SPHEROIDISATION OF ALUMINO-SILICATE PARTICLES IN A THREE PHASE A.C. PLASMA FURNACE

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Keywords : Three phase plasma, spheroidisation.

Compounds : Alumino-Silicate.

ABSTRACT.

The economic feasibility of spheroidising high-alumina fired clay particles in a three phase a.c. plasma furnace (nominally 100 kW) was investigated. The furnace is described, especially the sheathed electrodes and the particle introduction. Depending on the particle grain size, up to 16 kgh^{-1} could be successfully processed.

1. INTRODUCTION.

Spheroidisation of refractory material is generally understood as an important application of thermal plasma technology. Proposals were made to use spherical material generally as refractories, or more specially for thixotropic liquids, for electrostatic copying processes, shot-peening or as proppants. Magnetite spheroidisation has been largely investigated /1/, /2/. /3/ and /4/ describe plasma spheroidisation of various metals, oxides and carbides.
We have reported spheroidisation of natural sand for production of vitrified silica /5/. The present study continues this preliminary work. Our aim is to understand better the multiple interactions between plasma flow and particles in order to optimize plasma processing of particles and thus to show its technical as well as its economical feasibility.

2. THE PLASMA FURNACE.

The main purpose of the furnace design is simplicity. A three phase a.c. arc is struck between sheathed electrodes ; the sheath gas (air, or a mixture of nitrogen and oxygen) blows the hot plasma gas into the furnace vessel where the particle treatment occurs.
Fig. 1 shows a simplified scheme :
- a particle feeder and injector (see 3),
- 3 electrodes, connected via current-limiting inductances and a transformer (open voltage up to 760 V phase to phase) to the mains (380 V, 50 Hz),
- a d.c. plasma gun for ignition of the main arc,
- the water-cooled vessel (stainless steel) which contains the plasma flow and consists of 2 cylindrical modules, an electrode-carrying top and conical fitting modules ; some

windows allow various observations,

- a unit for particle collection and gas exhaust to a fan.

The semi-consumable, water-cooled electrode tip (Fig.2-1) is made of electrolytic copper and is easy and cheap to replace. The sheathing-cone (Fig.2-2), made of stainless steel and electrically insulated, leads the plasma gas evenly along the electrode tip through a conical slit (width about 1 mm). This gas stabilises the first few centimeters of the arc and prevents arcing from taking place at the side of the electrodes. The distance between electrodes is greatly reduced during the ignition phase by the action of air-jacks and is adjustable in order to control the arc voltage.

3. THE PARTICLES AND THEIR INJECTION.

The material to be processed is commercial grade "chamotte" (natural clay fired at 1300°C and ground). Its composition, in weight %, is :
40-42 % Al_2O_3 ; 53,5-55,5 % SiO_2 ; 1,7 % Fe_2O_3 ; 1,6 % TiO_2 ; 0,2 % K_2O ; 0,1 % Na_2O_2 ; 0,2 % CaO ; 0,1 % MgO.
Table 1 shows the grain size distribution.
The requirements on particle feeding depend upon the characteristics of plasma, particles and kind of treatment. In our case, the plasma is slow (1 - 10 ms^{-1}) and rather large, the particles have to be melted quite thoroughly. The two main requirements are :

- low initial particle velocity (to increase the residence time),
- homogeneous dilution of the particles in the entrance section of the plasma (to make maximum use of the plasma power).

These conditions have best been met by the following arrangement : A worm type feeder delivers the particles at a rate of 5-50 kg h^{-1} on the top of a fluidised bed (100 mm dia, height about 100 mm, gas flow rate about 10^{-3} stp m^3s^{-1}). This bed is continuously discharged through 8 horizontal holes (dia 2 mm) into the vertical injection tube (30 mm inner dia), which is coaxial to the vessel and water-cooled at its lower end which reaches about 50 mm into the vessel.

4. MEASUREMENTS AND RESULTS.

The electrode erosion has been measured by weighing after various runs of particle treatment (table 4). For cheap operation, air is used as plasma gas, directly from a compressor, but we made several runs with mixtures of nitrogen with oxygen (or air). The lack of oxygen leads in our case to violent erosion with pronounced craters. We think about two possible explanations for this phenomenon : metastable oxygen species may help in re-igniting the arc after current zero, and/or the presence of a sufficient oxide layer is necessary for low erosion /6/. The lowest erosion rate occurs with nitrogen plus about 1 % oxygen.

The electric parameters (rms phase to phase voltages and phase currents) are continuously recorded by a data acquisition unit which computes as well the average electric power. A storage oscilloscope indicates the instantaneous values and displays the instantaneous power obtained by analogue multiplication. Voltage is non-sinusoidal, both voltage and current exhibit fluctuations the amplitude of which depends upon the time scale considered and the presence of particles (Table 2).

The power losses are continuously recorded by the data acquisition unit (i.e. the temperature differences in the cooling water circuits are measured, the water flow rates being kept constant).. The particles alter the thermal balance (probably through radiation) and lower the exhaust enthalpy.

The rate of successfully treated particles is calculated from the particle feed rate times treatment efficiency, which is determined on particle samples. Two criteria are used :

- content of vitrified material (by X-ray analysis)
- percentage of spherical particles (with a vibrating table).

The requirements from the potential users of the particles are neither sphericity nor vitrification, but a pore-free surface. Both above mentioned criteria are too stringent, specially the sphericity.

For sensible comparison, the treatment efficiency is shown (Fig. 3) versus specific energy consumption (available power at the entry of the vessel divided by the rate of injected particles). We noticed that an important dispersion in grain size lowers the efficiency. This and the results obtained are reasonably confirmed by a one-dimensional numerical model which will be reported later.

5. CONCLUSIONS.

The performances are shown in Table 4. The process efficiency is fair, but for economical application, the relative costs have still to be divided by a factor of about 3.

REFERENCES.

(1) M.G. FEY, C.B. WOLF, F.J. HARVEY, International Round Table on Study and Applications of Transport Phenomena in Thermal Plasmas, Odeillo, 12-16 September 1975.

(2) P.H. DUNDAS, International Round Table on Study and Applications of Transport Phenomena in Thermal Plasmas, Odeillo 12-16 September 1975.

(3) B. WALDIE, The Chemical Engineer, n° 259, 92, (1972).

(4) N.N. RYKALIN, I.U.P.A.C., Plasma Chemistry 2, Pergamon Press, 1976, p. 179.

(5) C. BONET, G. VALLBONA, M. FOEX, Bull.Soc.Fse.Ceram, 94, p. 27-34 (1972).

(6) A.E. GUILE, A.H. HITCHCOCK, J.Appl.Phys. 49, 4275 (1978).

Table 1 - Grain size distribution of two classes of particles to be treated (Mass percentage).

diameter (µm)	class A called "100-200 µm"	class B called "200-315 µm"
d < 50	6	0,5
50 < d < 100	41	7
100 < d < 200	49	40
200 < d < 315	4	52,5

Table 2 - Range of electric fluctuations.

Time Scale	Quantity	Standard Deviation
instantaneous	power amplitude	30 % approx.
1 second	current without particles	1 - 4 %
	current with particles	0,5 - 2,5 %
	voltage without particles	4 - 8 %
	voltage with particles	5 - 10 %
20 seconds	power	1,5 %

Table 3 - Typical calorimetric power balance (power losses relative to input power, %).

	without	with particles
3 electrodes	8,3	8,6
Top of furnace	8,3	10,7
Upper cylinder	29,9	35,8
Lower cylinder	19,2	18,3
Exhaust unit	14,7	10,7
Remainder (exhaust gas + particles)	19,6	15,9

Table 4 - Synopsis of performances.

Power	Input 95-130 kW	Available at reactor vessel entry 70 - 100 kW	
Gas flow rate (air or mixture of N_2 + O_2)		7,5 - 16 stp m^3h^{-1}	
Electrode erosion rate	in air $90-140.10^{-6}Cg^{-1}$	in N_2 + 1,5 % O_2 $35-65.10^{-6}Cg^{-1}$	
Electrode tip life time	0,5 h	1,5 h	
particle grain size	50<d<100µm	100<d<200µm	200<d<315 µm
max feed rate	20 kgh^{-1}	15 kgh^{-1}	10 kgh^{-1}
successfully treated particles : - vitrified	16 kgh^{-1}	13,8 kgh^{-1}	-
- spheroidised	-	11 kgh^{-1}	9 kgh^{-1}

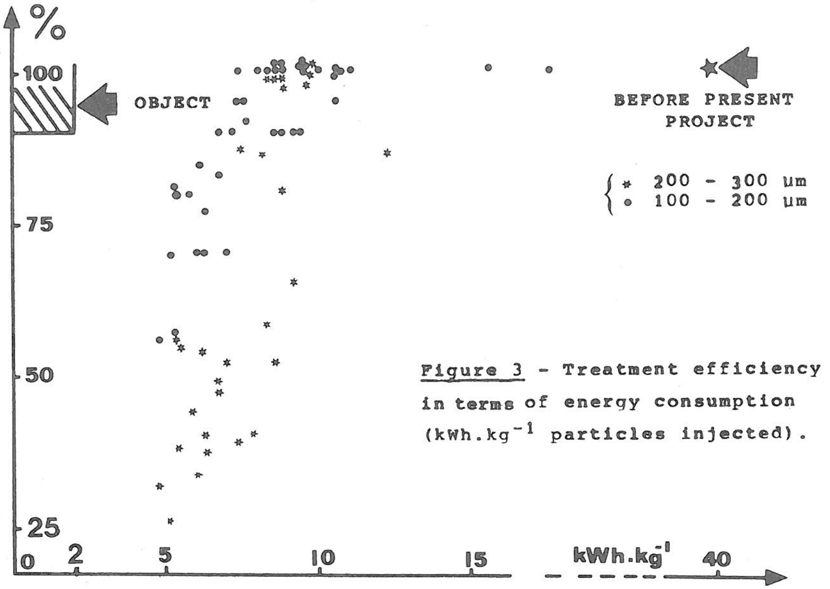

Figure 3 - **Treatment efficiency in terms of energy consumption ($kWh.kg^{-1}$ particles injected).**

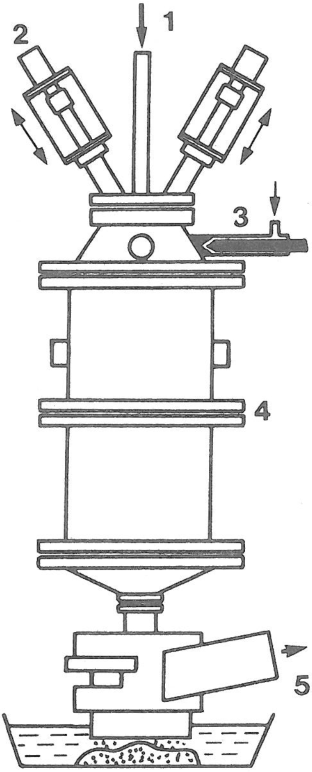

Figure 1 - Scheme of the plasma furnace, 1 : particle injector ; 2 ; three electrodes with air-jacks ; 3 : d.c. plasma-gun for arc ignition ;
4 : water-cooled vessel assembly ;
5 : unit for particle collection and hot gas exhaust.

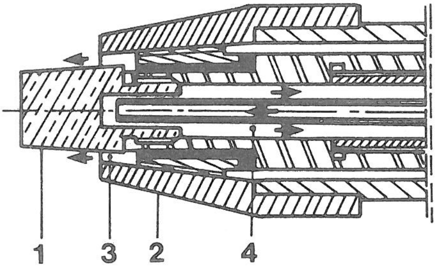

Figure 2 - Scheme of the electrode.
1 : water-cooled copper tip ;
2 : insulated sheathing cone ;
3 : conical slit for gas sheathing ;
4 : water-cooling.

ACKNOWLEDGEMENT.

The financial support of Electricity of France and Argiles et Minéraux to carry out the present research, is gratefully acknowledged.