71st WORLD FOUNDRY CONGRESS
BILBAO 2014
Advanced Sustainable Foundry
19-21 May 2014 • Palacio Euskalduna, BILBAO

Importance and Effect of Foaming Slag on Energy Efficiency

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ABSTRACT

The present paper is an overview of the benefit of the foaming slag being used as major elements in the energy efficiency campaign. The aim of this work is to show and demonstrate the importance of using a foaming slag in the furnaces to reduce energy consumption, the heat loss or either to decrease the melting time during the process. Different methodologies have been used according to authors. Some have used injected gases to enhance the creation of the foam, other have added some carbon particles contents which creates a chemical reaction by forming bubbles as a foam and insulator layer. Impressive results have been found and real changes have been made. The results have contributed to different purpose such as: decreasing the global warming by controlling the retaining heat, decreasing the noise and vibration in furnace and finally decrease the use of the electrical energy consumption.

Keywords-: Foaming slag, energy, efficiency, furnaces, heat loss, electrical energy consumption, bubbles.

INTRODUCTION

In the world industry especially in steelmaking processing the foaming slag quality is known as an important parameter. The foaming slag have the ability of helping in reduction of energy cost because of an increase in heat retention, improving the efficiency, and decreasing the electric arc furnace (EAF) sound, vibration, and electrode consumption during the melting process. These are some of the advantages and importance of good foaming slag. The pioneer of the slag foaming is Professor R.J. Fruehan, whom has done many researches regarding the foaming slag.

In fact, the meaning of efficiency is to run a process by consuming minimum resources while generating the optimum output or utilize more power with the same amount of resources [1]. It has been noticed that irregular charge surface or melting turbulence causes large instability in electric arc furnace's currents, high current disturbance, and extreme nonlinearity in the current of different phases. A good quality foaming slag protects the charges by creating a horizontal uniform way for conducting current in electrodes in EAF. Thus, foaming slag helps reduce the power quality singularities and maintain a certain balance in the current. The quality of the slag is influenced by many factors such as additives and direct reduced iron (DRI) to scrap ratio. And the quality of the slag has an impact on the creation of the foaming slag. The maximum output or productivity can be achieved by using the maximum available electrical power and chemical energy input such as: oxygen, gas, and others.

Couples of researches on electrical energy consumption have been conducted and solution have been given on how to control the electrical energy consumption on furnaces by controlling the addition [2], injecting gases [3] [4]. Nevertheless, researches on slag quality control regarding the electrical energy consumption have been done mostly in EAF, but few applications have been done in other types of furnaces.

This research has considered only few of the methods to predict the electrical energy consumption. First, the creation of the foaming slag has been entrained by the content of FeO, the basicity, the height of the slag, and secondly the electrical energy consumption has been controlled by the oxygen gas injected, thirdly the controlled has been considered by added sponged pellet (DRI).

The aim of this paper is to give an overview of the slag foaming and the impact that it might have on the control of the electrical energy consumption in the furnaces. The project also depends on:

- Reduction of electrical energy consumption;
- Reduce the greenhouse gases;
- Decrease the melting time;

Whatever the methods used, the objectives to reach are in optimizing the performance of the furnaces.

LITERATURE REVIEW

BACKGROUND ON THE SLAG FOAMING

According to the principal, the slag creation process is all the same in any kind of furnaces and the procedure of how to get a sustainable foaming slag start by following elements that should be taking care of:

Creation of the Gas

The most important thing to know is the constitution of foam. Foam has always constituted of bubbles (Figure 1) which are generated by gases. In the case of foam created into the furnaces, the species of gas know in this phase is monoxide of carbon (CO) which is in a big amount and few of CO_2.

Fig. *1. Different types of bubbles forming foam*

The presence of CO_2 is due frequently to the calcination of extra carbonate in the lime or dolomite added in the furnace. The monoxide of carbon is generated according to the reaction below:

$$C + \frac{1}{2}O_2 = CO_{(g)} \quad (1)$$

$$FeO + C = Fe + CO_{(g)} \quad (2)$$

And $FeO + CO = Fe + CO_{2(g)}$ (3)

Good results of having a good foaming slag depend on how the CO gas is generated and the most preferably way is at the liquid bath level [5]. Foamy slag can be obtained by injecting carbon (granular coal) and oxygen, or by lancing of oxygen only. Slag foaming increases the electric power efficiency by at least 20% in spite of a higher arc voltage [6]. It may also increase the output through reduced tap-to-tap times.

The presence of the oxygen in the furnace comes either from the chemical composition of the elements in the solution or can be injected by using lances. The lancing or burners in the electric arc furnaces (EAF) can be installed to diminish electricity consumption by substituting electricity by fuels. The lancing is important because it can also increase heat transfer and reduces heat losses. Beside that oxygen removes elements such as: phosphorous, silicon and carbon [6].

Regarding the carbon, three types of carbonaceous materials can be used as charge in the EAF operations: anthracite coal, metallurgical coke and green petroleum. But coke is also used as a slag foaming injectant [7].

The foaming slag created early and maintain longer can have a positive impact on the power input (Figure 2) and will be increased. The impact of slag foam covering the arc will help the energy to be transferred directly into the molten metal and the loss will be minimized (Figure 3).

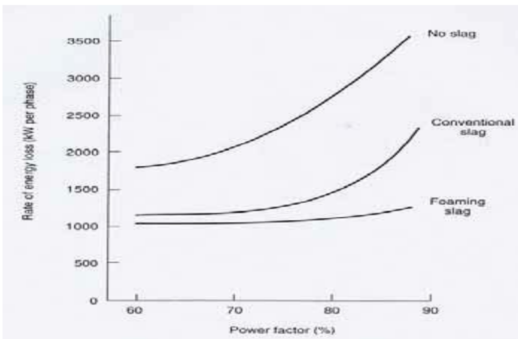

Fig. ***2. Rate of heat loss compare to the power factor with an EAF with no slag, conventional and foaming slag***

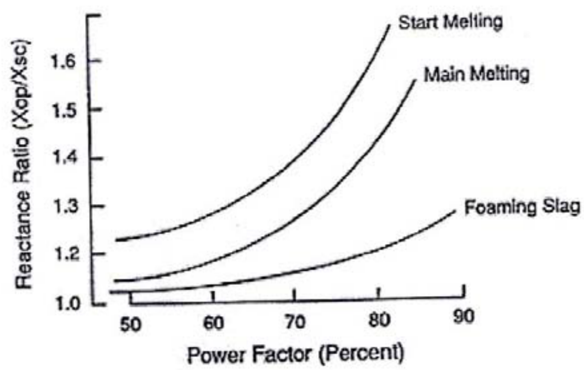

Fig. ***3. Impact of the foaming slag on the power factor compare to the other stage of the melting without foam***

The foaming slag has given positive results regarding it use for the energy efficiency and specially the heat loss during the melting. In 1986 Ameling and Petry have showed the effect of the foamy slag on the energy and the electrode consumption per ton (Figure 4) [7].

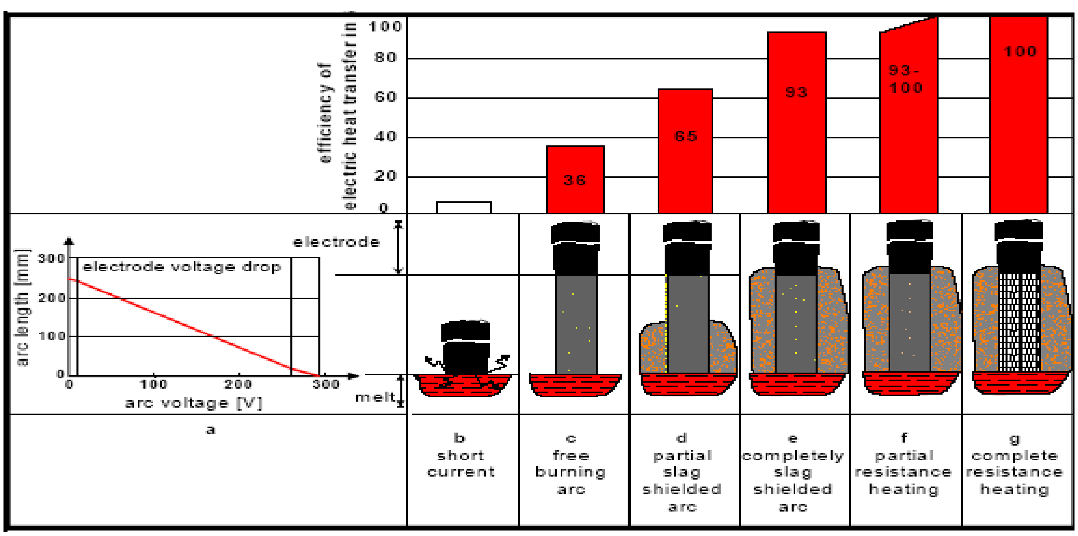

Fig. ***4. Representation of the effect of the foaming slag on the energy***

Surface Tension and Viscosity

Viscosity and surface tension are the most important element for a slag to foam and it is known that increasing viscosity decrease the surface tension and that way the foam can be created. Besides being the most important parameters of the foaming, the particles in the slag have also a big influence on the foaming property. At a good optimum slags (Figure5), the creation of the bubbles are favorable because small and stable gas bubbles start a foaming.

The better viscosity equation is given by:

$$\eta_e = \eta(1 - 1.35\,\theta)^{-\frac{5}{2}} \qquad (3)$$

η_e: Effective viscosity of the slag

η: viscosity of the molten slag

θ: fraction of precipitated solid phases

The foaming slag height is tested by the Foaming index test and it is defined such as: the relative level of air entraining agent needed during concrete mixing, with or without mineral additives [8].

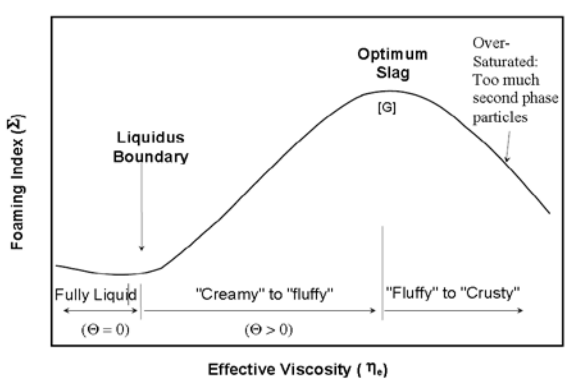

Fig. *5. Foaming index and effective viscosity with optimum slag.*

Basicity of the Slag

Talking about basicity, slags are divided into two groups: acidic oxides and basic oxides and they are respectively SiO2, FeO, MnO, etc. for the acidic or fluxes and MgO and CaO for the basic. The creation of the foaming came from the balance between the acidic and basic. It had been found that an excess of basic oxides is required for excellent foaming. By trying to achieve the balance between the acidic and basic various definitions have been made such as:

$$V_B B_2 = \frac{\%CaO}{\%SiO_2} \qquad (4)$$

$$B_3 = \frac{\%CaO}{\%SiO_2 + \%Al_2O_3} \qquad (5)$$

$$B_4 = \frac{\%CaO + \%MgO}{\%SiO_2 + \%Al_2O_3} \qquad (6)$$

$$B_5 = \frac{\%CaO + \%MgO}{\%SiO_2} \qquad (7)$$

The variation of slag basicity can go from less than 1.5 to more than 3.0 with FeO levels fluctuating between 10% to 50%, while still achieving good slag foaming behavior (Figure 6).

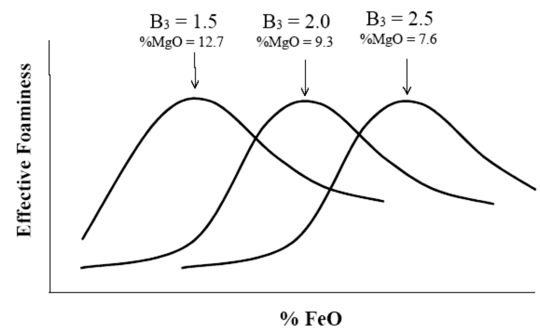

Fig. *6. Behavior of the effective foaming relative basicity and FeO contents*

To achieve a better foaming, the presence of the surface-active substance is important, it helps lowers surface tension of the bubbles films and protects layer for bubble combination. The surface tension has an impact on the slag height that means that it impacts on the foaminess of the slag (Figure 7).

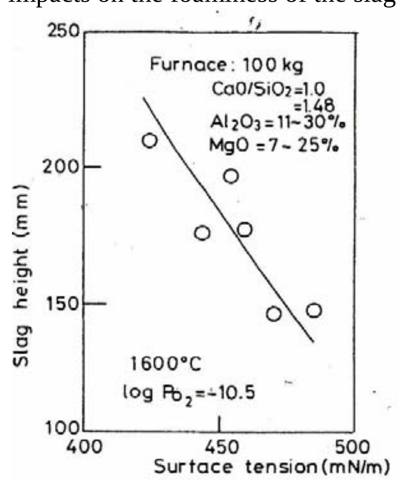

Fig. *7. Effect of surface tension on the slag height*

Temperature

The life time of foam depend on different parameters but also on the temperature. The foamability of slags is influenced by the temperature as seen on the figure 8 below Bahri and Fruehan have conducted some experience to prove that [9].

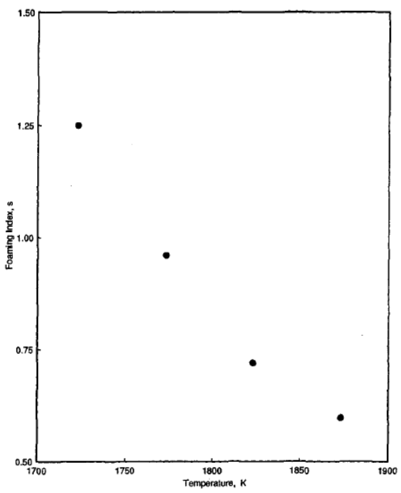

Fig. *8. Temperature effect on foaming index*

The temperature affects viscosity and surface tension but has most influence on the viscosity because of the presence of the second particles. According to their experience the temperature dependence of foaming index is given by:

$$\Sigma = 1.78x10^{-5}exp\left[\frac{16797}{T}\right] \qquad (7)$$

139.6 kJ/ mole were the apparent activation energy for the decay of the foam. The foam height as a function of superficial gas velocity for a slag containing: 48 pct CaO, 32 pct SiO_2, 10 pct $A1_20_3$, and 10 pct FeO at 1773 K. The small increase in the foaming index might be due to the gas hold-up in the slag. Data in literature point out that the effect of temperature on the foaming behavior of slags used in ironmaking and steelmaking operations has not been investigated in detail and most of the work done was at temperature less than 1773 K (1499.85°C), whereas 1823 K (1600°C) to 1923 K (1700°C) is more typical of steelmaking temperatures.

RESEARCH METHODS OR PROCESS

The crusade toward the energy efficiency has attracted so many researchers and many companies by working on the energy efficiency using the foaming slag to protect and save the industry.

In 2002, Sima and Hossein [10] have worked in an AC electric arc furnace of capacity: 5.5 m diameter of hearth, the liquid steel capacity of 200 metric ton per heat by 90 MVA. The charging material was DRI (Table 1) of 40 tone scrap and 1 tone lump coke. A triple supersonic lance was used to inject oxygen, methane and carbon. Gases were injected at 18 min from the melting start. Different types of gases were injected at different volume: 1150 m^3/hr and 400 m^3/hr. 30 minutes later, 2300 m^3/hr O_2 and 800 m^3/hr CH_4. The size of the coke was between 0-3 mm.

Table 1. DRI Composition

Component	C	Fe_m	Fe_t	Mt	FeO	SiO_2	CaO	Al_2O_3	MgO
Percent	1.93	81.58	88.97	91.6	9.54	2.26	2.1	0.38	0.76

Authors used foamy index to have quantitative identification for foamy behavior of slag and used the equation: $\Sigma = 359\mu/(g\rho\sigma)^{0.5}$ (8)

The slag used was a ternary system of FeO, CaO+MgO+MnO, Al_2O_3+SiO_2+P_2O_5 group at 1550°C. Sima and Hossein have used basicity, FeO contents, and height of slag.

In 2011, Veena [11] and others started how to enhance the foaming process. They used different type of polymeric materials such as: rubber, high density Polyethylene (HDPE) and Polyethylene Therephtalate (PET). The used like the others gases, they have added rubber and plastics and coke.

In 2001, Praxair's CoJet [12] company uses oxygen by improving the injectors function as a burner, lance and post-combustion device. The objective was to create a coherent jet replacing the lance. The coherent jet penetration depth is 80% more than a conventional Jet (Figure 9) and it principle is give above (Figure 10). The operation has been tried to many companies.

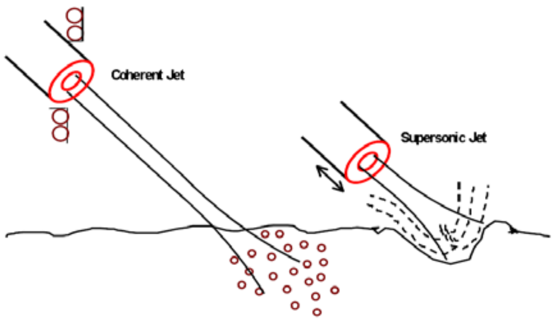

Fig. *9. Coherent and conventional Jet*

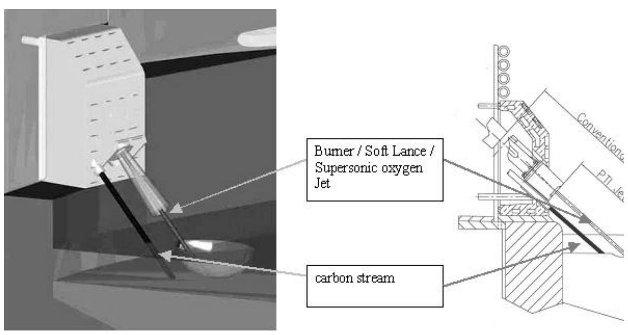

Fig. *10. Principle of Jet Box*

The G-Steel Public Company, have worked on the repositioning the EAF Burner. The reposition (Figure 11) has been made and some results have come out from the experiments. Differently to the others, this work has only focused the idea on the oxygen usage in the EAF Furnace [13].

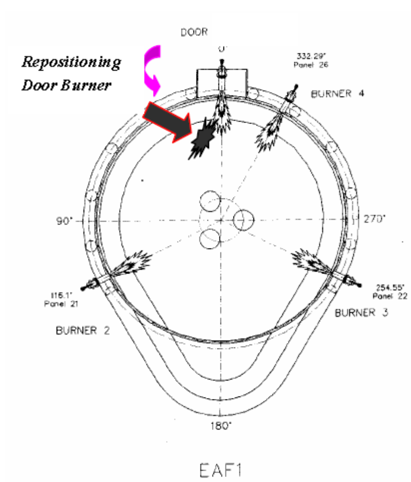

Fig. *11. Repositioning of the burner*

In 1990, Sadrnezhaad uses sponge DRI as charge materials in electric induction furnace (EIF) to reduce the energy efficiency. The tests have been conducted in two different EIF: a 25 kg and 1.5 ton. The author have worked on different types of parameters: feeding rate, size of the pellets, types of feeding methods. The process is represented on the figure 12 below.

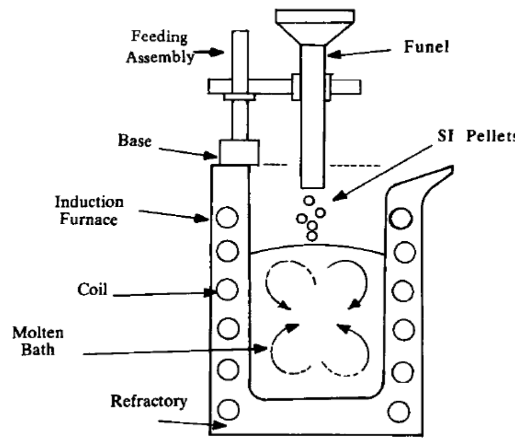

Fig. *12. Schematic representation of an EIF being feed*

All the researches notified in this paper have the same objective: to reduce the electrical energy consumption. Different types of methods have actually being used and results will shows the way and procedure to use for using the methods used years ago.

RESULTS

From different perspectives any of the researchers have found some results which all direct to same conclusion. Sima and Hossein have concluded after their intensive researches that to obtain a sustainable foaming slag into the EAF. The FeO content should be in between 20-25%, the basicity 2-2.2. After the experiments they come to a conclusion that, they could reduce 670 kWh/t to 580 kWh/ton and they could reduce the melting time to 130 to 115 min. the experiment have proven the importance of the carbon injection on the energy consumption (Figure 13).

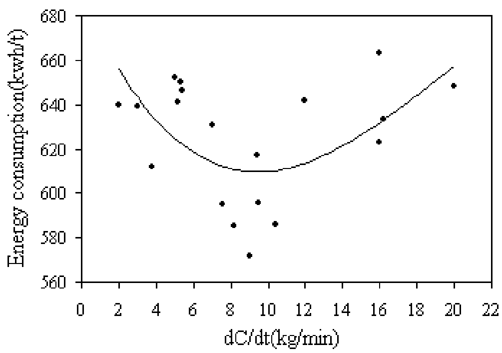

Fig. *13. Carbon rate injection and energy consumption variations*

The influence of the height of the slag also has results on the energy consumption (Figure 14).

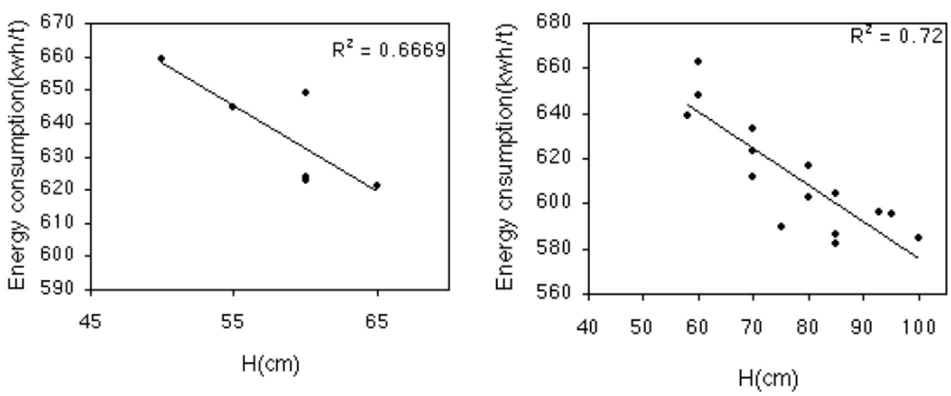

Fig. *14. Variation of height slag and energy consumption*

The basicity at point up to 2.1 can decrease the electric energy consumption. The best basicity chosen was between 2-2.2 (Figure 15).

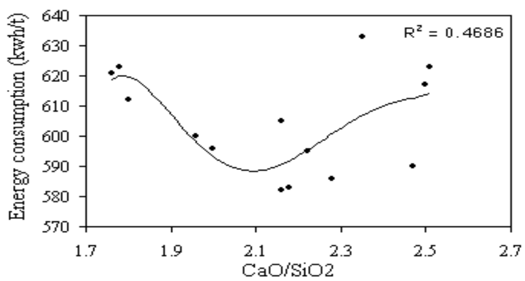

Fig. *15.Slag basicity and electric energy consumption*

Other more specific that show the direct influence of the electric energy consumption is the content of FeO in the solution. The result comes after having our optimum basicity. The figure 16 shows us the specific condition for stable foam.

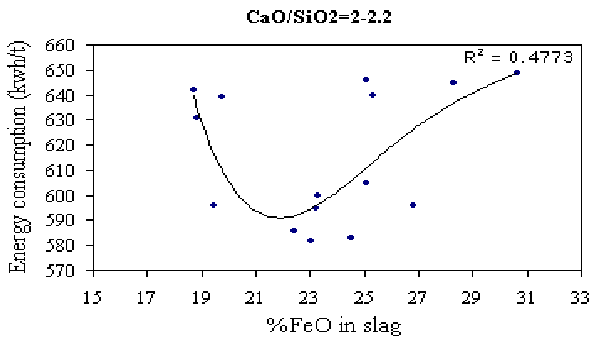

Fig. *16. FeO content and energy consumption at basicity 2-2.2*

Sima and Hossein have brought some tremendous changes in their research with the results that they have coming to.
Veena, the use of rubber and coke blend is no longer considered a trial at OneSteel plants and is instead standard practice. Industrial implementations showed enhanced slag foaming performance for polymers compared to coke. Carbon additions have been reduced by 56-73kg/heat, while the FeO percentage in the slag was reduced slightly. Reduction in the electrical energy usage from 424 KWh/t when coke alone was used to 412.4KWh/t in case of rubber blend, reaching 406 KWh/t when HDPE blend was injected.

Praxair's CoJet company has brought the research to different companies and each of them has some results regarding the energy efficiency and it been represent in the table 2 below.

Table 2. Comparison of average results of before and after CoJet

TABLE 2 : Comparison of Average Results at Birmingham Steel, Seattle [6]			
Variable	**1998**	**1999 w/CoJet**	**% Change**
TPH	105.5	112.18	6.3
Delays	[illegible]	[illegible]	[illegible]
Tap-to-Tap Time	65.44	54.5	-16.7
Power kwh/t.	426.12	396.87	-6.9
Electrode,kg/t	1.97	1.66	-15.4
Gunning,kg/t	1.06	1.39	31.8
Delta	88.74	219.25	147.1
Oxygen	19.2	29.7	54.8
Natural Gas	5.6	8.2	46.4

G-Steel company has found that they could reduce with their method 12 to 28% of energy consumption. The tables 3 and 4 below give us the results before and after improvements.

Table 3. Energy used in EAF before improvement

	Electricity		Carbon		Oxygen		Natural Gas		Total
	KWh/ton	MBtu/ton	Kg/ton	MBtu/ton	Nm3/ton	MBtu/ton	Nm3/ton	MBtu/ton	
G-Steel	430	4.52	7	0.19	31	0.19	7	0.25	5.15
Bench mark	392	4.21	16	0.44	38	0.23	9	0.32	5.11

After the repositioning of the burner door, the energy consumption has been reduced to 378.55 kWh/ton liquid steel in the G-Steel. The total energy reduced was 4.55 MBtu/ton liquid steel.

Table 4. Energy used in EAF after improvement

	Electricity		Carbon		Oxygen		Natural Gas		Total
	Kwh/ton	MBtu/ton	Kg/ton	MBtu/ton	Nm3/ton	MBtu/ton	Nm3/ton	MBtu/ton	
G-Steel	378.55	4.06	4.09	0.11	32.88	0.20	4.91	0.18	4.55
Bench mark	392	4.21	16	0.44	38	0.23	9	0.32	5.11

According to different types of production used to create and sustain the foam in the way to reduce energy consumptions. Some suitable results have come out and the variation of electrical energy consumption was made from 5 to 28% depending on the type of methods used. This shows the interest and the rentability of the foaming slag.

CONCLUSIONS

The creation of the slag in the industry is an operation to take with many values as it has allowed several companies to work with a very affordable cost and lower costs compared to the energy consumed. Taking seriously the use of foam slag is a very important operation and capital for the smooth running of society and specially the company or the objective is to reduce the use of electric energy.

ACKNOWLEDGMENTS

Our thanks go to the Department of Extractive Metallurgy and especially to Dr. X Pan for his support, his help and encouragement during difficult times during elaboration of this work. My thanks go to the University of Johannesburg ever to train and support those who want to learn. Special thank to Bitjoka Alice M. for her support.

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