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Thermal plasma process development in Norway

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Abstract. This report describes research and development work on thermal plasma technology applied to extractive metallurgy and high-temperature chemical processing carried out by SINTEF - NTNU in collaboration with major Norwegian companies and the Norwegian Research Council.

INTRODUCTION

In 1987 a thermal plasma research group was established at NTNU - SINTEF with financial support from the Norwegian Research Council (NFR), the ferroalloys industry and other industrial companies. This group has since been engaged in practical *process development* projects as well as *mathematical modelling* work on thermal plasmas including DC transferred and non-transferred arcs and, free-burning low-current AC arcs (100-1000 A) and high-current three-phase AC arcs (~100 kA) - see [1, 2, 3 and 4]. Emphasis has been on the role of the arc as a convective and radiative heat sources for metallurgical and chemical processes and, lately, on the behaviour of the AC arcs as non-linear elements in the electric circuits of three-phase industrial furnaces.

The present paper will focus on the process development activities.

IMMERSED PLASMA LANCE

In this plasma device for heating liquid metals, which actually emerged already in the late 1970-ies, a DC arc burns radially between an outer tubular electrode and a central graphite rod electrode. A gas stream expells the metallic melt from the annular inter-electrode space so that short-circuiting is avoided. Originally, the "normal" polarity with a cathodic rod electrode was used. It turned out, however, that the electric instability due to upstream penetration of metal droplets into the discharge region between the electrodes was greately reduced when the polarity was reversed. Immersed operation with the arc (actually several sub-arcs in parallel) burning 0.5-1 m below the surface of the liquid metal was successfully obtained. Two industrial MW-sized units were tested in ferrosilicon contained in 3 cbm ladles [5].

The main problem hampering commercial use of the immersed plasma lance was to find a suitable graphite quality able to withstand the extreme thermal tensions caused by the arcs. In the steel works the problem is to design a water or preferably oil-cooled tube electrode for prolonged immersed operation in liquid steel.

THE PRESS REACTOR

The test facility PRESS shown in Fig. 1 includes a multi-purpose reactor with one or three plasma torches, and three separate DC power supplies (each with a current capacity of 500 A and a max. voltage of 300 V). An extensive experimental program has been run in the PRESS reactor [5]. Some examples are given here:

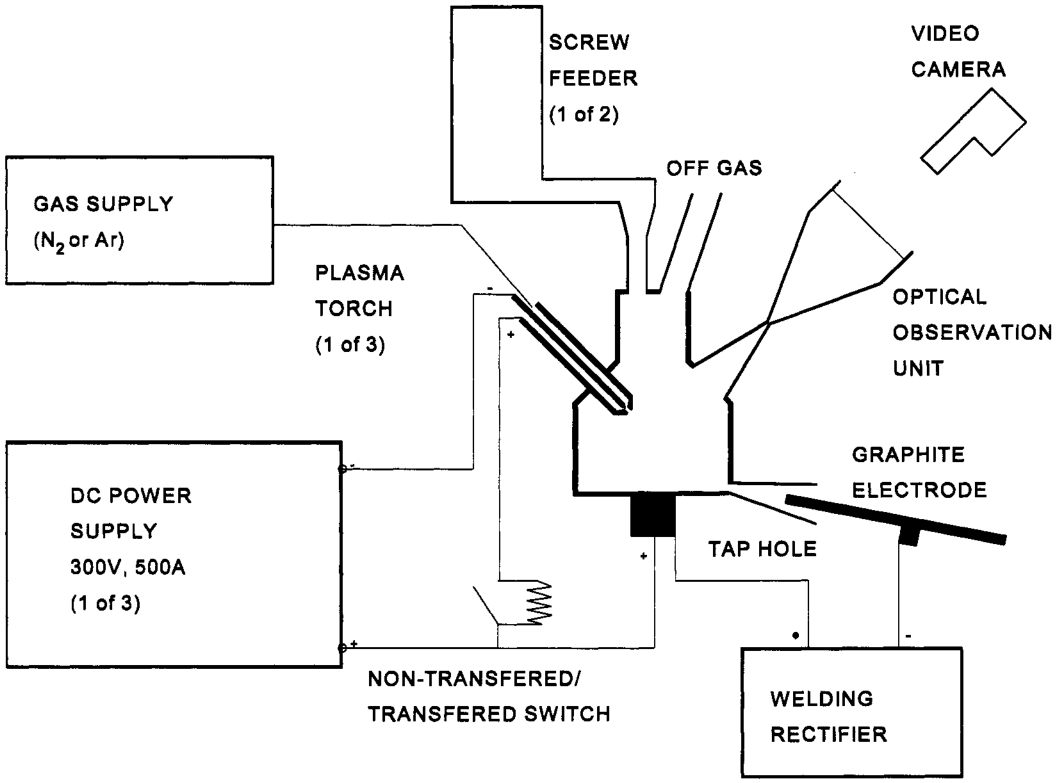

Fig. 1 PRESS plasma reactor facility at SINTEF

REMELTING OF SILICON METAL FINES

Fines of silicon metal has been remelted in the PRESS reactor. The remelting capacity during continuous operation was 93 kg/h and the specific energy consumption 1.7 kWh/kg fines. The loss of fine particles through the off-gas duct was insignificant. A refining effect was achieved without additions of refining agents during the remelting: the contents of aluminium and calcium were substantially reduced [5].

ULTRAFINE SILICA PARTICLES

have been produced by feeding metallurgical grade silicon metal and SiO_2 as quartz sand into a special version of the PRESS reactor. The SiO-gas formed on the surface of the silicon metal bath by the strongly endothermic reaction

$$Si_l + SiO_{2l} \rightarrow 2SiO_g$$

was oxidized to SiO_2 and quenched by a large surplus of cold air with small additions of water in a combustion chamber. The "Nanosilica" powder collected in the filter bags had a specific surface area of 250 m^2/g, high purity: > 99.6% and high reflectivity: > 90% [5].

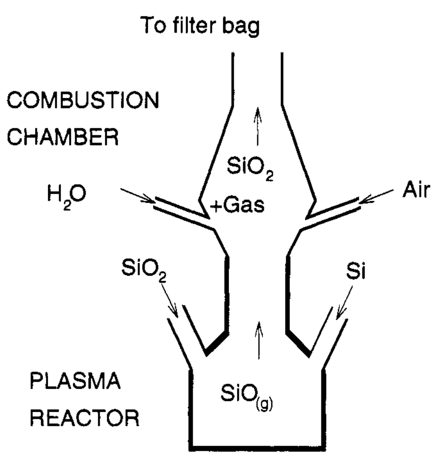

Fig. 2 Plasma reactor for production of ultrafine silica.

THREE-STEP PROCESS FOR SILICON METAL

A novel process for production of silicon metal from quartz (e.g. sand) and coke has been partly developed based on experiments in the PRESS reactor. The three process steps are shown diagramatically in Fig. 3. All the SiO_2 consumed by the process is fed to the highly endothermic Step 1, where the transferred DC arcs(s) supply the heat. To maintain the required temperature level of 2000°C in the metal producing Step 2 appoximately 16 % of the total electric energy must be added here. All the carbon is added in Step 3. Theoretically, the specific energy consumption is 9.3 kWh / kg silicon metal by a silicon yield of 97 % [5]. The overall reaction is $SiO_{2l} + 2C_s \rightarrow Si_l + 2CO_g$.

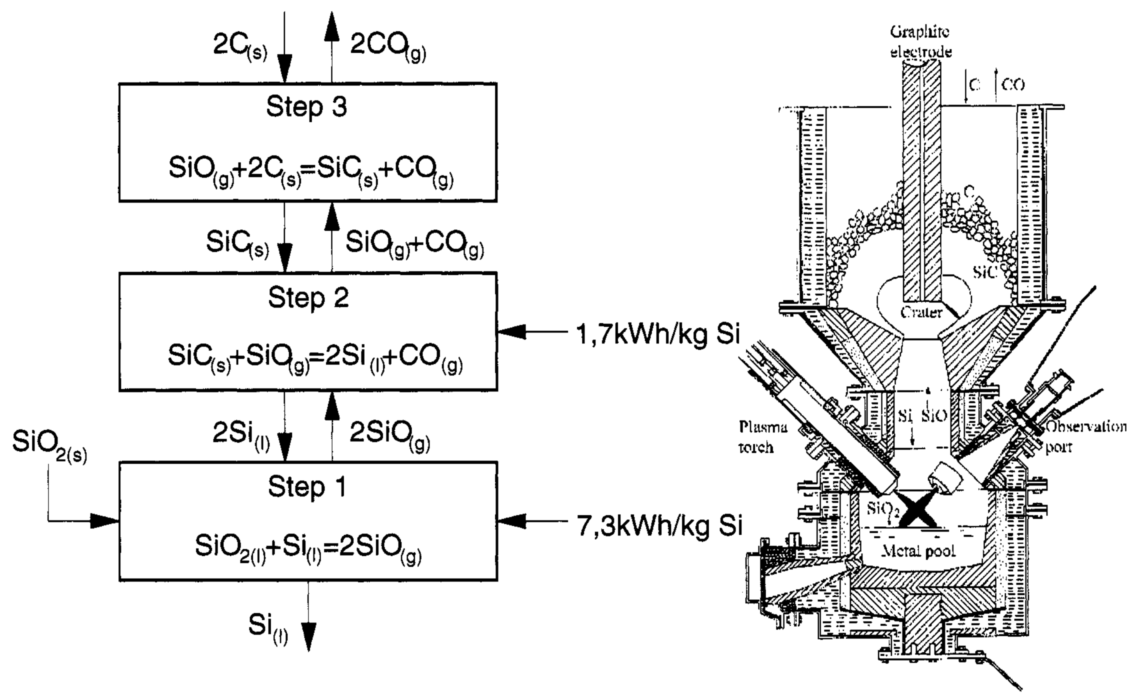

Fig. 3 Three-step plasma process for silicon metal production.

CARBON BLACK AND HYDROGEN

Another important plasma activity at SINTEF - in close collaboration with Kvaerner Engineering - has been the successful development of a new process for Carbon Black and hydrogen. These two elements are in great demand in the market in their purified forms. Carbon Black is widely used in vehicle tyres, paints, vanishes, toners and as additives in the metallurgical industry. Today, the main consumers of hydrogen are the ammonia producers. Hydrogen is also regarded as the energy carrier of the future.

The process, which decomposes hydrocarbons directly into carbon and hydrogen, is based on a specially designed version of SINTEF's plasma torch with coaxial graphite electrodes. It functions well on several types of non-oxidizing plasma gas such as pure H_2, CO, Ar and N_2. To ensure uniform heating of the feedstock and the plasma gas, the arc discharge is rotated at a predetermined speed by means of an applied DC magnetic field generated by a coil on the outside of the graphite lined and carbon black isolated reactor [6].

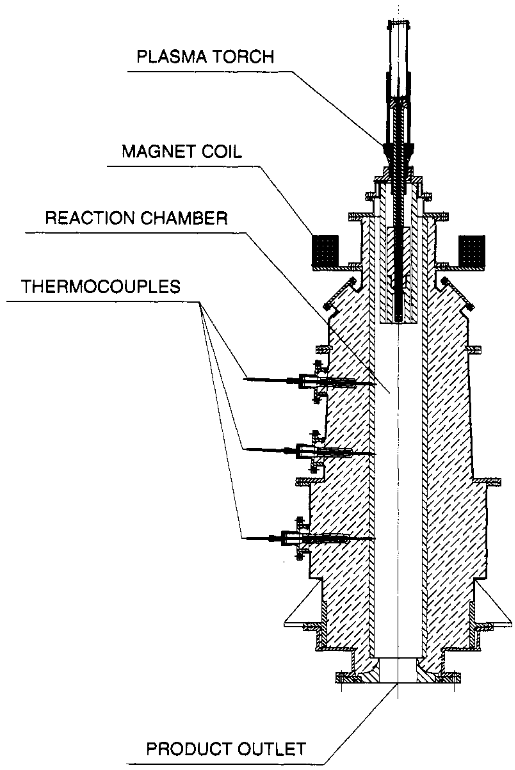

Fig. 5 Plasma reactor for carbon black and hydrogen.

An auxilliary magnet coil is installed to ensure that the arc burns at the front end of the electrodes.The rotation of the arc is an important factor controlling the energy density distribution and to ensure a low consumption of electrode carbon. Numerical modelling of the flow field has been used to optimize the design. SINTEF is currently using a 150 kW laboratory torch, which has been further developed by Kvaerner into a 6 MW industrial-scale unit.

A wide range of traditional as well as new qualities of Carbon Black can be produced by varying the process parameters, i.e. the plasma gas flow rate and temperature, the feedstock flow rates and temperature, and the location and number of feedstock injection points. As an example, the rare fullerenes (conical and tube shaped graphitic molecules) have been produced [7]. The impurity content is on the ppm level as the only source of impurities is the feedstock [8].

In addition to being very energy efficient, this process utilizes 100% of the raw materials which can be almost any kind of liquid or gaseous hydrocarbons. Compared to traditional production methods for Carbon Black and hydrogen, the new process does not emit CO_2 or NO_x.

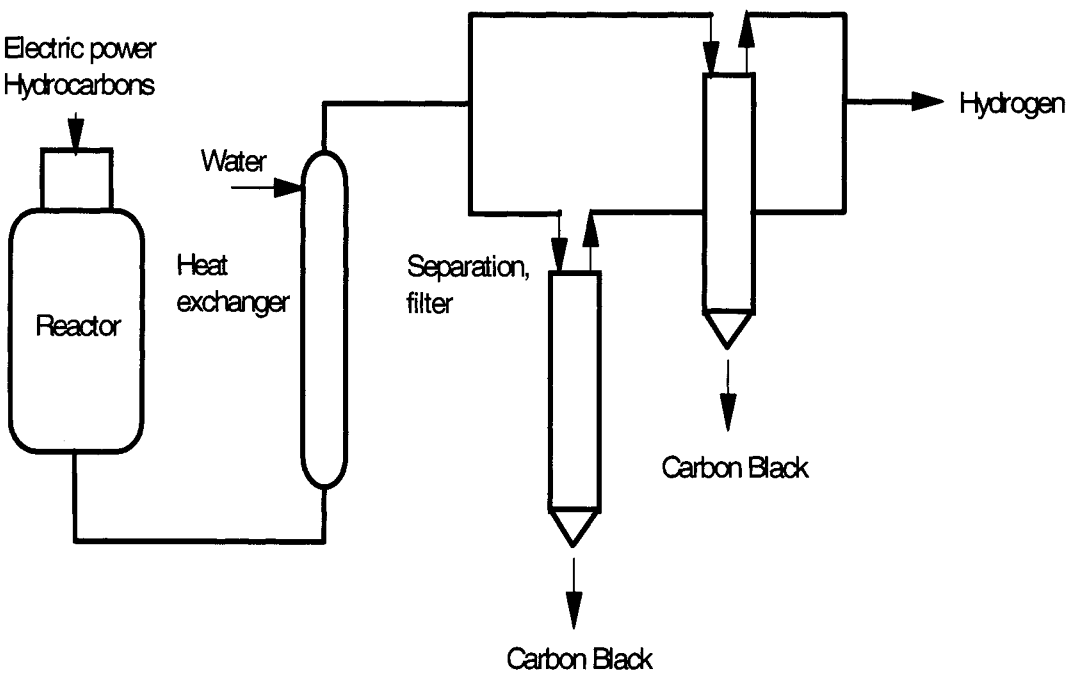

Fig. 6 Flow sheet for Kvaerner's plasma process for Carbon Black and hydrogen.

An extensive test program has been carried out both in pilot scale with the 150 kW torch in SINTEF's laboratory and, since 1992, in an industrial-scale pilot plant with the 3 MW unit. The process is now ready for commercialization. The construction of an industrial plant will start this year in Canada.

Table 1 Expected characteristics of a 10 MW industrial plasma torch.

Characteristics	Data
Output power per torch	appr. 10 MW
Thermal efficiency	95 - 99%
Electrode material	graphite
Electrode consumption	less than 0.1 g/kWh
Plasma gas	Hydrogen recirculated from the process
Enthalpy, plasma gas	2 - 20 kWh/Nm^3

PLASMA ROTARY FURNACE

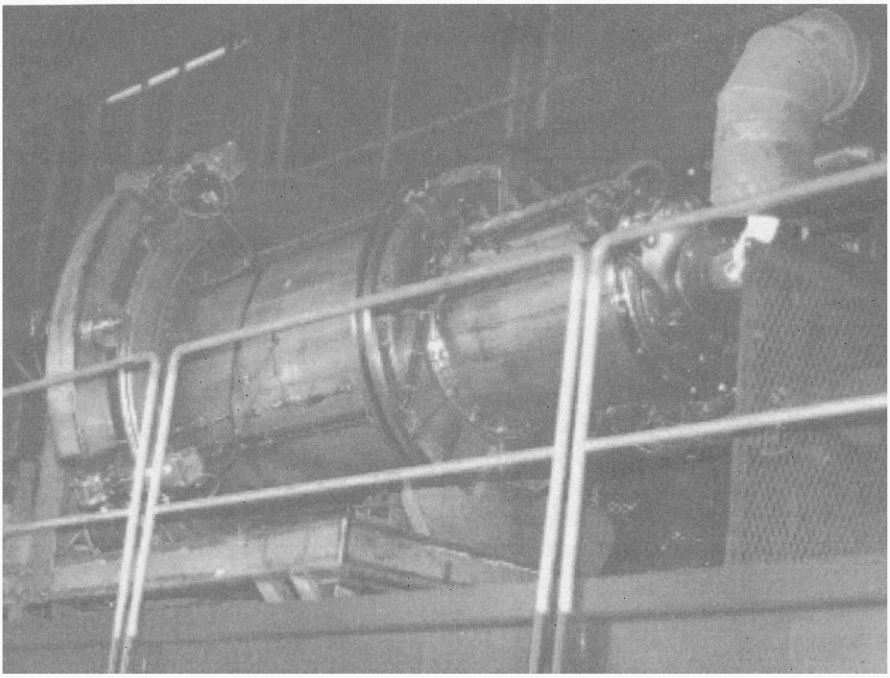

Fig. 7 Plasma rotary furnace in SINTEF's laboratory.

A rotary furnace (2.75 m long x 1.0 m dia.) with a graphite inner lining is located at SINTEF's laboratory in Trondheim. This furnace is suited for processing or heat treatment of solid materials at elevated temperatures up to 2000°C in reducing or inert atmosphere. Patents have been applied for. The heat source is also in this case a special version of SINTEF's graphite plasma torch. The torch rotates with the furnace and the rotational velocity can be varied.

The temperature distribution in the furnace lining and the cooling water temperatures are measured and recorded with a data logger which also rotates with the furnace. The measured values are transmitted via radio signals to a PC in the control room. An external DC magnet coil provides a smooth rotation of the arc between the inner rod electrode and the outer tube electrode. The graphite consumption of the central electrode is acceptable: 0.22-0.25 g/kWh. The outer electrode consumption increases to 0.4 g/kWh at high arc currents. The operating power is 200 kW at an arc voltage of 200 V. The plasma torch has been run continuously for several days without any problems.

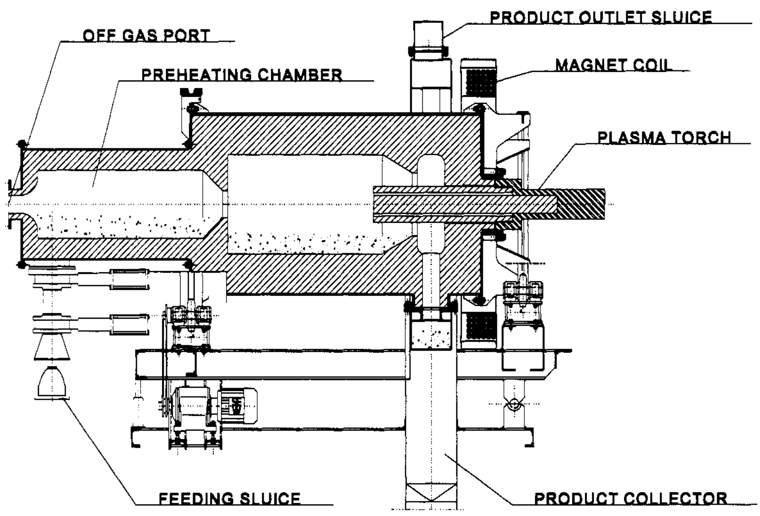

Fig. 8 Plasma rotary furnace.

The charge materials are fed through a sluice into a preheating chamber from which they move counter-current with the off-gas into the main reaction chamber. On it's way out, the processed materials pass an outlet chamber and are cooled down in a water-cooled ring chamber before they are discharged through the outlet sluice. A better utilisation of the off-gas heat content was achieved after installing the preheating chamber. The inlet sluice provides a very smooth introduction of the feed into the furnace, minimizing the loss of dust to the off-gas. The outlet sluice effectively prevents the previously occuring small explosions during discharging, when air could penetrate into the furnace and react with hydrogen and CO.

Several high-temperature synthesis and heat treatment applications of the plasma rotary furnace have been tested with good results. A great advantage of this reactor from an environmental point of view is that it is fully enclosed and the emission of harmful gases as SO_2 can easily be controlled.

CONCLUSION

The plasma process development activities at SINTEF suported by mathematical modelling work at NTNU have established knowledge and experience with new environmentally friendly technology. A graphite plasma torch invented at SINTEF in the late 1970-ies and first used as an immersed plasma lance, is proving to be a robust and energy efficient heat source under reducing and inert atmosphere conditions. The graphite plasma torch is now ready for commercialization in Kvaerner's plasma process for Carbon Black and hydrogen. A recently developed plasma rotary furnace is also expected to be commercialized.

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