sufficiently long periods to yield meaningful results.

For the three results given, the power flux was held constant with a deviation of less than ±2.5 per cent while the feed flux was increased by a factor of greater than 3.

The experimentally determined furnace efficiencies are presented in Table 2. The thermal efficiency of the furnace is defined as the ratio of the thermodynamic energy requirement to the actual electrical energy supplied. The thermodynamic energy requirement was determined from the difference between the total enthalpy (relative to the elements in their standard states at 25°C, 101.3 kPa (abs)) of the streams leaving the furnace (slag, metal, and gas) and the total enthalpy of all the streams entering the furnace. This approach renders the calculation independent of assumptions regarding the actual chemical reactions and the temperatures at which they occur.

The uncertainty in the reported values due to errors in the measurements is estimated to be ±3 per cent (absolute error). Within the limits of the experimental error, there is no significant difference in the furnace efficiency despite a three-fold increase in the feed flux. This result demonstrates that the rate of energy loss was independent of the feed flux at constant power flux. Combined with the work of Curr *et al.*(2), this result implies that the rate of energy loss is independent of both feed flux and power flux. The temperature of the furnace as a whole rather than local temperatures (e.g. the arc temperature or the in-flight temperature of the feed materials) therefore appears to determine the magnitude of the energy losses.

Although pretreatment of the feed does not improve the rigorously defined thermal efficiency of the furnace, it is clear from Table 3 that the energy loss from the furnace per unit of metal produced decreases with increasing degree of pretreatment. Provided that the energy required for pretreatment can be supplied more cheaply than the electrical energy consumed in the furnace, which is certainly the case with preheating, there is a clear economic advantage to be gained from pretreatment.

To clarify this point, a definition of the efficiency of utilization of electrical energy is convenient. In any definition of efficiency, the actual energy consumed is compared to some chosen ideal case or datum. To show the effect of preheating a suitable choice of datum is the electrical energy that would have been required in the absence of preheating.

On this basis, the efficiency of utilization of electrical energy in these experiments for the remelting of cold DRI is 44.4 per cent (which is the same as that calculated by the previous method), while that for the remelting of preheated DRI is 61.3 per cent. Stated differently: without preheating of the feed, some 2.25 times the thermodynamic requirement of energy was supplied electrically, whereas preheating of the feed reduced this to only 1.63 times.

CONCLUSIONS

(1) Preheating of the feed to a plasma-arc furnace has a marked effect on the efficiency of utilization of electrical energy. For the remelting of DRI, the delivery of the DRI to the furnace at a temperature of 700°C increased this efficiency from 44.4 to 61.3 per cent.

(2) Preheating of the feed to a plasma furnace permits increased throughputs without uprating of the transformer, and results in a lower cost per ton of metal produced.

(3) The overall thermal efficiency of an open-bath transferred plasma-arc furnace operated at constant power is independent of feed pretreatment or, equivalently, feed flux.

(4) At a constant power flux, the rate of energy loss from a plasma-arc furnace is independent of the feed flux.

(5) When the results of this work are combined with the results of Curr *et al.*(2), it can be concluded that the rate of energy loss from an open-bath transferred plasma-arc furnace is independent of both power and feed flux, provided that these two dependent variables are correctly balanced according to thermodynamic requirements.

6) The magnitude of the energy losses from a plasma furnace are not strongly influenced by the local conditions around the arc or the feed stream.

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TABLE 1

Operating conditions

Operation	Period of steady operation h	Availability %	No. of taps	Mass fed kg	Feed rate kg/h	Thermodynamic energy requirement kW.h/kg*	Tap temp. °C
Smelting cold hematite	17.65	91.0	7	722	45.0	1.630	1510 ±80
Remelting cold DRI	23.95	84.8	18	2153	106.0	0.591	1470 ±50
Remelting preheated DRI**	11.80	79.0	11	1290	138.5	0.457	1550 ±30

* Of metal produced
** Net preheating temperature 700°C

TABLE 2

Experimental furnace efficiency

Operation	Actual ave. power kW	Power flux kW/m²	Feed flux kg/h.m²	η* %
Smelting cold hematite	121	616	229	43.1
Remelting cold DRI	117	596	540	44.4
Remelting preheated DRI	122	621	705	45.4

* Assuming a constant off-gas temperature of 1300°C

TABLE 3

Specific energy loss from furnace

Operation	Actual rate of energy loss kW	Specific energy loss kW.h/kg*
Smelting cold hematite	66.0	3.63
Remelting cold DRI	63.5	0.80
Remelting preheated DRI	65.2	0.63

* Of metal produced

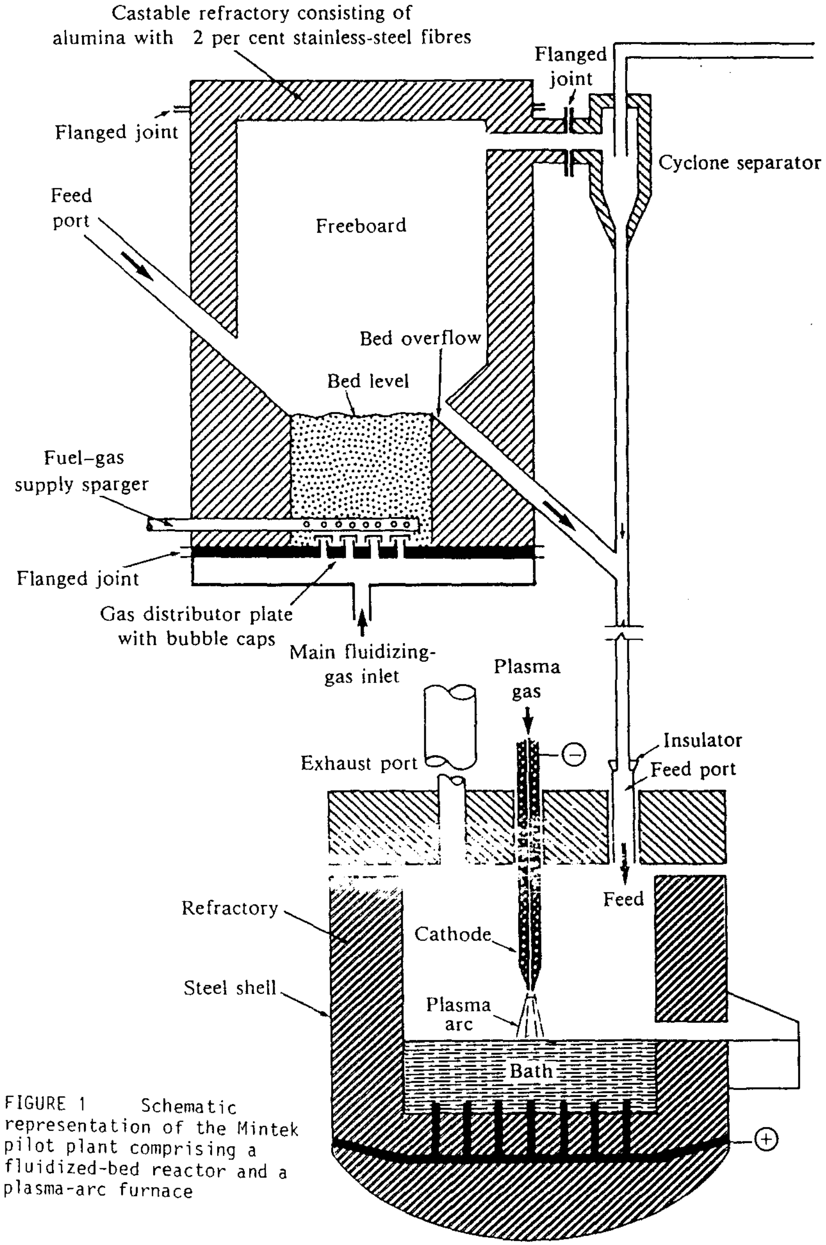

FIGURE 1 Schematic representation of the Mintek pilot plant comprising a fluidized-bed reactor and a plasma-arc furnace