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BOF PRESSURE EFFECTS OVER JET PENETRATION AT CSA THYSSENKRUPP

Abstract

BOF, due to operational conditions and location, suffer variations in the parameters whose effects on the liquid bath are usually neglected. The present paper investigated mainly two aspects: inner BOF pressure and oxygen temperature in the stagnant reservoir. The results shown that oxygen temperature changes properties like density and velocity but has small influence on jet penetration. The BOF pressure has significant influence on jet penetration and creates a new dilemma regarding nozzles dimensions considering overexpanding and underexpading jets.

Keywords

BOF Pressure; Jet Penetration; Oxygen Temperature, Mass movement

1. INTRODUCTION

The concepts involved in sonic jets originate in energy conservation equations, mass conservation and state equations applied in systems at stationary state. To simplify the calculations developed, oxygen will be considered ideal gas. The energy conservation equation establishes a relation between fluid velocity, change of the potential energy, energy associated with the level of pressure and fluid work done. A first simplified Bernoulli equation to describe the behavior of sonic jets consists in considering a tube horizontally, turbulent; neglecting the effects of frictional forces and finally assumes that no work is perfomed in the proximity. Besides these simplifications, for compressible fluid, the equation is differentiated in terms of the average speed, considering one-dimensional flow. From this equation are established relations between velocity, pressure and density which necessitate the introduction of others relations to form a system of equations. Shapiro[1] describe the sound wave as a wave of pressure which causes a small pertubation which propagates through a gas, liquid or solid, with a speed "vs" and depends on average properties. Thus, applying the principle of mass conservation for pertubation caused by this sound wave is possible to establish a relation between velocity and density. Throught a balance forces, still in this ambience, a relation between the changes in velocity with the change in pressure is established. Considering the variation in the transversal section of the duct, and combined with the previously established relations are obtained:

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$$\frac{dA}{A} = -\frac{dv}{\bar{v}} \times \left(1 - Ma^2\right) \quad (1)$$

Where " Ma " - dimensionless Mach number , "A" - area and " v" = Speed (m.s-1).

The dimensionless Mach number is a relation between the fluid velocity and the sound velocity at environment. The Figure 1 shows the evolution of subsonic speed to supersonic in relation to area

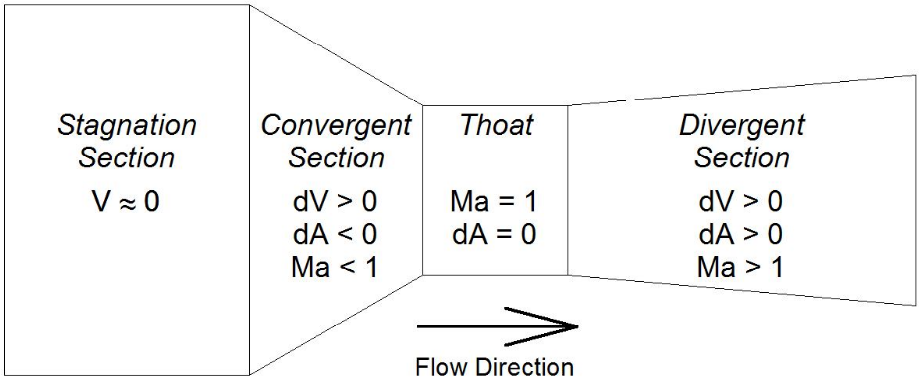

Figure 1- Inlet and outlet of a supersonic nozzles[2-3].

The variations in the gas properties can be expressed in graphical form as a function of Mach number, as seen in Figure 2 .The development of expressions relating to pressure, temperature and density of the gas is hard-working and considers an energy balance in an adiabatic and isentropic process by providing a relation between any two points along the duct. Changes in flow properties are gradual in all cases except when the ratio A / A * is near unity, where the flow characteristics are changed rapidly with small changes in section. Surrounding this region is called the transonic, because it is the transition from subsonic to supersonic regime. The calculations are long and laborious and the results represent the average values over the length of the jet axis, not being possible to evaluate the variations in the properties of the nozzle section.

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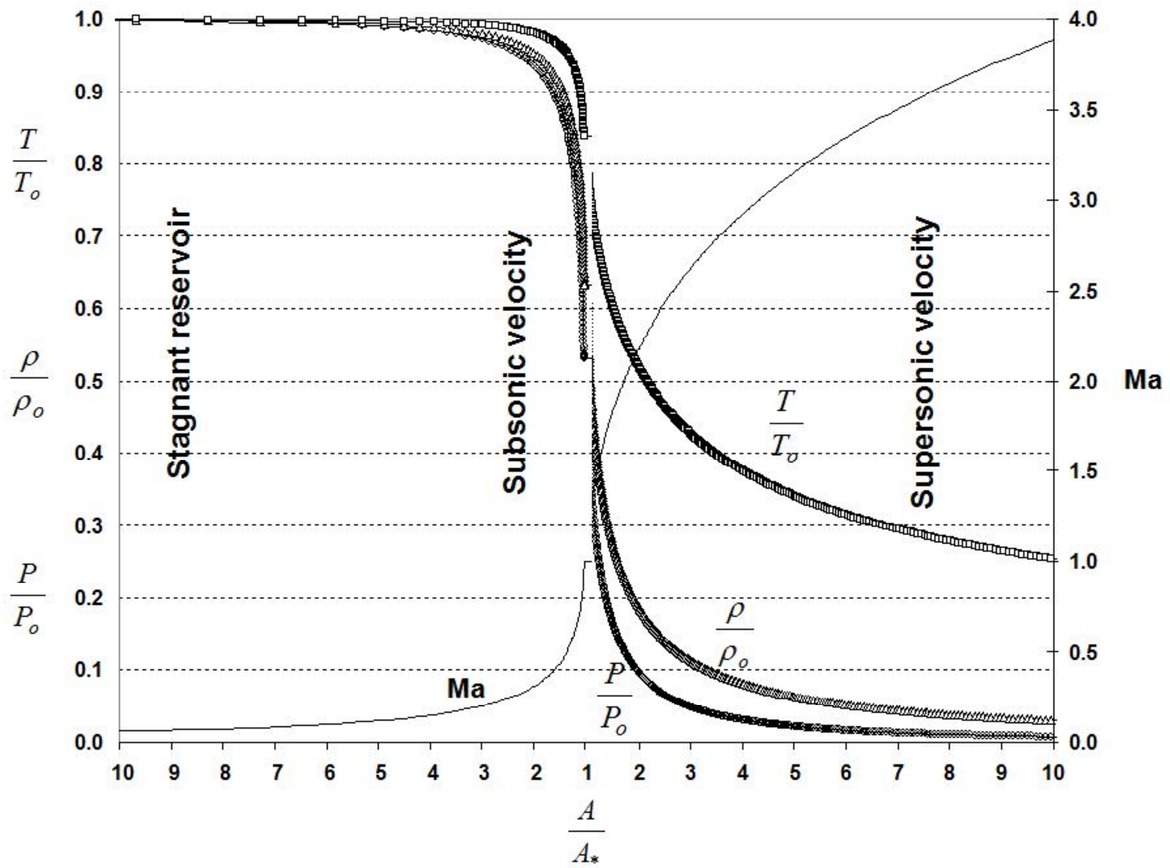

Figure 2 – Variation of flow properties with A / A * variation [4].

2. METHODS AND MATERIALS

For this study was considered for reference absolute pressure in the stagnant reservoir 9,83x105Pa as well fixed dimensions for the nozzle conditions and varying ambient pressures as Table I below:

Table I – Environment pressure conditions.

$P_{EXIT} / P_{O\ (\#)}$	**Condition**
$P_{EXIT} / P_{O\ =}$ **0,1104**	Environment
$P_{EXIT} / P_{O\ >}$ **0,1104**	Over pressure environment
$P_{EXIT} / P_{O\ <\ 0,}$**1104**	Under pressure environment

The Mach number is influenced by environmental conditions inside the converter denoted by equation showed for Ferri [5]:

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$$Ma = \sqrt{\frac{2}{(\gamma - 1)} \times \left(\left(\frac{1}{\left(\frac{P_{BOF}}{P_O} \right)} \right)^{\left(\frac{\gamma - 1}{\gamma} \right)} - 1 \right)} \quad (2)$$

Where: "P_{BOF}" – BOF pressure (Pa); "P_O" – Stagnant reservoir pressure (Pa); "γ" - constant Adiabatic gas.

In this equation for a fixed pressure at stagnant reservoir and change the pressure into BOF furnace is possible note that low pressure environmental or near vacuum the relationship between pressure tendency to zero and has effects on Mach number reducing. For the other side, pressurized BOF furnaces, the relationship between pressures tendency to unit value, than BOF pressure increase for the same pressure into stagnant reservoir and don't allow flow and Mach number tendency to zero.

For the theorical values of jet bath penetration was relationship the amount of movement by energy balance into the deep formation and correlated with modified Froude number, according of arrangement between equations developed by Szekely [6], Meidani [7] e Alam [8-10], and proposed for Maia [3] and shown at Figure 3.

$$\frac{\pi \times \rho_{GAS} \times V_{EXIT}^{2} \times D_{EXIT}^{2} \times \cos\theta \times n}{4 \times \rho_{LIQUID} \times g \times H^{3}} = \frac{\pi}{2 \times K^{2}} \times \frac{P}{H} \left(1 + \frac{P}{H \times \cos\theta} \right)^{2} \quad (3)$$

Where "ρ_{GAS}" – gas density (kg.m^{-3}), "ρ_{LIQUID}" – bath density (kg.m^{-3}), "g" – gravity (m.s^{-2}), "P" – Penetração (m), "H" – distance lance bath (m), "K" – empirical factor, "θ" – tip nozzles angle, "n" – number of nozzles.

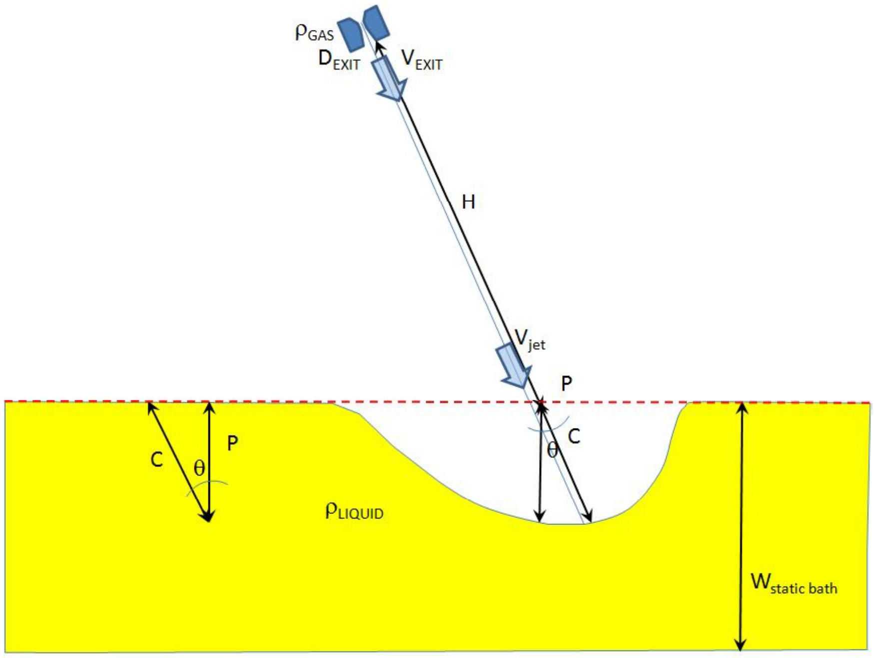

Figure 3 – Schematic draw for gas jet penetration into liquid bath.

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Considering that each nozzle creates one deep and that this radius represents the jet penetration thus was calculated volume amount moving and follows the mass rate.

3. DISCUSSION AND ANALYSES

The first calculations was made considered conditions at 220t converter and showed in Figure 4 pressure variations into BOF over oxygen jet for fixed pressure at stagnant reservoir.

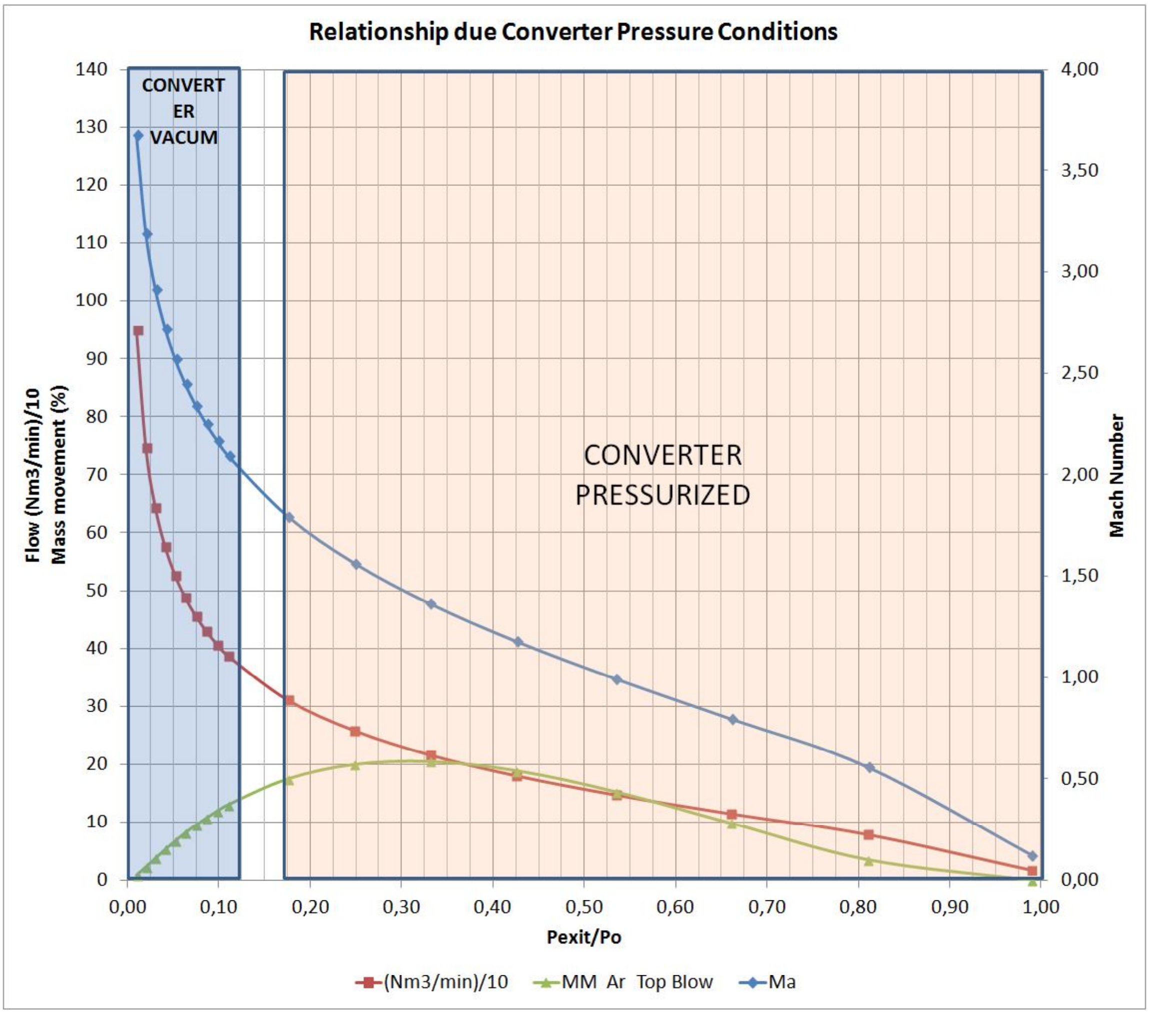

Figure 4- Oxygen jet behavior x BOF internal pressures for 220t.

The Mach number like equation 1 is affected by relationship between stagnant reservoir pressure and environmental furnace pressure. Thus the smaller this reason, thas mean, bigger difference between two different places, bigger will be the increase of Mach number. This mean can be interpreted with same behavior of subexpanded jets, increase volumetric expansion, that consequence will be increase the flow. However this behavior has negative effects over oxygen mass transfer rate for liquid bath for fixed distance lance bath, implied at low bath penetration.

For the other extreme, when the converter pressure is near of stagnant reservoir, the oxygen suffer resistance to cross the exit nozzle diameter and then Mach number is near zero. This behavior is similar to subexpanded gas. This resistance imposed for furnace pressure is

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responsible for low mass transfer that will be reaching the bath surface reducing the mass movement.

The mass moviment, thats mean, the amount of liquid bath that jet is able to move, has a parabolic behavior being the inflection point into curve a place when the pressure is high than environmental pressure, around $1{,}96x10^5$Pa. After this value the mass movement start drops again.

Figure 5 shown divergent aspects to supersonic nozzles dimensions. All designer, with the premise to increase the tip life, has a tendency to reach subexpanded jet behaviors. This avoid potentials post combustion around exit nozzle and start small fusions located dye high temperatures and even copper recrystallisation processes. For the other side, to increase the mass transfer rate to liquid bath into converters, pressure above environmental pressure, around $1{,}96x10^5$Pa are ideal (inflection point at parabolic curve), but this condition is too favorable to appear overexpanded jets, responsible for damages around nozzles.

It was made a study of oxygen temperature influence into stagnant reservoir, like shown at Figure 6.

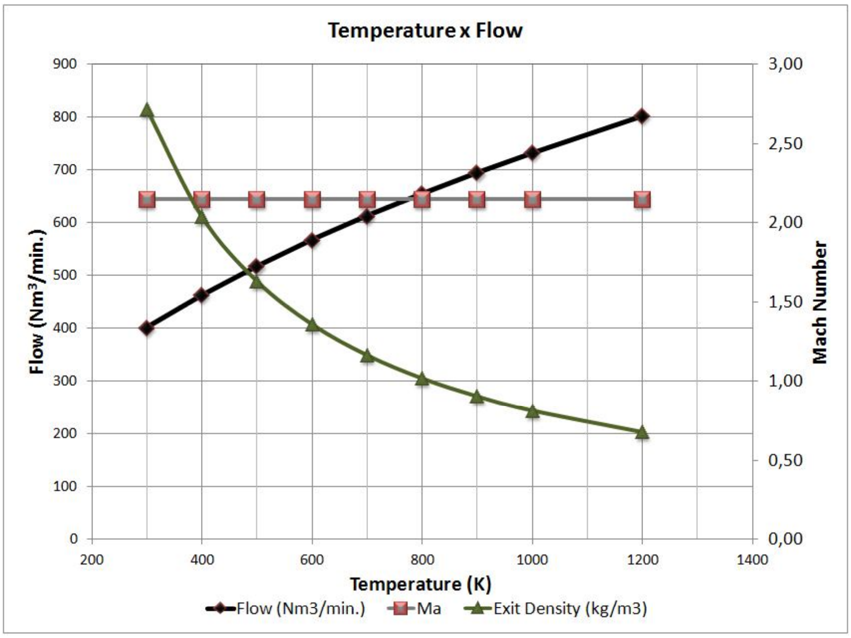

Figure 5 – Oxygen temperature x oxygen flow and density behavior.

Figure 6 reinforce that Mach number is depends on stagnant pressure into reservoir and BOF environmental pressure. In this case, was use $1{,}96x10^5$Pa, environmental pressure. However, oxygen temperature affects sounds velocity in the furnace environmental and oxygen density at exit nozzle. Therefore, when oxygen temperature increase, the velocity at the exit nozzle increase too and so volumetric flow will increase consider fixed throat and exit nozzles diameter. But, when the exit nozzle velocity increases, increase too, the environmental velocity due temperature effects to reduce the oxygen density like equations (5) and (6).

$$v_{SOUND} = \left(\gamma \times \frac{R \times T_{EXIT}}{\left(\rho_{GAS} / 1000 \right)} \right)^{1/2} \qquad (5)$$

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$$\rho_{GAS} = \frac{\left(P_O / P_{ATM} \right) \times PM_{GAS}}{R \times T_O} \qquad (6)$$

Where "ρ_{GAS}" – exit gas density ($kg.m^{-3}$), "ρ_{LIQUID}" – bath density ($kg.m^{-3}$), "g" – gravity ($m.s^{-2}$), "P" – penetration (m), "H" – Distance Bath Lance or DBL (m), "K" – empirical factor , "θ" - angle tip nozzles with vertical position, "n" – nozzles number.

Thus, transfer mass rate will keep constant due inversion proportional relationship between velocity that increases and density that decreases due high oxygen temperature effects. In this way for a same distance lance bath (DBL), the jet penetration and mass movement will constant like shown at Figure 7.

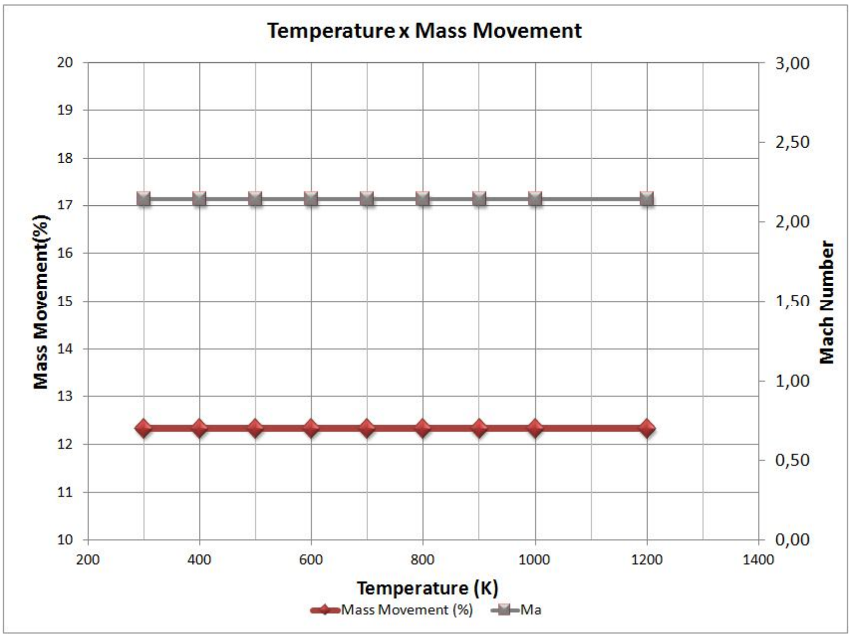

Figure 6 – Temperature effect over Mach number and mass movement.

Figure 8 shown plot similar at Figure 5, but in this case was simulated high oxygen temperature, 498K.

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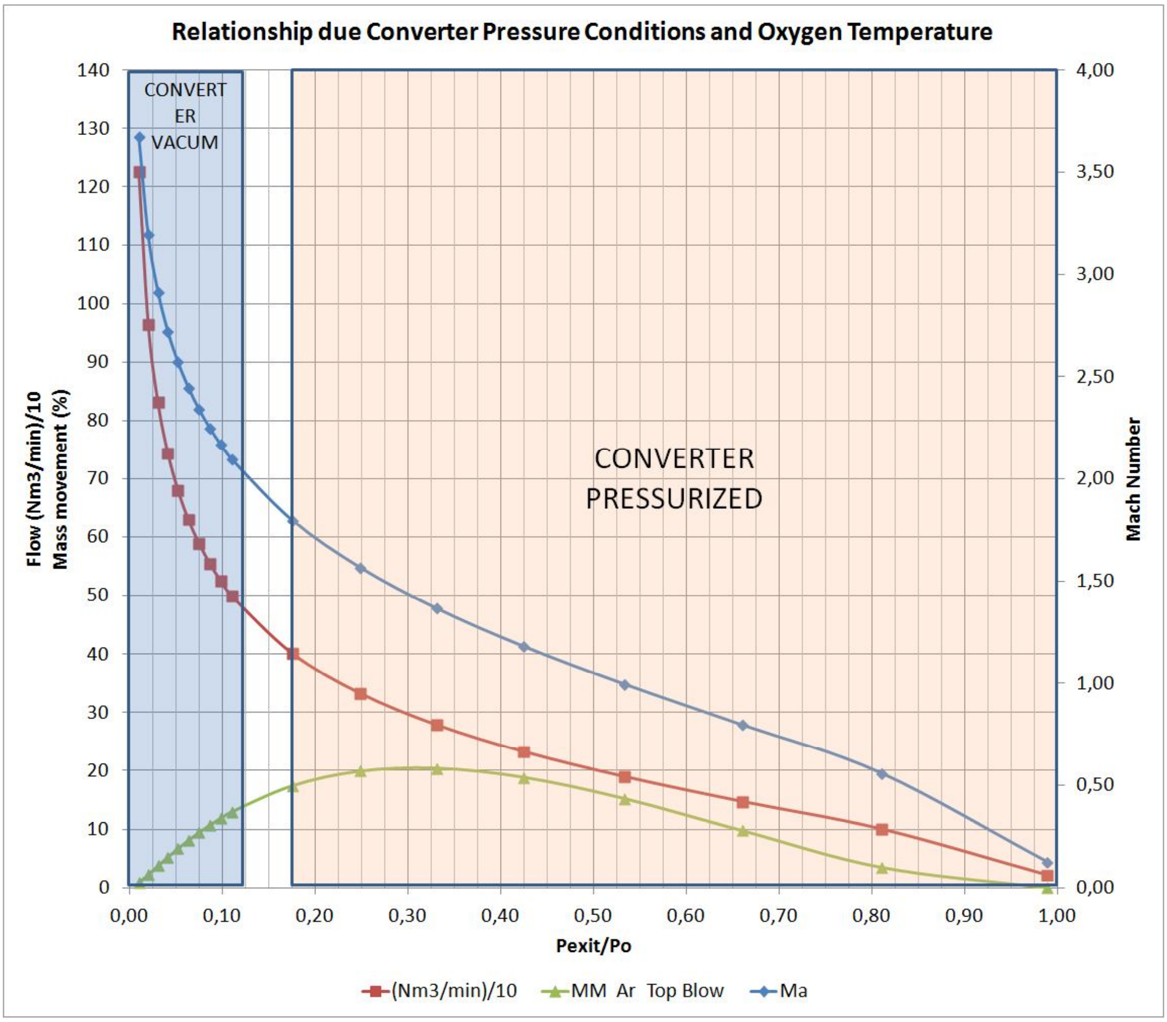

Figure 7- Oxygen jet behavior at 498K x internal BOF pressures.

At Figure 8 in comparison with Figure 5 is possible to see that Mach number behavior and mass movement due top blow don't soffer any modification in function of hot oxygen into stagnant reservoir. But in function of high temperature has a volumetric expansion and flow increase in exit nozzle.

4. CONCLUSIONS

The mainly conclusions are:

- Furnace pressure has influence over nozzles dimensions;
- Oxygen pressure has effects over mass movement for all pressure into converter;
- For best mass movement, converters need to work with positive pressure;

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