APPLICATION OF PLASMA TO METALLURGICAL PROCESSES

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ABSTRACT

The application of plasma to metallurgical processes is emerging from the infancy of its development. Systematic and carefully planned trials on various potential applications are being done at Tetronics R & D Ltd, Faringdon in conjunction with Foster Wheeler Energy Ltd, Reading. Results to date have been extremely encouraging and the first commercial plant is now within sight.

INTRODUCTION

Many metallurgical processes are performed by heating a large quantity of feedstock or reactants to the temperature at which the required reaction will proceed readily. This is for example done in a slag melt underlying a burden in the submerged arc furnace.

With the introduction of plasma to the pyrometallurgical scene, it is possible to drive rapidly to completion the reaction by utilising the high energy intensity of the plasma. The desired production rate is achieved by a high throughput. There are significant cost and environmental advantages in the applications tried to date.

PLASMA: THE REACTION DRIVING FORCE

Some plasmas are formed by the passage of an electric current through a charged gas stream. An electrical discharge occurs and temperatures of 10,000^{o}C and higher are reached. It is within this plasma discharge that large amounts of energy can be transmitted. By feeding the appropriate mixture of chemical reactants into plasma it is possible to almost instaneously drive a reaction by utilising the very high energy density which the plasma provides.

The ability to achieve and maintain metallurgical reaction zone temperatures in excess of 2000^{o}C allows more efficient routes to complete chemical reactions to be followed. In addition, the reaction kinetics occurring in the plasma may be faster than in other more conventional processes.

The properties of plasma and their potential application to the chemical and metallurgical industries have been known for some time. Until recently, however, widespread application has been prevented by the instability of the plasma and the inability to utilise efficiently the contained energy. With the advent of sophisticated electronic control systems it has been possible to control the plasma instability and successfully utilise plasma as the driving force in metallurgical reactions.

THE TETRONICS PLASMA SYSTEM

The Tetronics Research and Development Co. Limited of Faringdon in Oxfordshire have developed a plasma system for performing chemical and metallurgical processes. It employs a transferred arc direct current plasma which operates between a thoriated tungsten cathode and a counter electrode, usually the melt in the hearth of the furnace. A stabilising plasma gas, such as argon, protects the cathode from rapid erosion. The plasma gun which is mounted in the roof of the furnace (see Fig 1) is precessed by a hydraulic drive so that the plasma arc describes a cone. This ensures the energy is distributed over a large circular area on the surface of the melt known as the reaction zone.

The feedstock to the 1.4 MVA furnace can vary in size from submicron particles up to 24mm diameter. It is transported by screw feeders to the roof entry ports. From there it falls by gravity into the reaction zone. The energy delivered by the plasma gun is partially independendent of the rate of feed and type of feedstock. The feedrate is normally adjusted to balance the power developed by the plasma gun and achieve thermal equilibrium in the furnace structure. With cold and frequently finely divided feedstock falling as a curtain around the plasma, the walls and roof of the furnace are shielded from the arc's radiant heat.

The plasma gun itself is a very compact device, typically a few centimetres in diameter and up to a metre long. The precession motor and the service connections occupy only a small additional space above the gun. Some energy is lost in gun cooling and shell losses but the total is only around 8 per cent of the rated power.

The power to the plasma arc is supplied by a twelve phase thyristor power pack with some smoothing provided by a choke. The arc voltage is dependent on the arc length, the feedrate, feed material characteristics and to a smaller extent on the arc current. A high voltage is chosen to reduce the current required for a given power and consequently to reduce the costs of the copper cabling and switchgear.

The electronic control circuits strive to maintain a constant current whilst the energy demands from the plasma are fluctuating. This is achieved by rapid real-time adjustment of the thyristors by feedback circuitry. The acoustic noise from such a d.c. plasma system is acceptably low and the electrical load seen by the a.c. supply is more balanced than that associated with a 'flickering' a.c. carbon arc furnace.

Perhaps the most significant technological advantage is the high degree of metallurgical control available. Unlike the submerged arc furnace the energy developed is not dependent on the slag composition because the major portion of the energy is released in the reaction zone above the melt. The slag chemistry can therefore be tuned to provide maximum product recovery and minimum refractory wear. Reactions occur in a semi-closed system where the gaseous environment can be controlled. The pressure can be adjusted by varying the offgas suction and the atmosphere can be made oxidising, neutral or reducing to suit the prevailing metallurgical requirements. Because the residual volume of the furnace is small, changes in the reactions or feedstocks are rapidly reflected in the products and process control by regulation of the melt temperature and composition can quickly retune the reaction.

There are a number of economic advantages. First, the electrodes are non-consumable. This removes the very significant cost of prebaked graphite or Söderberg electrodes used in other metallurgical furnaces. There are also savings in capital costs because the prebaked/Söderberg electrodes require bulky mechanical handling equipment and substantial building height to house them. Second, since fine feedstocks down to submicron size are acceptable the need to briquette or pelletise is avoided; the cost savings are in the region of £5-£10 per tonne of feedstock. Third, in smelting processes it is not necessary to use expensive metallurgical coke as a reductant. Any quality coal is acceptable. The plasma can be made stable in the presence of volatiles and coal fines, allowing their use in many instances where they would be economically desirable but technically unusable in other systems.

PLASMA APPLICATIONS

Within the metallurgical industry there are a number of reactions or processes to which plasma could be applied. There are melting processes to recover valuable metals from impure or finely divided metallic feedstocks and there are reduction reactions in which the metallic or elemental product is obtained by reducing the relevant ores.

Only some of the potential applications have been tried by Foster Wheeler and Tetronics at Faringdon. Those that have been tried have been successful with good yields, reasonable energy consumption and reliable performance. Stability of the plasma gun, arc, control and power systems have been proved. One application which is currently being developed at Faringdon is the melting of cast iron chips or borings. There is a large quantity of wet and oily swarf worldwide, produced when iron castings are machined. Using plasma, wet and oily cast iron chips have been successfully melted in a 1.4 MVA furnace. The molten iron reclaimed can be tapped off periodically without interrupting the operation of the plasma power source. The total heat input required is around 500 KWH per tonne of hot iron. The stability of the plasma arc is generally unaffected by the moisture in the feedstock so it is unlikely that drying would be required in a commercial plant.

Advantages are the avoidance of drying and a saving of around £5 per tonne of borings by eliminating the briquetting requirement for conventional furnaces, the very good carbon retention in the hot metal and the relatively clean offgas.

Another excellent plasma application is the smelting of ferrochrome from chromite concentrates. Successful results have been obtained from a series of trials in a 1.4 MVA furnace. The projected energy consumption is lower than for conventional plant and there are profitable savings to be made in the use of coal and chromites fines without expensive agglomeration. Even more significant perhaps is the improved recovery of ferrochrome with low residual Cr_2O_3 in the slag.

Other promising applications of the Tetronics Plasma System are to ferromanganese and ferrosilicon but these are at an early stage in their development.

SCALE-UP

The current state of the art in plasma power at Tetronics is 1.4 MVA. This is the size of the furnace used in trials to melt cast iron borings and produce ferrchrome. No unusual technical problems are expected in scale-up from 1.4 MVA to say 15 MVA with the exception of the plasma gun. In cost terms it seems desirable to avoid multiple gun arrangements. Consequently, development work is being done to uprate the plasma gun by at least an order of magnitude. This can be achieved either by increasing the voltage or the current or both. In a simple view the voltage can be increased by raising the gun and lengthening the arc.

The other way is to increase the current. Recent tests have indicated that the current carrying ability can be substantially increased. A 3 MW gun has been proven and there is a high degree of confidence that 10 MW plus can be achieved.

There are also the inevitable scale-up problems associated with progression from a small experimental plant to a commercial plant. In the laboratory, where short term trials are run, it is acceptable to underdesign, repair equipment failures temporarily and generally get by with equipment performing below par; it is all part of the development process. However, with a commercial plant, down time must be minimal because the production record directly relates to the success of the process.

Scale-up from experimental plant must therefore include a change in philosophy from experimental engineering to sound commercial construction incorporating correctly specified equipment by proven vendors and some degree of redundancy to cope with breakdowns in prime movers, mechanical handling equipment and electrical gear.

THE FUTURE OF PLASMA

The prospects for the future development of plasma arc systems are extremely favourable. The opportunity for the introduction of new technology is always present but never more so than in the current world energy situation. As energy becomes a more scarce resource, the incentive to search for advanced energy efficient and energy flexible metallurgical processes is provided. The Tetronics Plasma System is one such process and there are several ways in which it is more energy efficient:

- it is a smaller tighter system with lower thermal losses than conventional processes
- the product yield is usually greater which improves the energy consumption per tonne of product
- any type of coal can be used as a reductant instead of costly metallurgical coke
- the energy which is used to briquette feedstock fines in conventional processes is saved
- it is flexible as well as efficient; the electricity to operate a plasma plant could be obtained from coal, nuclear, tidal, solar or any other future generation source.

These advantages provide the incentive for the future growth of plasma based metallurgical processing.

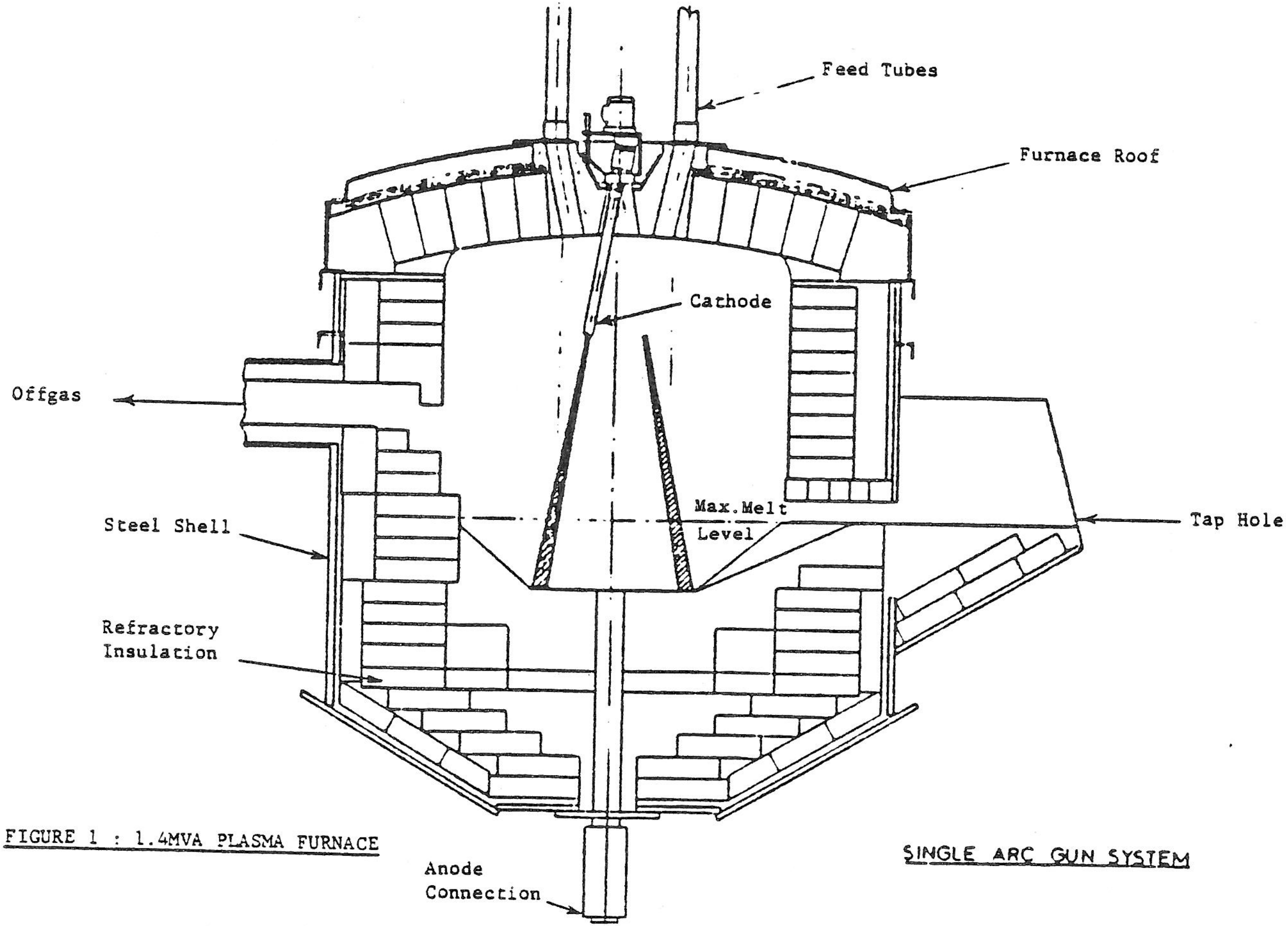

FIGURE 1 : 1.4MVA PLASMA FURNACE

SINGLE ARC GUN SYSTEM