THERMAL PLASMA TECHNOLOGY FOR PROCESSING OF REFRACTORY MATERIALS

C. BONET,

Laboratoire des Ultra-Réfractaires, C.N.R.S.
B.P. n° 5 - ODEILLO - 66120 - FONT-ROMEU (France).

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Extended abstract :

In the applications which will be considered, one reactant at least is a condensed phase, generally introduced as a solid into the plasma furnace. Energy E is supplied to the condensed phase through various mechanisms (namely by conduction, convection and radiation) ; it represents the integral of the net local power transferred, over time τ which is the residence time of the charge in the plasma zone.

$$(1) \quad E = \int_0^\tau q(M)dt$$

For a particulate feedstock, the expression of E by unit mass is the following :

$$(2) \quad E = \frac{6}{\rho d} \int_0^\tau \left[\frac{Nu}{d} \int_{T_s}^{T_p} K dT + \sigma \varepsilon (T_o^4 - T_s^4)\right] dt$$

Respective terms in the integral represent i) heat supplied by conduction and convection, between respective temperatures T_p of the plasma flow far from the particle, and T_s at the surface of the particle ii) net radiation flux exchanged between the particle and the wall at T_o.
Emittance of the particle of diameter d is ε ; density of the material if ρ.
K is the thermal conductivity of the plasma, and Nu the parameter for heat exchange.
Radiative interaction between the particles is neglected.
Let P be the total power available, and $\dot{m}$ the flow-rate of material entering the furnace. In any case :

$$(3) \quad E < \frac{P}{\dot{m}}$$

Feasibility of the process is demonstrated when E is more than the theoretical value : E_t.
Energetic feasibility of the process is demonstrated when $P/\dot{m}$ is less than a critical value E_c, based upon economic considerations.
Previous requirements are usually interprated during experiments as following : with $\frac{P}{\dot{m}} < E_c$, increase E so that $E > E_t$.
So the simple question is now, what type of plasma furnace is the most suitable for a given process ?
Examination of equation (2) leads to the analysis of various operating parameters and to the consequent definition of some types of plasma furnaces.

Indeed increase of E is effective by :

- increase of the residence time τ
- increase of Nu (parameter for heat exchange) by enhancing convective transfer
- increase of heat potential $S = \int_{T_s}^{T_p} KdT$
- increase of the temperature of the wall T_o
- decrease of the diameter of the particles d.

These proposed directions are not independant. Furthermore, some of them are contradictory against each other : enhancement of convective heat transfer is detrimental for the residence time of the particles. At the same time limitations can exist : as an example, introduction of very fine particles ($d < 10$ µm) into the plasma stream is recognized as a difficult operation. Therefore we consider 4 main parameters for operation of the plasma furnace (τ, d, S, T_o). Each proposed combination will lead to the definition of a different type of plasma furnace.

Table 1.

τ s	d 10^{-6} m	$S = \int_{T_s}^{T_p} KdT$	T_o K	Type of plasma furnace.
10^{-3}	100	high	cold wall	a
$10^{-1}-1$	100	mean	cold wall	b_1
			$> 2 \times 10^3$	b_2
10^2	∞	mean	$> 2 \times 10^3$	c

The 3 types of plasma furnaces which have been defined result from a combination of the operating parameters. They are the so-called a) the Ionarc type reactor, for treatment of particulate material into the discharge itself, b) the sedimentation plasma furnace with cold (b_1) or hot (b_2) walls c) the liquid wall plasma furnace, either fixed and vertical or rotating. We will briefly discuss each type.

In a second part we will consider among applications those devoted to processing of inorganic raw materials. Indeed plasma technology offers a high potential in the field of mineralurgy and extractive metallurgy. Analysis of operating costs for simple operations such as melting, spheroidization, fuming, decomposition shows evidence of three main factors : energy consumption, plasma gas consumption and electrode (erosion rate and cost of the electrodes).

Utilization of air as plasma gas when possible offers, comparatively to nitrogen, the most promising figure, but poses a difficult problem of electrode erosion. Electrode materials such as zirconium (Zr) and zirconia (ZrO_2) for d.c., copper and graphite for a.c. operation are proposed possible solutions. In such a situation, the three phase plasma generator operating directly with air and equipped with very simple and cheap electrodes exhibiting a controlled erosion rate appears worthwhile being considered for such applications.

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