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DEVELOPMENT AND TEST IN SITU OF A LOW FLUX HEAVY OIL BURNER

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Abstract. *The importance of fuel atomization in the combustion process and how to do it in our specific application were discussed. A twin fluid atomizer (air/heavy oil) was proposed to substitute the original one in an open baking furnace of an aluminum smelter.*
The new heavy fuel oil burner, developed with self-resources, is compared with the old one in a new baking furnace in the same process characteristics. Important aspects like: oil consumption, final anode temperature in the well top layer and the thermal profile in the combustion chamber were analyzed to prove the better efficiency of the twin fluid atomizer. Finally, the potential economical impact of the bumer`s change in the anode production cost was studied.

Key words: *Burner, Atomizers, Heavy oil, Bake furnace, Aluminum smelter*

1. INTRODUCTION

It is known that the characteristics of an atomized liquid fuel flame are, to a significant extent, influenced by the quality of the spray. Liquid fuel requires to be broken up into small droplets in order that it can effectively burn in combustion chambers. Atomization of the liquid fuel is most commonly carried out by injecting the fuel through small orifices at high pressure or by mixing the fuel with high-pressure air or gas.

Twin-fluid atomizer is called an atomizer that uses high velocity gas stream to atomize fuel in a relatively low velocity liquid fuel stream. This kind of atomizing has the advantage of producing smaller droplets than the pressure atomizers. The most common atomizing fluid used in industrial applications are high-pressure steam and high-pressure air. The selection of steam or air is based upon its availability and cost, since, from the point of view of atomization, there appears to be no significant difference in using steam or air (Chigier, 1976).

The heavy fuel oil atomization by using air-atomizers was intensively studied, in recent works, by Costa *et al.* (1991a) and Costa *et al.* (1991b). These works show the pressure air flux influence in the radial mass distribution and in the Sauter Mean Diameter (SMD) of the fuel oil droplets, besides, produce a best understanding of the narrow correlation between the spray quality and the combustion efficiency. The present work does not intend to study the spray formation phenomena but make a performance comparative study between the original and the new burner.

The most part of the heavy oil burners used in industrial applications has large flux capacity. That makes a burner for bake furnace of an aluminum smelter to be a very particular kind of burner, where low flux oil capacities (below 10 l/h) are needed and the combustion air into the chamber has a perpendicular flux direction. That makes more difficult the cooling process of the burner nozzle (when the combustion air has the same direction of the oil flux, it can also have the hole of cooling the burner nozzle). For heavy oils burners this is a big problem, due to the great possibility of the nozzle burner obstruction by the oil solidification provoked for high temperatures in the nozzle if it don't have good refrigeration.

2. THE AIR-ATOMIZER BURNER PROJECT

As we do not have, at Albras (a aluminum smelter located in the north of Brazil), steam readily available from a boiler next to the bake furnace, we decided use air like atomizing fluid for the burners. The air that, at the old burner project was used just for refrigerate the burner nozzle, will start to be used for fuel atomization too.

The original burner is a low flux pressure jet atomizer. The oil flux is intermittent, controlled by a solenoid valve located in the burner body, according to the demand defined by the control system. In fact, it is not a very efficient atomizer. However, in order to save money, it's very important to minimize the changes in the actual facilities obtaining good results with the lowest cost possible. Thinking this way, we decide to maintain the same system control, the intermittent oil flux alimentation and the old burner body. We just change original pair rod-nozzle for a new one that uses air to atomize the heavy oil.

The new pair rod-nozzle is the Y-Jet atomizer (see sketch in Fig. 1). The nozzle at the bottom edge (right in Fig. 1) has two functions: better controlling the cone sheet and making easy the maintenance, avoiding an obstruction in a most difficult access piece.

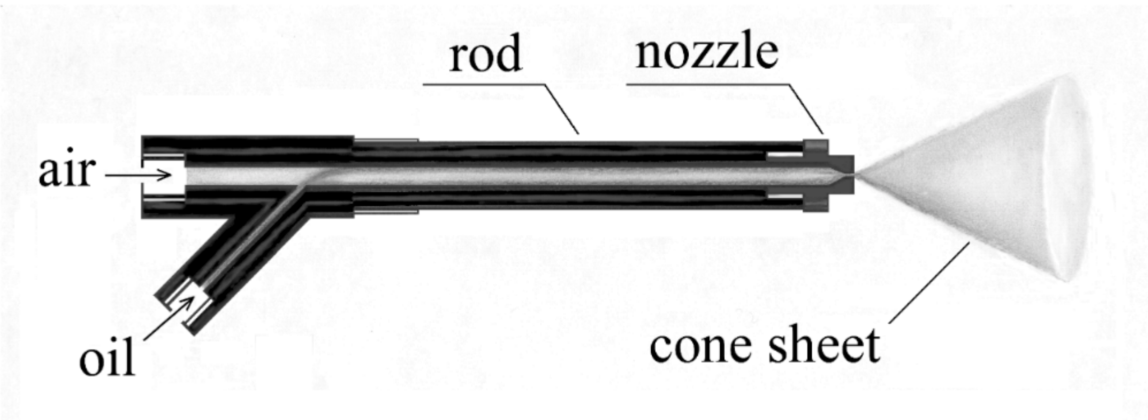


Figure 1- The Y-Jet Atomizer and its assumed Conical Sheet.

The liquid oil upon entering the mixing chamber is pushed against its walls by the incoming pressurized air generating a liquid film. This liquid film is then ejected from the discharge orifice as a nearly conical sheet, which disintegrates into fragments, which form unstable ligaments that contract under action of surface tension, forming droplets. The principles of functioning of the Y-Jet atomizers were described in an experimental paper by Mullinger & Chigier (1974). This work evaluates the effects of flow parameters on the spray droplet mean diameter using an empirical correlation obtained by Wigg (1964). These works were very useful to get start parameters for the new burner prototype.

3. BAKE FURNACE

A basic explanation about the process of anode baking is fundamental for a best understanding of the tests in situ and about the importance of a good burner in the process.

An open anode bake furnace is basically a civil structure made of refractory and isolating bricks. There are fans insufflating air into the chambers and there are tubes, on the two sides of the furnace, connected in one edge with the chambers by exhauster's manifolds and with exhausters in the other to collect the combustion gas from the combustion chambers. The furnace is divided in several sections separated by the Head Walls (chambers that permits the combustion gas flux passage between sections). Multi-purpose cranes enable anode handling and petroleum coke is used as anode packing material.

The Albras FURNACE B (where the tests in situ were made) is a furnace where two fires groups work in 36 sections composed by 7 combustion chambers and 6 pit furnaces or, anode wells, with 12 anodes capacity (4 layers of 3 anodes per layer). The Fig. 2 shows a general view of the Albras 36 sections furnace where are represented the sections with they anodes wells and combustion chambers, the cooling manifolds (FAN) and exhausters manifolds (ME), the combustion units (UC), the pre-heating area, the heating area, the refrigeration area, the crossover (ducts that connect one furnace side each other).

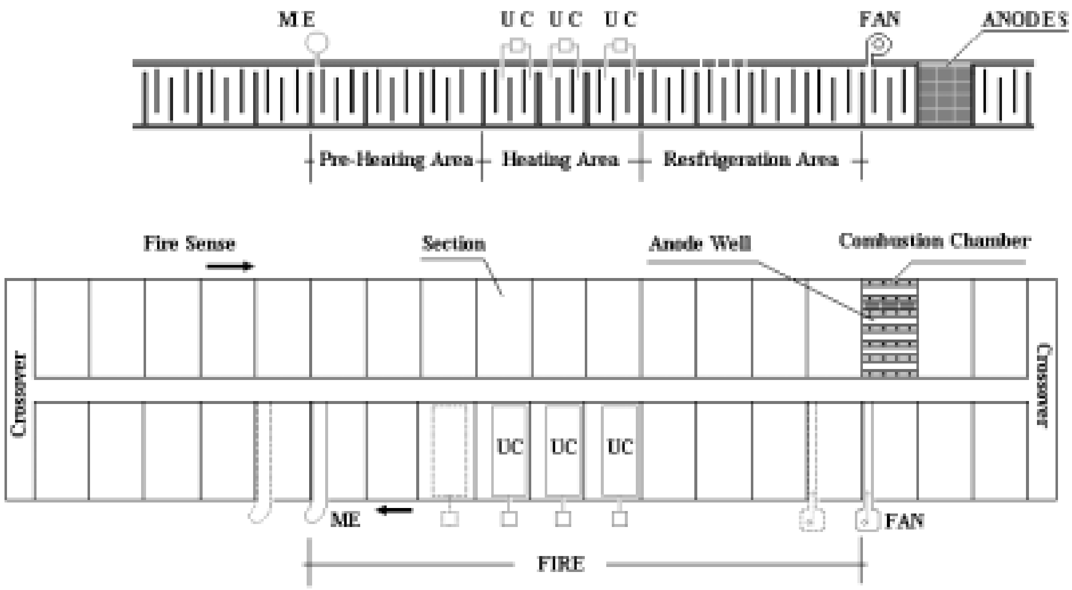


Figure 2- Schematic view of an Albras bake furnace with 36 sections.

A fire is the area between a cooling manifold and an exhauster manifold and contains, in Albras case, besides them, 3 combustion units with 14 burners each (two for combustion chamber). The fire moves for the sections of the furnace according to a cycle, in a sense that change, every semester, between clock-wise and counter-clock-wise. When one cycle finish, the fan, the first combustion unit and the exhauster manifolds moves in the sense of the fire (the dotted lines in Fig. 2 represent the future location of each equipment after a cycle). Thus, more one lot of baked anodes is produced and another green anodes lot starts to be baked.

An automatic control system controls the combustion air flux (indirect by the pressure) and the temperatures in the combustion chambers. A thermocouple placed in each chamber under a UC gives information for the system that act, injecting plus or less fuel in the two burners of that section chamber, to maintain the temperature in accordance with a temperature curve pre-established.

The calcination influence in important anode properties is showed in several works: Rhedey & Nadkami (1984), Lavigne & Castonguay (1993), Fischer *et al.* (1993) and Mannweiler (1994). When the calcination temperature grows to an optimum value, the anode tends to present bests characteristics (the air and CO_2 reactivity down, the real density ups, etc.) and, consequently, improves its performance in pot lines (cells where the carbon from the anodes reacts with the alumna, expending a lot of energy, to produce aluminum).

A temperature 50°C below the optimum value has an impact in the anode net consumption between 15 and 20 kg°C/t. Otherwise, a temperature about 50°C above the optimum value raises the energy consumption in 10% and, reduces the combustion chamber live in about 30% (Fischer *et al.*, 1993). According to Fischer, a good anode calcination temperature must be between 1000°C and 1100°C.

A unique bad baked anode affects the others performances in a reduction cell. Then, an efficient bake process needs to be capable to produce anodes well calcined and with small differences between them. Besides the furnace project, the actual live stage and many process parameters, the burner quality is very important to obtain a uniform thermal profile in the combustion chambers and, hence, temperature differences between the anodes produced.

When, we do not have a good thermal profile in the combustion chambers, normally, we work with a long baking times or high chambers temperatures in order to guarantee a well quality in the top layer anodes (the coldest ones). These actions can contribute in an unfavorable way increasing the fuel consumption and deteriorating the furnace faster.

Improving the burners, we planning to obtain a best combustion and, thus, a best thermal profile. Then we can start to work in more favorable process conditions.

4. TESTS IN SITU AND DISCUSSION

Before testing the Y-Jet last prototype we did several tests with many different twin-fluid burners. Although, almost all of them presented good results in process area, they had serious problems in maintenance area: Frequent nozzle obstructions. With the last prototype arrival this problem seems to be solved.

In fact, the last Y-Jet burner tests start together with others twin-fluid atomizer burners in January of 1999. Its good performance makes we decide to extend the tests first, to one combustion unit (UC) after, to an entire fire, and finally, to all Furnace B. In the beginning of March we changed the burners of the first UC, in March, 23 we already had the Fire 1 burners completely changed and, before closing the month, all Furnace B operated with new burners. The Figure 3 gives an idea of the tests evolution (the temperature peaks were produced by Y-Jet burners).

4.1- Test Parameters

For better comparing the burners, the most parameters at Furnace B were maintained constant during the tests. However, the natural differences between the new and the old burner project force us to change the air pressure (the air is used just to cool the nozzle burner in the original burners) and the oil flux control. As the automatic system controls the oil flux by the number of opening and closing of a solenoid valve and not directly in cubic meters per second; the pulse time (the valve open time per pulse) and/or the number of pulses permitted per minute most be adjusted according the burner project, specially according the nozzle diameters. See at Table 1 a summary of the test parameters used with each burner during the performing tests.

Table 1- Main parameters used at Furnace B, with each burner, during the tests

Parameter	Original Burner	Y-Jet Burner
Fire cycle (h)	22	22
Maximum chamber temperature (°C)	1160	1160
Minimum chamber pressure (Pa)	-245	-245
Oil operating temperature (°C)	110	110
Oil operating viscosity (cSt)	~52	~52
Oil operating pressure (MPa)	2.3 - 2.5	1 - 1.5
Air pressure (MPa)	~ 0.2	0.5 - 0.6
Oil flux automatic control (pulse per minute - ppm)	0 - 220	0 - 35
Oil pulse time (ms)	90	90
Burner nozzle diameter (mm)	0.5	2

4.2- Anode Top-Layer Temperature Comparing Measurements

At Albras we have a procedure to measure, by using thermocouples, the temperature of every top-layer first column anode in all the six wells of a section, as soon as, a cycle finish (the anodes baked in this position are historically the coldest ones). The six chambers average temperature of the measurements made in March/1999, in both Furnace B fires, are showed in Fig. 3.

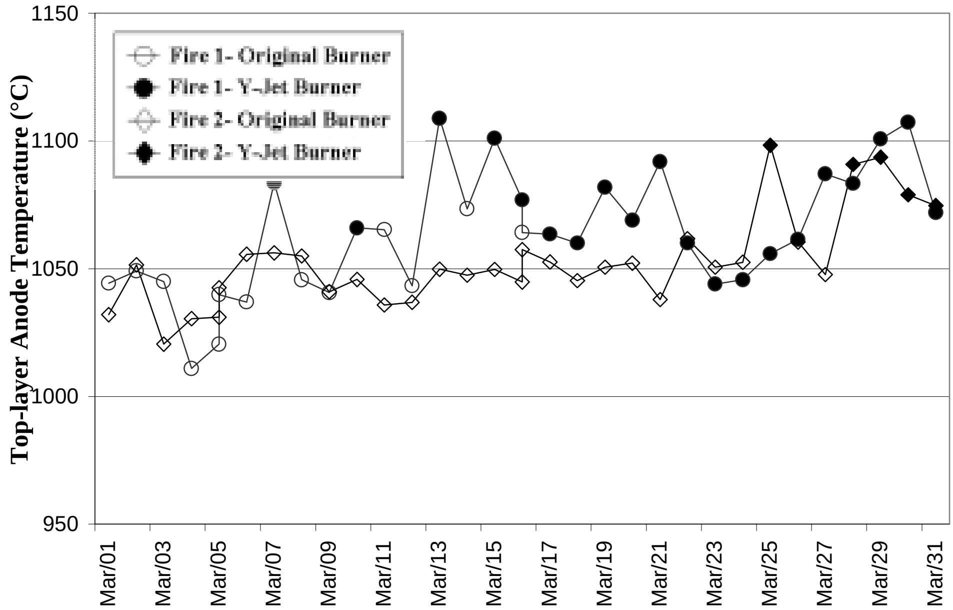


Figure 3- Calcination Temperature of the Anodes from the Top-Layer.

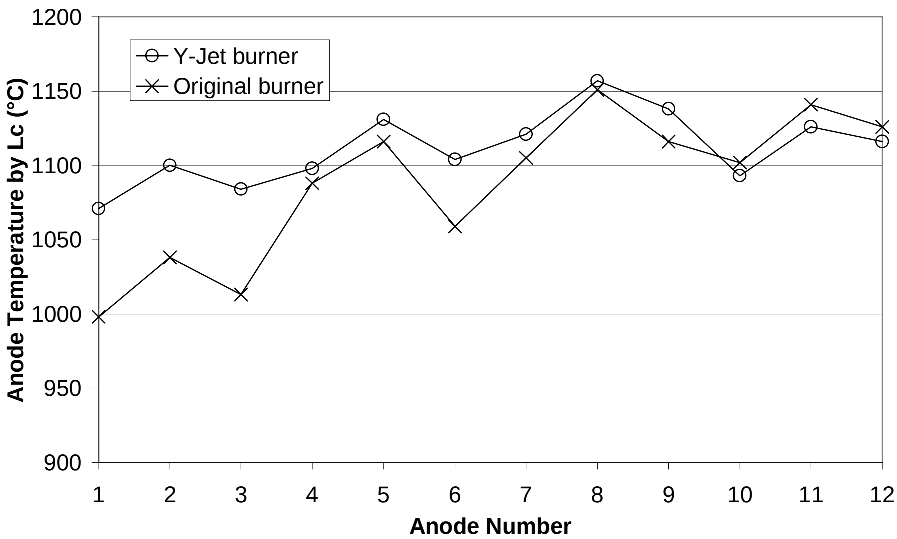
Analyzing the data in Fig. 3, we notice that the temperature peaks were produced by Y-Jet burners, then we can observe that using the new burner it will be possible to work in a high level of calcination temperature in the anodes from the top-layer. It's possible working easily now with anode temperatures between 1050 and 1100°C, what was something very difficult in the past.

4.3- Temperature Measurements in Other Layers

It's very important to know the calcination temperature of anodes from other layers. This knowledge gives us an indication of the thermal profile in the combustion chambers.

In order to measure the temperature in the layers below the top-layer we decide to use an indirect method, called "L_c method" instead to use long thermocouples. The average crystallite height (L_c) consists in using a "standard" reference green coke as an indicator for the calcining level in the baking furnace. A calibration curve for the development of L_c vs. temperature was obtained by heat treating samples of the green coke by rapidly increasing the temperature to the desired level, where the soaking time was 120 ± 0.5 min at 1100°C. The samples are quenched and subjected to X-ray diffraction analysis for determination of the average crystallite height. A graphite crucible containing a reference green coke sample is placed in the anode subhole prior loading into baking furnace. After baking, the sample is analyzed by X-ray diffraction (XRD). This analysis gives some indication of the degree of graphitisation of the sample. By comparing this value with the calibration curve an "equivalent" baking temperature (°E) is obtained. Foosnaes *et al.* (1995) and Hughes (1996) studied the L_c method in detail.

At Figure 4, there are anode temperature results, obtained by L_c method, for the 24 anodes from two different section (12 anodes in each section 4th furnace pit): One baked by Y-Jet burners and another by the original ones. At the right side there is a schema of a furnace pit where the 12 anodes were numbered.



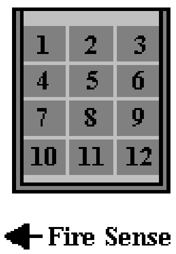


Figure 4- Anode temperature by L_c method

Analyzing the chart at Fig.4, it's easy observed that the Y-Jet burner produced a best thermal profile in the combustion chambers. The temperature standard deviation between the anodes from its well was 23.4°C against, 47.7°C between the anodes from the other well. Besides, the difference between the heater and the coldest anode was just 83°C at the Y-Jet burner well against 153°C at the Original burner. Well, it's also important to say that the average temperature was higher and the anodes from the top-layer were calcined at, almost, the same temperature level than the others, in the well baked with the new burners.

4.4- Temperature measurements in refractory bricks

We measure the chamber floor, below the burners by using an infrared instrument at two different Furnace B sections, one under Y-Jet burners and another under the original ones. The refractory brick was considered a gray body with emissivity (ε) equal 0.95. The measure was performed at the same baking time (27 h after the UC departure). These measurements are showed at Fig.5.

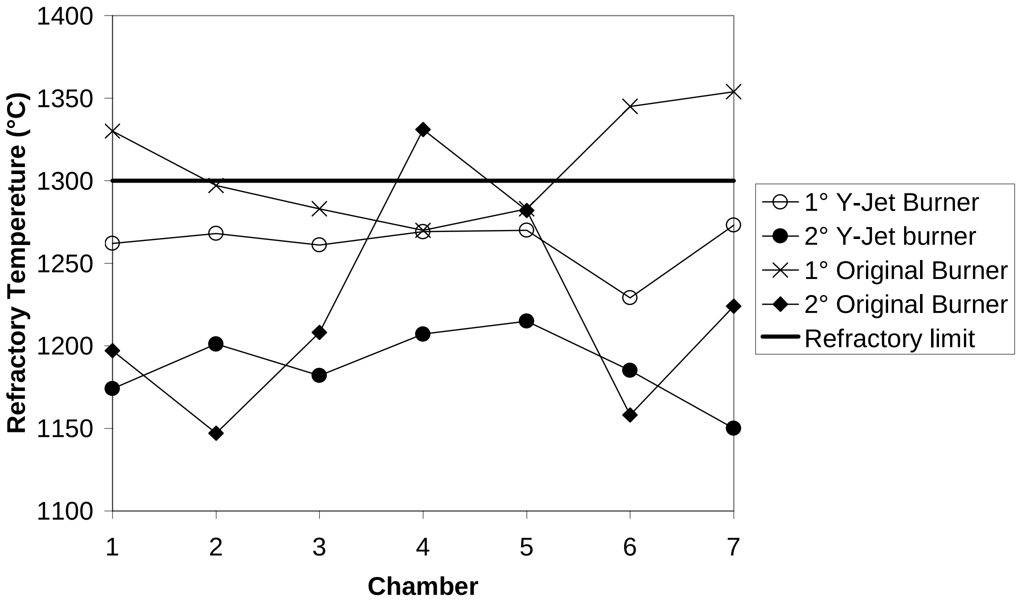


Figure 5- Chamber refractory brick temperature below burners

The refractory limit (the maximum working temperature of the bricks), 1300°C, was reached four times at chambers working with original burners against no occurrences in that ones working with Y-Jet burners. Do not exceed this limit is very important to provide a good time life to the furnace.

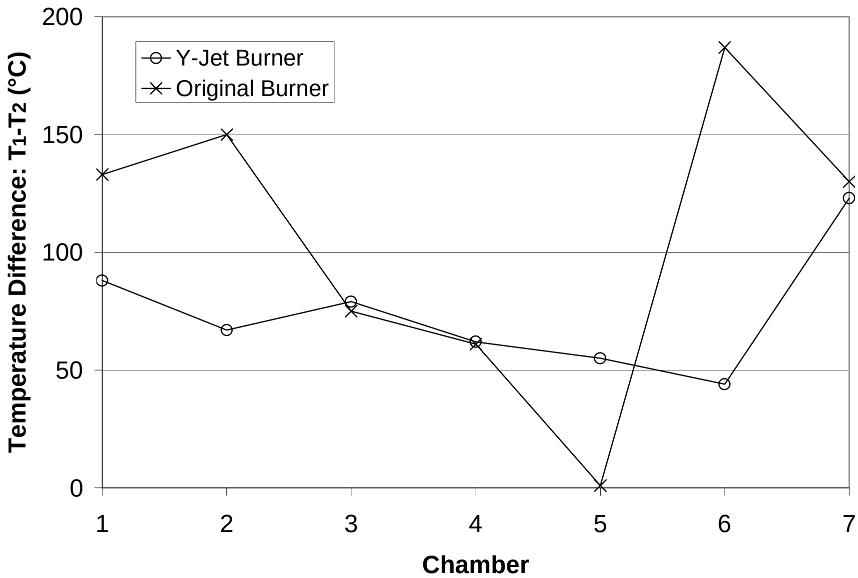


Figure 6- Temperature differences between areas of each chamber.

It's also possible to notice that the temperature differences between chambers are low at the Y-Jet burner section. The Figure 6 shows a chart that permit us a better analyze of the refractory temperature difference between the areas of a same chamber. T_1 and T_2 is, respectively, the temperature below the first and the second burner of each chamber of the two sections measured.

Analyzing Fig.6 we can conclude that the temperature differences are lower and more constant at the Y-Jet burner section than at the original burner section.

All these data give us more indications that the new burner can provide a best temperature chamber profile than the original one.

4.5- Consumption Evaluation

The system control records relevant process data from Albras furnaces each 5 minutes. Between several information there are: the chamber temperature and the pulse per minute of every burner. Then, choosing 10 sections (5 baked with each burner) we calculate the average ppm to each burner: 132 ppm for the original burner and 18.1 ppm for the Y-Jet burner.

In order to compare the consumption between the burners, we start finding curves relating the pulses per minutes controlled and recorded by the system control with the oil flux in kilos per hour (see Fig. 7). With a fix ppm and the time (3 min) we collect the oil from several Y-Jet and original burners in vessels and weigh them in accuracy balances.

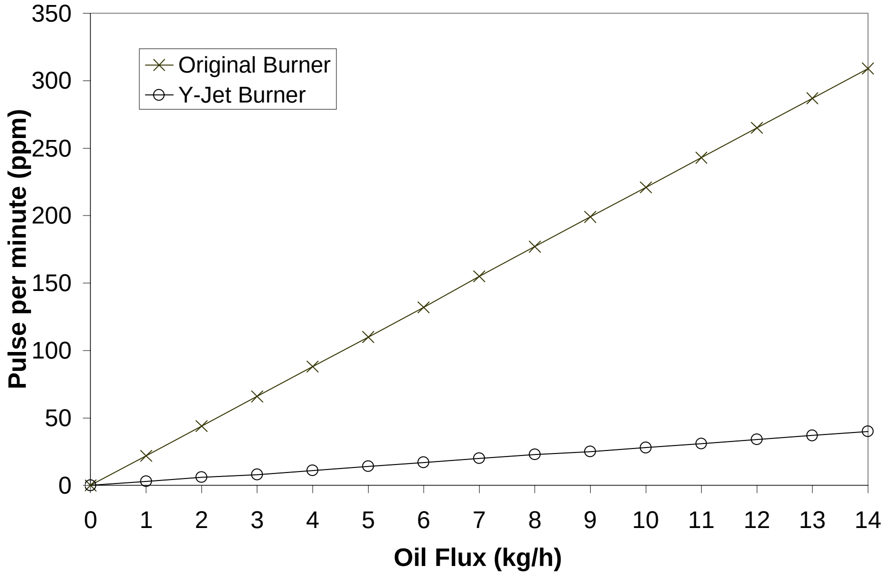


Figure 7- Oil flux in function of the each burner pulse per minute.

According to the measurements the average pulse, 132 ppm of the original burner and 18.1 ppm of the Y-Jet burner correspond to an oil flux of about 6.10 kg/h and 6.43 kg/h respectively. That is, the Y-Jet burner consumes circa 5.4% more fuel than the original one.

4.6- Economical Analysis

The Investment. The total investment in burner modification at all ALBRAS furnaces is about US$50,000.00. That means about US$ 125.00 per burner in operation. In fact, this is a really low investment.

The operational costs raising. The raise of 5,4% in oil consumption implicates in an additional cost of circa US$ 120,000.00 per year. Notwithstanding, we can't guarantee that this raise in oil consumption will continue, because, we can reduce it making adjusts in the control of oil flux.

Potential advantages. Just the reduction of 80% in the rework in the old furnace, provoked by the low anode temperature at the top-layer, justifies the investment (below 950°C we bake the anode again). Last year, we had to cook twice about 1000 anodes; that is, we lose about US$ 80,000.00. Besides, there are advantages much more significant then that. For example, if we improve the anode quality enough to raise in a half day its cycle in pot lines, we save about 1.4 million dollars per year.

Other important potential advantages are: a longer refractory time live, a better temperature distribution in the flues (combustion chambers), etc.

Anyway, just with a longer accompaniment we can really know the economical results of the Y-Jet burner project.

5. CONCLUSIONS

The results show that the Y-Jet burner can produce better thermal profile in the combustion chambers, higher temperatures in the top-layer and lower refractory temperatures below the burner in the flues than the original burner. Furthermore, the economical analyses indicate that the investment can be easily paid, in a more or less a year, even with some raises in fuel consumption.

Thus, the great efficiency results and the low investment of this project indicate that there's no motive to do not start its implantation in all Albras furnaces now.

Acknowledgments

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