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Effect of Slag Foaming in EAF & Factors affecting It: A Review

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Abstract: The discussion about foaming of slag in the EAF in order to achieve higher efficiency at low cost is made in this paper. Slag foaming is carried out by injecting oxygen and carbon to produce CO gas.The slag foam covers the arc and thus direct transfer of energy takes place to the melt. It also reduces radiation loses thus protects the refractory and also reduces electrode consumption. Noise and vibrations are also reduced. This paper discusses about the factors affecting slag foaming like viscosity, basicity, FeO content in the slag, foam height, bubble diameter, etc. and also the interelations between them.
Keywords: Foaming, slag, EAF, viscosity, basicity, FeO content, foam height, bubble diameter

I. INTRODUCTION

EAF is a well-known process in steel making and is a very important scrap recycling process. In this, electrical energy provided by the arcs is employed for the melting of charge. The charge may be of DRI/ HBI, scrap, pig iron and hot metal.[1]Steel and slag are produced as a result of the energy provided by the arc to the charge. Lime is added along with the charge for the production of slag. The composition of EAF slag is calcium oxide, iron oxide, magnesium oxide, silica and aluminium oxide.

Many techniques have been employed to increase the overall efficiency of the EAF and the steel making process to obtain the desired grade of steel at low cost and energy consumption. Slag foaming is one such technique. Foamy slag is used because it not only saves energy but has the following other advantages:

A. Protects electrodes and cover the arcs
B. Decreases radiation loses and thus protects the refractories, water cooling tubes and other parts of the furnace and thus the maintenance is reduced.
C. Decreases noise and vibrations.[2].There is also in reduction in harmonics due to direct immersion of electrodes in slag.[3]
D. Decreases the power and voltage consumption.[2][4]

In the slag foaming process FeO plays a very important role. Foamy slag formation can be divided into two main steps: (1) Oxygen injection in the molten metal through lance at supersonic velocities.The lancing is important as it saves energy by increasing heat transfer and reducing heat losses[5], and (2) Carbon injection into the slag. The following are the reactions taking place:

$$C_{(in\ metal)} + \frac{1}{2} O_2 = CO \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$FeO_{(in\ slag)} + C = CO + Fe \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Here Fig.1 shows the injection of oxygen and carbon in the slag.

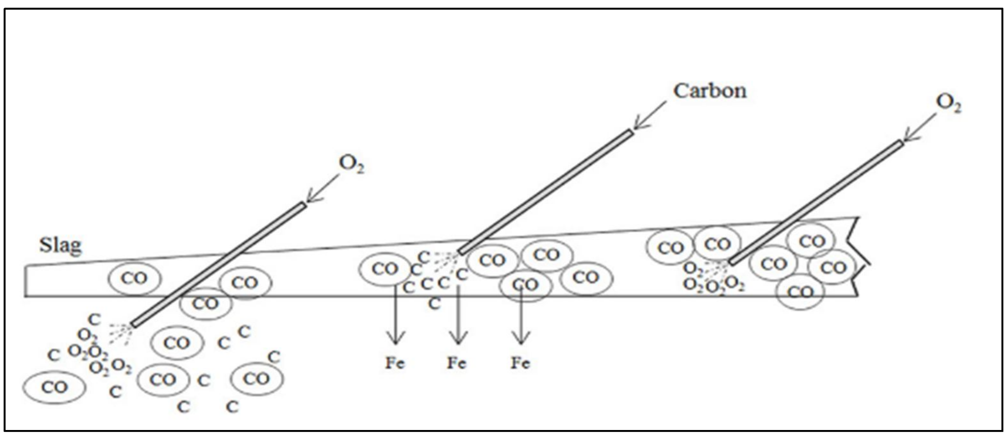

Fig. 1 Formation of gas bubbles[6]

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II. LITERATURE REVIEW

The foaming of slag is due to the production of CO formed as a result of the above reactions. As stated above the oxygen injection takes place through lance or may enter through burners or as a result of some chemical reactions. The amount of oxygen is very imp because if large amount of oxygen if injected it will lead to the formation of large amount of FeO in the slag resulting in the wastage of charge. It is found that the bubbles produced by reaction (2) are smaller than those produced in (1) leading to a more stable foam.[6]. For calculation of the stability or effective time of slag foam we use a term known as **foaming index**.

It is defined as the time taken by the gas moving with superficial velocity (V_g) to reach at the top of the slag of height ΔH.
Mathematically it is defined as

$$\Sigma = \Delta H / V_g$$

Here the term Σ represents the foaming index and has unit seconds(s).[7]
There are many factors which affect the slag foamability such as slag viscosity, FeO content, Basicity of slag, bubble diameter and slag thickness/height etc.

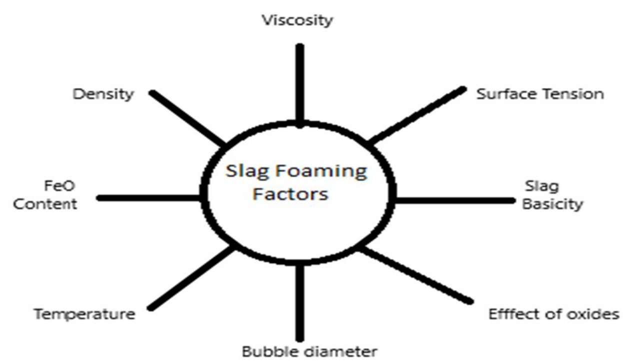

Fig. 2 Factors related to slag foaming

Some of the factors are discussed below-

A. *Effect of Viscosity on Slag Foaming*

A high viscosity is required for steady foam because a higher viscosity slag would be able to withstand and hold the foam for a longer time.
An empirical relationship between foaming index and viscosity can be written as follows-

$$\Sigma_o = 1.82U'/ (dv)^{0.5} (D)^{0.9}$$

Where, Σ_o = foaming index in absence of solid particle
U'= particle viscosity in absence of solid particle.
d = density of slag (kg/m3)
v = surface tension (N/m)

This relation shows that the foaming index increases with increase in viscosity and decreases with increase in density or surface tension.[8]. And Fig.2 shows the relation between foaming index and viscosity.

Presence of some solid particles is also very important as they serve as nucleation sites for a large number of small bubbles thus increasing the foaming of slag like addition of lime. The effective viscosity of the slag can be determined using the given formula considering the presence of solid particles.[9]

$$U=U' (1-E)^{-2.5}$$

Where, U = particle viscosity in presence of solid particle.
U'= particle viscosity in absence of solid particle.
E = particle concentration

$$\Sigma = \Sigma_o (1-E)^{-2.5}$$

Σ = foaming index in presence of solid particle.[9]

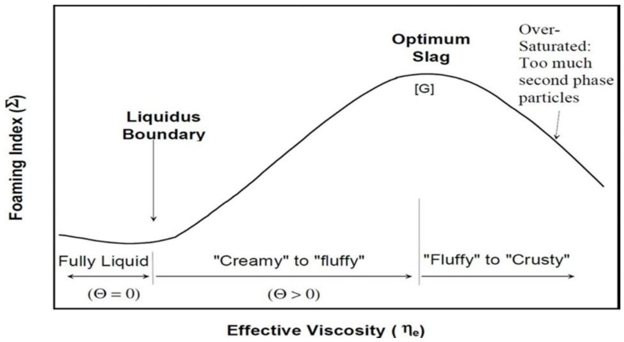

Fig. 3 Variation of foaming index with slag viscosity[6]

It has been observed that the slag viscosity decreases with the basicity but after crossing a certain critical value it again increases.[2] A higher FeO content in the slag may decreases the viscosity.

B. *Effect of Slag Basicity on Slag Foaming*

As mentioned above the EAF slag mainly contains CaO (calcium oxide), FeO (ferrous oxide), MgO (magnesium oxide), SiO_2 (silica) and Al_2O_3 (aluminium oxide). Slag can be divided as Acidic slag or Basic slag based on the components present in it. If the slag has SiO_2, FeO, MnO, etc it is called acidic slag and if the slag has MgO and CaO it is called basic slag. Balance between acidic slag and basic slag is necessary for producing good quality foam.[10]

Basicity is usually defined as the ratio of basic components in the slag to the acidic components and is represented by usually the given formula

$$\text{Basicity} = \%CaO/\%SiO_2$$

The components of slag can also be divided as refractory and fluxing oxides. The addition of refractory oxides like CaO beyond the liquidus composition results in the increase in the effective viscosity of the slag thus improving foaming index and foaming.[11].On the other hand oxides like SiO_2, Al_2O_3 increases the fluidity and thus the foaminess decreases.[12]

Basicity has a strong influence on slag foaming both in case of acidic as well as basic slag.

In acidic slag increase in CaO content (i.e increase in basicity) will decrease the viscosity thus causing a decrease in foaming index.

On the other hand in basic slag increase in the CaO content will increase the viscosity resulting an increase in foaming index. Here the foaming index increases because increase in CaO leads to formation of solid particles in the slag which act as nucleation sites for bubbles.

C. *Effect of FeO Content on Slag Foaming-*

Foaming significantly decreases with increase in FeO content. Initially as FeO content increases the CO gas generation increases and thus foaming increases.But having a FeO content above some critical value the viscosity eventually decreases and density increases leading to decrease in foaming.[7].

In a system of liquids a gradient in surface tension can induce motion and is known as Marongini effect. The FeO content is lower in the slag metal interface as compared to the slag and thus there is lower surface tension there giving rise to Marongini effect. Thus new surfaces can be formed easily with lower surface tension.[2]

Addition of carbonaceous materials reduces high iron contents in slag and thus helps in foaming.[13].Depending on cost and availability some of the examples of carbonaceous materials used are anthracite, petroleum coke, coke breeze etc.[1]

The relation between foaming index and FeO content is shown in Fig.4.

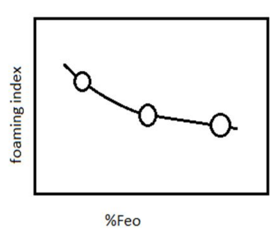

Fig.4 Curve showing relation between foaming index and FeO content[14]

D. Factors Affecting Foam Height and Bubble Diameter of the Foam

Foam life can be determined using foam height as one of the factor and thus used to determine the foaming index as discussed above. Foam life can be defined as the time required by the foam to drop down to certain level after the gas flow is stopped.[2]

Foam height can be taken as a function of FeO content in the slag. The foaming height increases linearly with the increase in the oxygen blowing rate. Foaming increases with the decrease in the FeO content due to low viscosity and greater amount of second phase solid particles in the slag.[14].The curve in Fig. 5 represents the variation of foam height with oxygen blow rate for different FeO content.

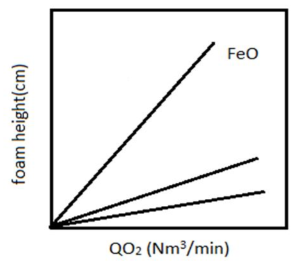

Fig. 5 Graph representing foam height variation with oxygen blow rate[14]

The realation between basicity and foam height is shown in Fig. 6.

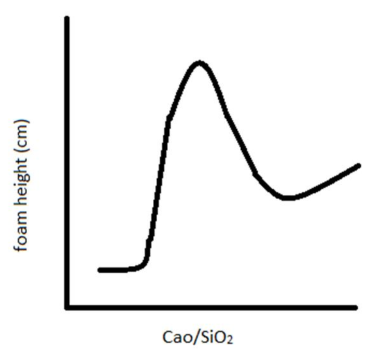

Fig. 6 Effect of basicity on foam height[14]

It has been found that the foam height increases significantly when we use multi-orifice nozzle as compared to single-orifice nozzle.[15].Coherent jets can be used for gas injections to improve the process.[16].

Bubble size plays a very important role in the foam stability. Bubbles of smaller diameter form more stable foam as compared to larger diameter bubbles. Generally small bubbles are the result of chemical reactions and gas injections produces larger diameter bubbles. Small bubbles ascend through the slag at slower rate than the larger ones and thus the life of foam is increased.[2]

Sulphur content in the charge plays an important role. As a surface active element it increases the contact angle resulting in larger diameter and less stable foam. High content of sulphur limits the foam level due to larger diameter and as the sulphur eventually is transferred to the slag from the molten metal the diameter decreases.[15]

E. Effect of Temperature on Foaming of Slag

The temperature in the furnace during steelmaking also plays a very important role in slag foaminess.The steelmaking temperature in EAF is around 1600°C and it increases so that during end of the heat to a tap temperature of nearly 1700°C is obtained.This temperature affects the foaming as the slag fluidity increases with increasing temperature the foaminess is not as good as it was at 1600°C.The increased slag fluidity reduces the amount of second phase particles as well as also retards the reduction reaction of the carbon injected, which increases the FeO content as consequently the slag foaming decreases.[11]

III. SUMMARY

Here we discussed some of the factors which affect the slag foaming process in the EAF. The various parameters are set such that we can get maximum efficiency by slag foaming. Thus we conclude that

A. A higher viscosity slag is required to maximize slag foaming and the density as well as the surface tension are inversely proportional to the foaming.
B. A higher basicity in acidic slag leads to decreased foaminess and on the other hand in basic slag it leads to high foaming slag.
C. High FeO content in the slag is detrimental as it leads to decrease in viscosity and thus the foaming stability is reduced.
D. Foaming height determines the effective foaming. It is directly related to oxygen blow rate and it is high at low FeO content.
E. Foam with smaller bubble diameter leads to a stable foam and the factors affecting it are discussed above.

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