NEW DESIGN OF REDUCTION PLASMA FURNACES INCLUDING THE ELECTRICAL TRANSFER TO THE BATH AND THE FALLING FILM

B. Pateyron, J. Aubreton, F. Kassabji, P. Fauchais
Université de Limoges - Laboratoire de Thermodynamique
123 avenue Albert Thomas - 87060 Limoges Cédex - France

ABSTRACT

We present here the realized adjustments to improve the technology of an extractive metallurgy process by plasma and the results obtained for different reactor configuration.
We designed a compound-reactor to benefit by the important reactive surface of the liquid film and the efficient heating of the bath by the anodic fall.

1. INTRODUCTION

Since 1977, the thermodynamic laboratory of Limoges University carries out the realization and the achievment of a 0.7 MW plasma furnace for extractive metallurgy operations.
We have presented this realization at the IV^{e} International Symposium of Plasma Chemistry in Zurich (1), with the first results obtained. Since this time we have continued the development and the modification of our reactor conception, its powder feeding and its working. We present here these modifications and the progress in our project.

2. OPTIMAL WORKING CONDITIONS OF PLASMA REACTORS

The brief plasma reactor theory that we presented in 1979 at Zurich (1) and in 1981 (2) in a summary paper of our first results on a power plasma reactor allows us to define the optimal working conditions for a plasma reactor in extractive metallurgy :

a) a limited radiation loss because of the high wall temperature reactor,
b) a uniform temperature of gas in the arc column giving to all the injected particles the same treatment,
c) a relatively low flow providing a maximum time of reaction ; however it is impossible to reach the necessary time to a complete chemical treatment. That means that the treatment has to be achieved in a heated crucible maintained at high temperature by the plasma gases,
d) the use of the anodic energy transfer by arc attachment on the liquid film (3, 4) or on the bath with the electrode in the crucible (5),
e) an optimization of powder injection.

3. THE FIRST LIMOGES PILOT UNIT AND ITS RESULTS

Based on these optimal conditions and some orientation experiments we have chosen a liquid film and long arc reactor conception. This long arc allows us to increase the residence time of the matter in the plasma, in order to melt the particles when they reach the wall. These particles initiate easily the liquid film and allow the arc attachment on it. The reduction reaction starting on the film will be completed in the crucible.

We have presented (1) the results of this reactor, especially those concerning the evolution of the degree of electrical conversion with gas enthalpy reaching 95 % at 0.8 MW. We have also demonstrated that the arc characteristic was entirely guided by the gas flow (2).

3.1. The influence on the arc characteristics

The voltage is independent from the intensity in our reactor when it works without powder injection. The introduction of a great quantity of powder (∿ 140 kg/h) leads to an important decrease of the mean plasma temperature, therefore a decrease of the electrical conductibility, then, for a constant intensity and arc length, an increase of the electrical field E and the voltage V.

Experimentally, and taking into considerations the arc instabilities, the voltage (so E) stays invariable ; that means that the electrical conductibity $\bar{\sigma}_o$ stays constant in spite of the decrease of the temperature. We explain this result by the presence of metallic vapors in the plasma. However the maximum metallurgical efficiency can be reached by a continuous control of the powder flow.

Following these experiments we have designed another reactor and another powder supplying unit.

4. THE NEW LIMOGES REACTOR WITH ITS PULVERULENT SUPPLYING

4.1. The reactor

We have maintained the main positive facts appearing in the precedent project :

- the long arc,
- the treated material as anode,
- the pulverulent mode of reactor alimentation.

The figure 1 presents the realized reactor. It is constituted by :

- a reaction chamber or crucible keeping the treated material in a liquid bath ; the electrode in the bottom of the crucible provides the electrical contact,
- a plunging electrode or cathode ; it is the gas sheathing cathode of the first reactor inserted in a protection tube. The space between the exterior tube and the cathode allows the reactor to be supplied with the pulverulent materials.

4.2. The powder supplying

To maintain a steady powder flow without perturbations by the counter-pressure generated in the reactor particularly by the acoustical conditions, we design a powder supplying (figure 2) based on the principle of elutriation with the powder removed from the core of a fluidised bed. The fluidised gases are used to dilute the powder suspension and to contribute to the pneumatical transport of matter.

5. COMPARISON OF WORKING CONDITIONS IN THE LIQUID FILM REACTOR AND THE BATH ELECTRODE REACTOR

It is important to note that the new reactor allows us to obtain characteristic results at powers (100 to 300 kW) less than those used previously in the liquid film. We have here a very efficient energy transfer between plasma and particles. The gas flow in the electrode still governs the arc characteristics but its influence stays less sensible than in the case of liquid film. Inversely, the relative position cathode-anode in this new configuration has a great importance. The figure 3 shows that the thermal efficiency of the reactor is superior to 75 %. It means that a value higher than 75 % (even 80 %) of the electrical energy is actually tranferred to the material. The total residual enthalpy of exit reactor gases is considered less than their combustion heat. We have indicated (1) that in case of liquid film the conversion of the electrical energy into gas enthalpy is about 95 % but the transferred energy to the treated material is only 20 %. Therefore we have here two very performant configuration types : the first one is used to heat reactive gases, the other one to heat materials for direct metallurgy. Consequently, we obtain from this excellent power transfer a local surface superheating of the bath in the anodic region, with an internal evaporation of matter. It seams that this region of the metallic ionised vapors creates a diffuse arc attachment on surfaces of about some cm^2. The visual observation shows the erratic displacement of this arc which is function of the state of the bath surface : new materials supply, quantity of non-reduced slag, liquid bath convection, gas bubble explosion on the surface etc...

6. METALLURGICAL RESULTS

We don't come back on the metallurgical results obtained in the liquid film reactor (2), however we mention that we obtained a very bad separation between the reduced metal and the oxide to reduce ; it means either a micro-dispersion of oxide in a metallic matrix (case of iron), or an emulsion of metallic nodules (1 μm to 3 cm) in the oxide (case of chromite).
With the bath anode reactor (BARP) we obtain a perfect separation of the metal from the non reduced oxide. This slag is easily increased by the crucible refractory.

6.1. General operation conditions in the bath electrodes furnace

The material is introduced in the reactor without any preheating. The only time necessary is needed to assure the natural sequence to start up the furnace. We carry out a low power of ab ut 90 kW to 300 kW as we have mentioned previously.
We work preferentially with a thin coke layer dispersed on the anode, in order to protect it in the bottom of the crucible and to assure the electric continuity with the cold material in the begining of the experiment. Indeed, this layer participates somewhat to the reduction reaction, but it allows us to decrease our gas flow as well as the electric power (§ 5).

6.2. Iron ore reduction

We obtain 7 to 15 kg of metal for a working time of about 30 to 60 min., with an electric power of 90 to 100 kW and a hydrogen gas flow of 200 Nl/min. This reduction is accompanied by an important powder vaporisation. The efficiency of the operation is about 4.5 to 5 kWh/kg of iron. The product are characterised by 0.7 % of silicium and 0.75 % of phosphor.

6.3. Chromite reduction

The experimental conditions are : a hydrogen flow of 300 Nl/h, an electrical power of about 110 kW during 30 mn, 15 kg of ore, 3 kg of carbon. We recover 3.8 kg of metal having this elementary analysis :

Cr = 73.31 %	Fe = 26.29 %
Si = 0.29 %	Ca = 0.11 %

The spectrum in the Guinier camera indicates a composite having a $M_{23}C_6$ type (M = Cr/Fe). This reduction is accompanied by an important material evaporation followed by a recondensation on the cold walls :

- a condensation on the external tube of the cathode where a some millimeters thickness of metallic film forms a deposit having the following analysis :

Cr = 31.35 %	Fe = 62.34 %	
Si = 1.89 %	S = 4.03 %	(from coke)

- in the end of the experiment and at the exit gas tube, a deposit matter formation obstructs almost all the way. This complex deposit contains metallic nodules having this following analysis :

Cr = 29 %	Fe = 67.71 %
Si = 0.54 %	S = 2.25 %

whereas the conglomerate is constituted in its oxide form by :

Cr = 35.24 % Fe = 29.76 %

Mg = 14.42 % Si = 12.81 %

Al = 3.8 %

It appears clearly that we obtain a selective evaporation between the iron and the other elements with the exclusion of the chromium which stays in its carbide form.

CONCLUSION

The chromite reduction with hydrogen only is not possible as it is for iron ore. The obtained results show that in this type of metallurgical process at high temperature it is absolutely necessary to considerate the evaporated material. Therefore we propose to take advantage of the high thermal gradient in the plasma reactor between the anode bathand the cold walls in order to create a liquid film of recondensed and chemically treated matter (figure 4). Finally, in the case of ferrochronium, it is desirable to continue the material treatment beyond the carbide phase, it can be reached at high temperature and with a partial pressure of co-reduced material (6). We intend to realise it by an argon or hydrogen injection in the liquid bath.

REFERENCES

(1) F. Kassabji, B. Pateyron, J. Aubreton, P. Fauchais, J. Amouroux, D. Morvan, IUPAC, Zurich1979, proceedings.

(2) F. Kassabji, B. Pateyron, J. Aubreton, P. Fauchais, M. Boulos, Conception d'un four à plasma de 0,7 MW pour la réduction des oxydes de fer, Rev. Int Hautes Temp. et Réfract. (accepted).

(3) R.G. Gold and alii, IUPAC, Odeillo, 1975, proceeding.

(4) D.R. Mac Rae and alii, IUPAC, Limoges, 1977, proceeding.

(5) T. Eujiwara, R. Yamaguchi, Int. Inclus. Seminar on Pilot Plant Experiences. Seabrook Island, 1980, South Carolina, USA.

(6) W.L. Worrell, Met. Trans., 233, 1965, 1173.

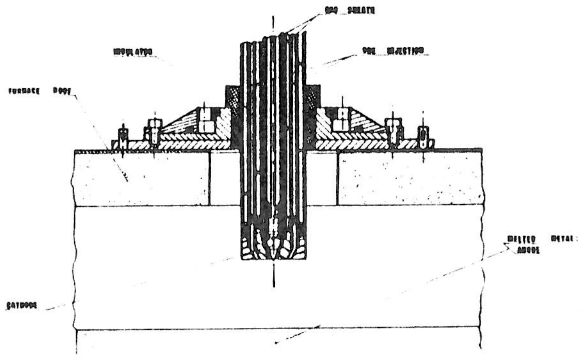

Fig. 1 - Plasma Reactor

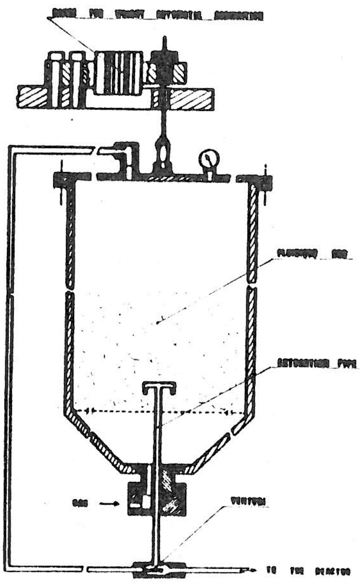

Fig. 2 - Powder feeder

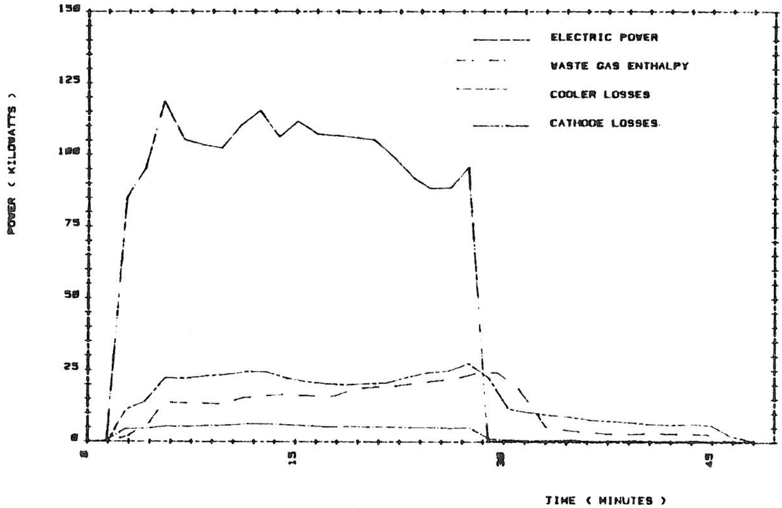

Fig.3 - Reactor thermal efficiency

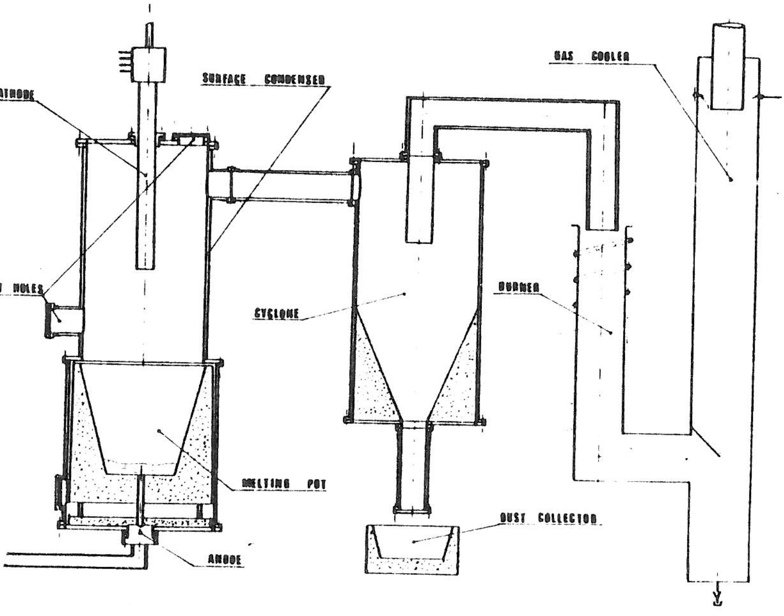

Fig.4 - New design of plasma reactor