Effects of Oxygen Temperature and BOF Pressure Under Jet Penetration

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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 assume 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, et al., 1988 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 change 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:

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

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

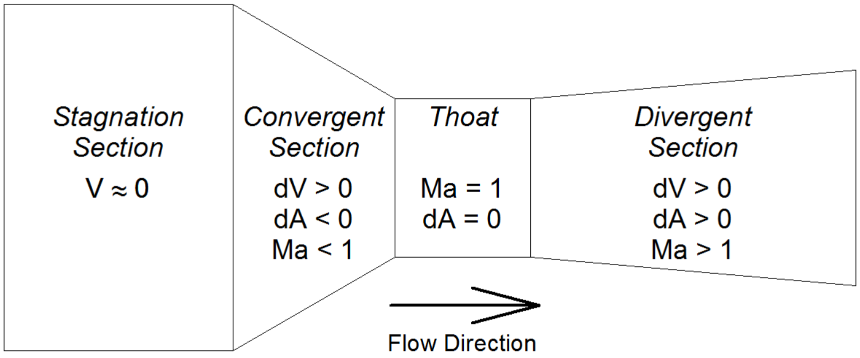

Figure 1: Inlet and outlet of a supersonic nozzle (NASCIMENTO, 2010).

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.

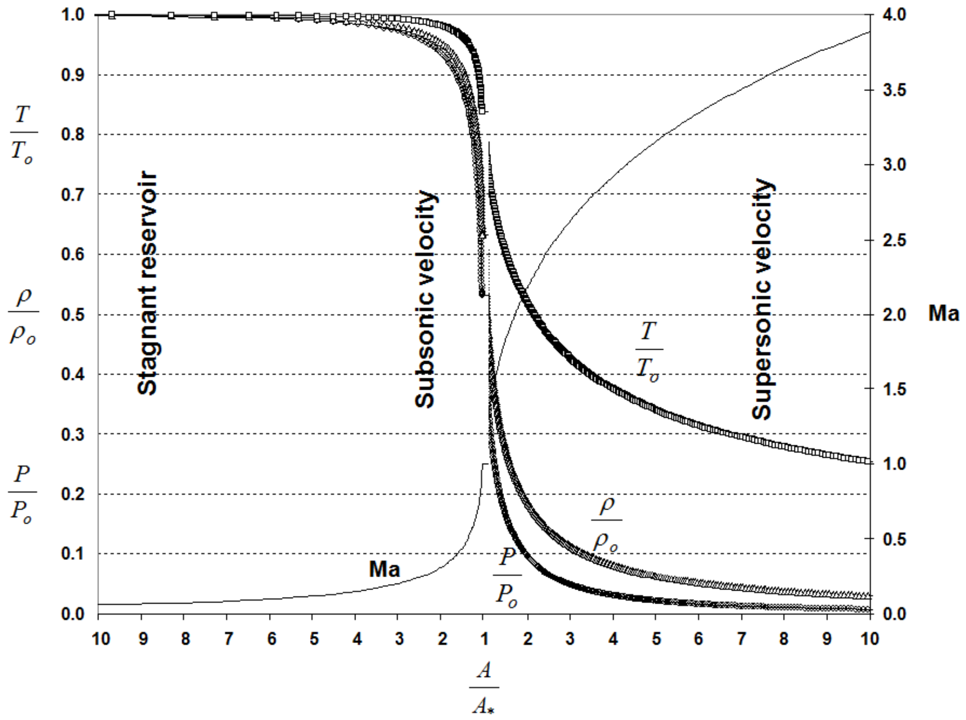

Figure 2:Variation of flow properties with A / A * variation(1).

METHODS AND MATERIALS

For this study was considered a fixed 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

Were fixed “Distance Bath Lance” (DBL) at 2048mm and tuyere flow in 12m^3/min. total for 12 tuyeres.

The Mach number is influenced by environmental conditions inside the converter denoted by equation (2) :

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

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

In this equation for a fixed pressure at estagnant 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(3), Meidani *et al* (4) e Alam *et al* (5,6,7), and proposed for Maia (8) and shown at Figure 3.

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

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.

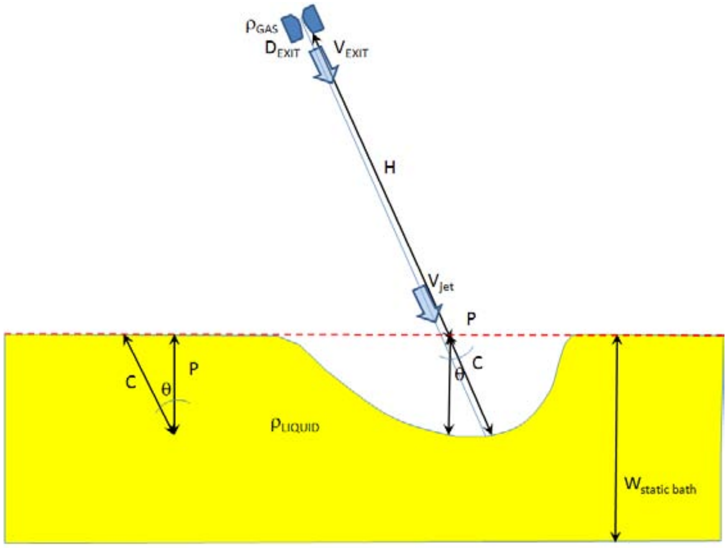

Figure 3 – Schematic draw for gas jet penetration into liquid bath.

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.

DISCUSSION AND ANALYSES

Study develped by Maia *et all*$^{(9)}$showed BOF internal pressure effect over 220t converter, like oxygen temperature into stagnant reservoir effects over jet velocity and flow that changed but Mach number and mass movement keep with same values.

Figure 5 shown this study for pressure variations into 220t BOF over oxygen jet for fixed pressure at stagnant reservoir.

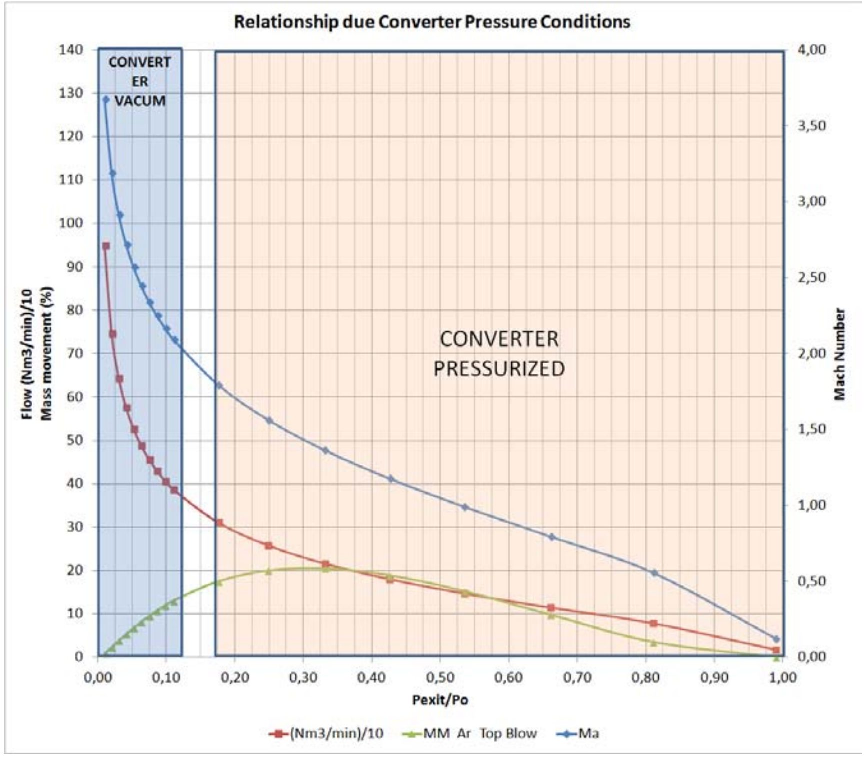

Figure 4- Oxygen jet behavior x BOF internal pressures.

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.

Considering data from 338t BOF converters, were made new calculations for this peculiar converter and conditions into oxygen stagnant reservoir. It is important comment that this converter has recovery gas system, operating with suppressed combustion system. Figure 5 shown the behavior for oxygen stagnant reservoir at 15kgf/cm^2.

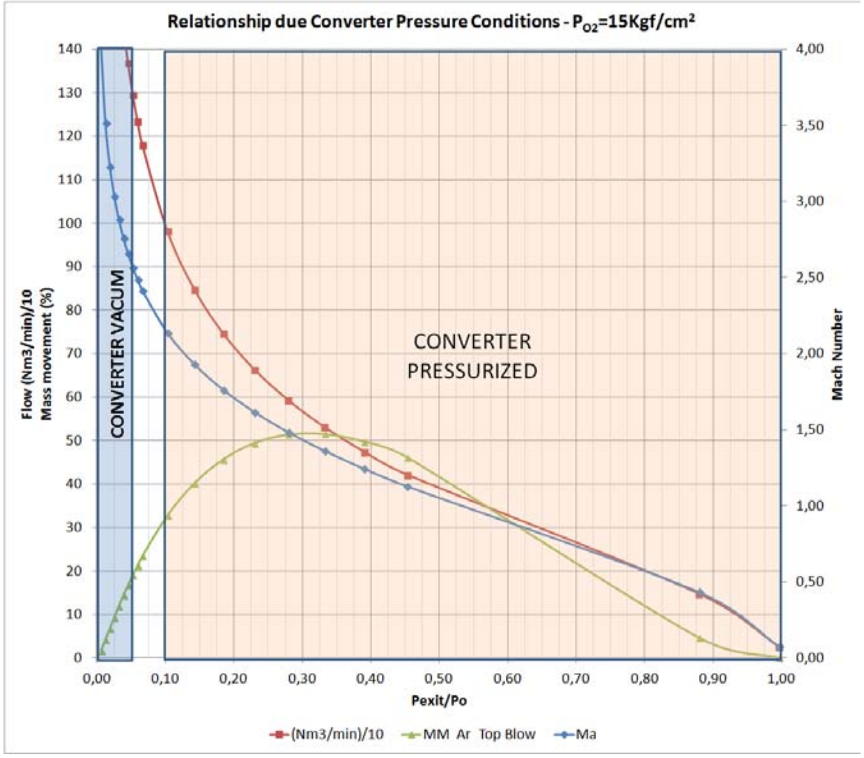

Figure 5 - Oxygen jet behavior at 15kgf/cm^2 x BOF internal pressures.

The pressure in the reservoir stagnant for fixed geometric conditions in the lance nozzles will be the determinant for the jet velocity, expressed by the Mach number. In turn, the Mach number will determine the kinetic energy dispatched in the lance nozzles. The increase in pressure in the stagnant reservoir then increases differential pressure with reflexes at the ambient pressure of the reference converter, expressed by the term "Po". In this way the jet properties are maximized under the low pressure conditions of the converter and in the vicinity of the equalization of the two pressures responsible for a sudden drop in these properties. The consequence of the high oxygen pressure is the increase of the kinetic energy reflecting on the mass of the liquid bath, however, close to the ends of the curve with the mass moving to zero, due to the degradation of the jet as a function of the ambient pressure of the converter .

Comparisons were made with oxygen pressures equal to and lower than industrial practice as shown in Figures 6 to 7.

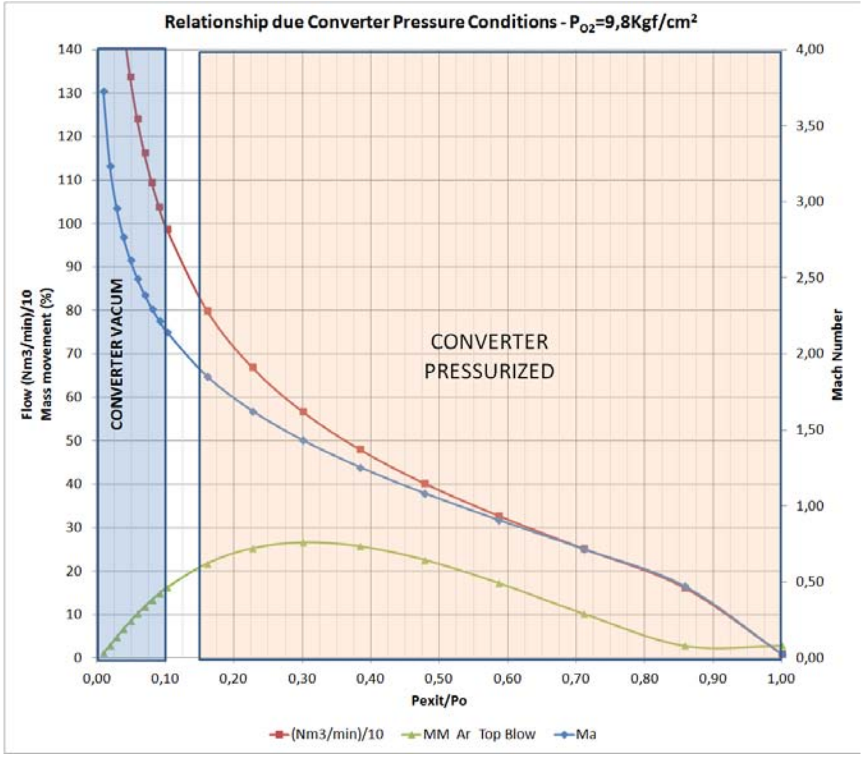

Figure 6 - Oxygen jet behavior at 9.8kgf/cm^2 x BOF internal pressures

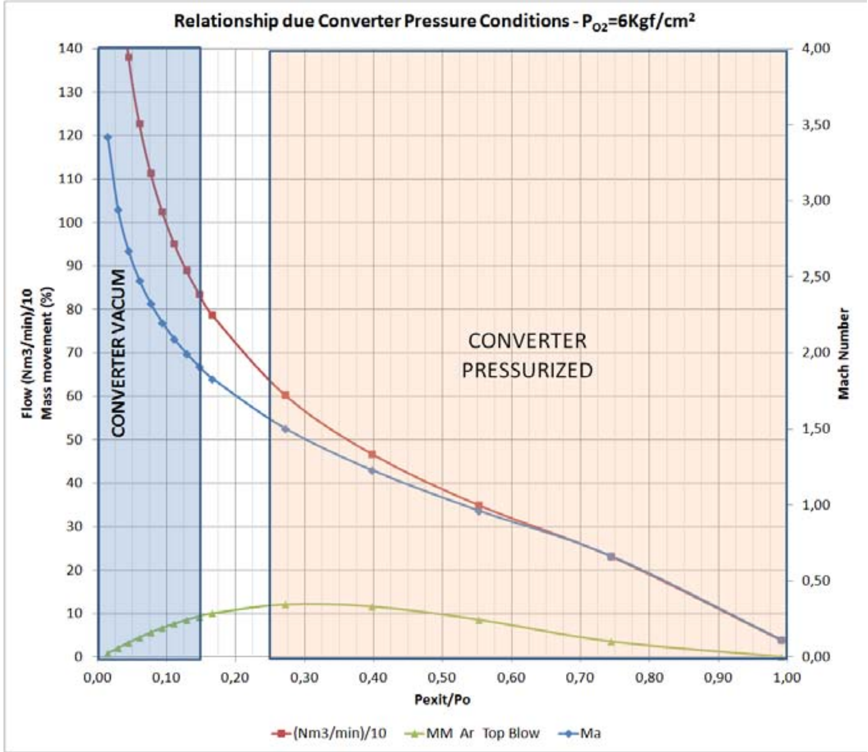

Figure 7 - Oxygen jet behavior at 6.0kgf/cm^2, x BOF internal pressures

In Figure 6 and Figure 7 the reduction in the pressure of the stagnant reservoir (oxygen pressure) reduces jet velocity in the nozzles, reducing the kinetic energy to be transferred to the bath with a direct impact in reducing the mass moved in the metallic bath. In Figure 5, Figure 7 shows that despite the influence of oxygen pressure on the flow of the oxygen jet and the amount of movement transferred to the bath, the behavior of the curves are similar. In all cases, the maximum moment transfer occurs in regions characterized by positive pressure inside the converters. Due to the oxygen pressure in the reservoir stagnant in relation to the pressure variation inside the converter, the region of pressures close to the environment undergoes gradual displacement with the reduction of the oxygen pressure. Another way to interpret is the relative ease of exhausts of the gas capture system, impose a negative pressure regime inside the converter if there is a drop in oxygen pressure. After this study, many real heats were investigated and below shown.

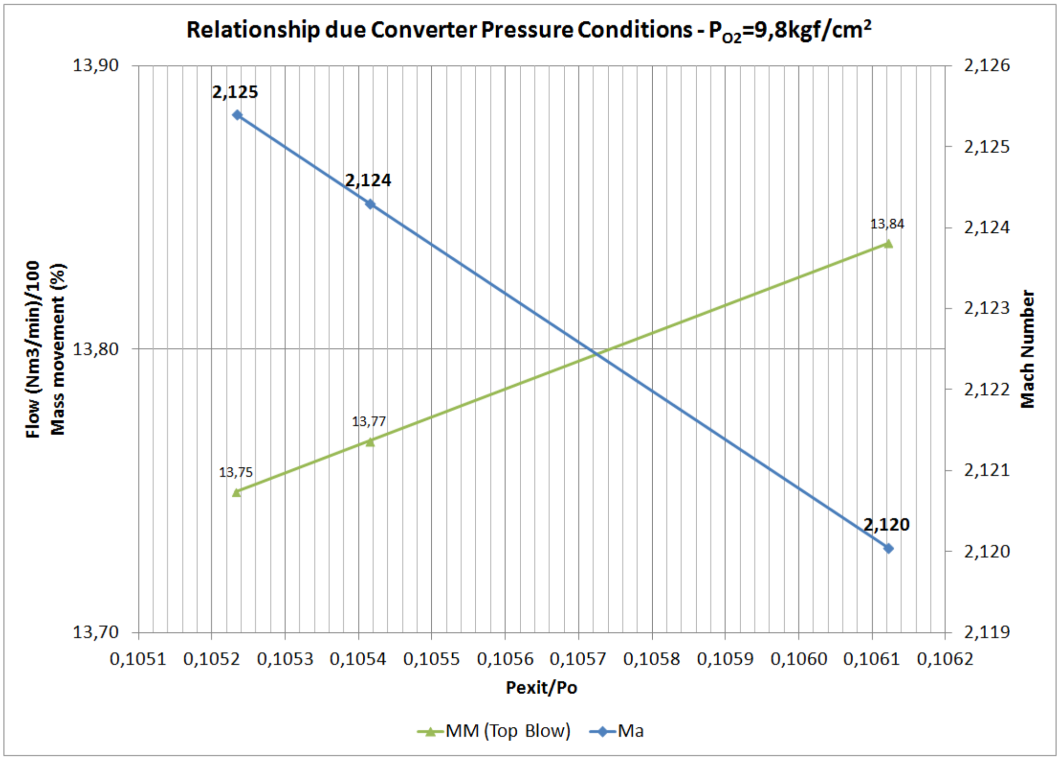

Figure 8 – Real Blow: Oxygen jet behavior at 9.8kgf/cm^2.

Figure 8 was performed based on information from the industrial process and is in accordance with the behavior described in Figure 6 for the same pressure region inside the converter for a fixed pressure in the stagnant reservoir of 9.8 kgf/cm^2. The region shown in Figure 8 shows that for this region of relative pressures, the behavior presented is contrary to what was expected. For once fixed: nozzle diameter, boom height, vent flow and pressure in the stagnant reservoir, a fixed Mach number was expected as well as fixed Mass. However, for this region of pressures inside the converter close to ambient pressure, an increase in the baking mass requires an increase in the furnace pressure. This works as a small restriction to the free output of oxygen in the nozzles reducing the number of Mach.

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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