

A DIFFERENT PERSPECTIVE ON CARBON & OXYGEN BALANCE (C_xO) IN THE EAF PROCESS

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Abstract

Due to the price advantage, the use of fossil fuels forms the basis of our industry and is also the most preferred fuel type in steel production. Therefore, steel processes are designed considering this fact. With the questioning of the impact of chemical energy use based on fossil fuels on the emission values of the EAF process chain and the emergence of the agenda that green production targets will be achieved with green electricity produced from renewable sources, many parameters in EAFs, which are the most important result of the current process preference, have started to be examined (carbon (C) and oxygen (O) balance, metallic yield & increased productivity, clean steel production, ferroalloy yield). The demands for controlling low oxygen and inclusion levels in steel enable some new developments in process control in the metallurgical aspect.

In today's steel production world, clean steel production requires the implementation of technologies that minimize the use of added alloys and additives to the system, leading to energy savings, maximizing metallic yield, and accelerating the entire steel production process, thus having a low oxygen bath from the beginning of the melting process to the solidification process, maintaining productivity, controlling oxidation intensity, optimizing slag amount.

This study investigated the melting of scrap in EAF's and Induction Furnaces with different melting technologies and examined and interpreted the parameters related to obtaining different levels of dissolved oxygen in the liquid bath.

1. Introduction

In the early stages of the Electric Arc Furnace (EAF) metallurgical process, various process applications existed, but only decarburization remains today. Other steelmaking operations have been transferred to secondary metallurgy units. The primary metallurgical process in modern EAFs—decarburization and carbon boiling—has become a natural consequence of the melting practice rather than an intended process. Consequently, the EAF has increasingly lost its characteristic as a metallurgical furnace and now functions primarily as a melting machine.

Initially, melting and primary steelmaking were predominantly conducted using electrical energy. However, over time, the increased use of chemical energy, which proved to be more economical than electrical energy, has transformed EAFs from electric melting furnaces to

electrochemical hybrid furnaces. Currently, up to 45-50% of the total energy input is chemical energy, with the remainder being electrical energy.

Especially Chemical energy packages, related equipments, EBT and LF applications that started in the second half of the 80s fueled this development, metallurgical concerns almost lost their importance in the EAF process and only electrical energy consumption and tons of liquid steel/hour melting performance became important. However, the effect of the process of staying away from metallurgical parameters on a number of very important elements remained implicit.

Recently as a part of decarbonisation studies on EAF's the impact of the use of chemical energy based on fossil fuels on the emission values of the EAF process chain has begun to be questioned and the fact that the net zero target will not be possible without holistic electrification based on green electricity obtained from renewable electricity production has come to the fore. That studies also has been brought to the agenda as a problem that is useful to be examined in terms of metallic yield, steel cleanliness, ferro alloy yield and many other parameters.

For that reason, Changes in Carbon and Oxygen balance in EAFs, which is the most important result of the current process choice is the subject of our study.

1.1. Decarburization and oxidation in EAFs

Traditionally, in the EAF melting process, the process of reducing the carbon value at the beginning of melting to the targeted carbon value for the product is carried out by natural atmospheric oxidation, where the process temperature and furnace atmosphere composition are also factors, and by oxygen gas injected through various means.

Although there are not many studies on the level of decarbonization caused by natural oxidation and the input carbon value of the raw material, there are many studies on the level of decarbonization made by the chemical energy package. Carbon removal or decarburization is also an important factor in the removal of dissolved H₂ and N in steel, depending on the magnitude of the difference between the initial and final carbon. The formation called carbon boiling is the most important element of the EAF metallurgical process. We can follow oxidation reactions depending on temperature and concentration with the Ellingham Diagram shown in Figure 1.

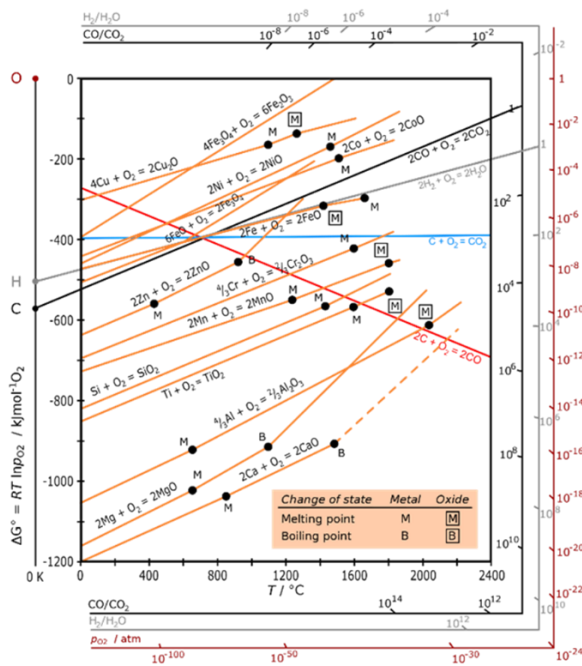


Figure 1. Ellingham Diagram

The energy balance of a typical scrap-based EAF process, is given in figure 2. The share of chemical energy is 52% of the total energy input in this example. Of course, this value is not the same in all cases, it may vary from furnace to furnace.

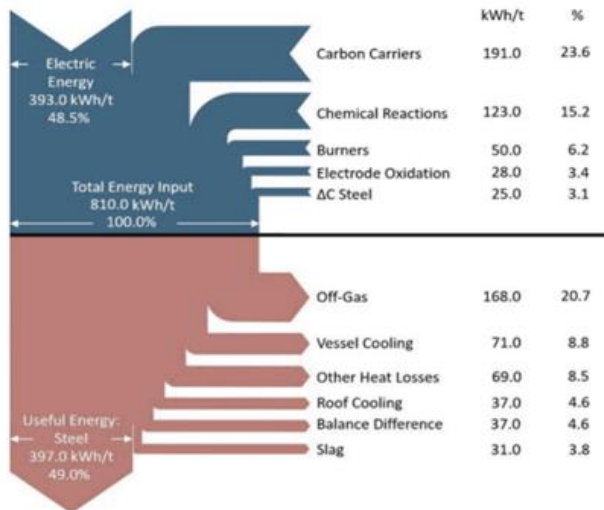


Figure 2. EAF Energy balance

Unfortunately oxidation, chemical energy and reactions have been considered important only in terms of the equivalent exothermic kWh energy input they cause, and their effects on the efficiency of elements such as Fe, Si, Mn, Al and Cr, the amount of slag and metallurgical cleanliness have been almost ignored. However, the concentrations and yields of all these elements during the process, furnace flue gas temperatures, gas volume and amounts, heat losses, slag and residue composition and amounts vary depending on the severity of oxidation.

Oxidation is the main determinant of scrap yield in EAFs.

1.2. Carbon-Oxygen Balance in EAFs

The effect of chemical energy use on the EAF emission value should be examined as a separate and very current issue, but as the subject of the presentation, the CxO relationship in scrap melting furnaces and its metallurgical effects will be briefly examined.

The dissolved oxygen level in ppm in liquid steel has long been applied as an important process control measurement in EAFs. In liquid steel, the CxO multiplier is constant under metallurgical equilibrium conditions, but equilibrium conditions are not possible in the actual process. This constant value is directly related to the CO pressure in the liquid steel.

The oxidation of carbon in liquid steel is defined as decarbonization, the reaction product CO provides the formation of CO bubbles in the metal and slag, which is called carbon boiling. The foaming of the slag and the movement of the CO bubble in the steel contribute significantly to the EAF process. In addition, the fact that CO formation is exothermic is meaningful as chemical energy support.

$$[\text{wt}\% \text{ C}] \times [\text{wt}\% \text{ O}] = P_{\text{CO}} / K_{\text{CO}}$$

K_{CO} constant is calculated with the formula $\text{Log } K_{\text{CO}} = 1056/T + 2.13$, $P_{\text{CO}} = 0.0405$ at 1 atm and 0.05% C, and 0.0202 at 0.1% C. The equilibrium state of $[\text{C}] \times [\text{O}] = 2.3 \times 10^{-3}$ (constant) at 1873 K⁰ temperature is given in Figure 3c. Figure 3b shows the balance between C and FeO_x. In Figure 3a, at the beginning of melting and casting.

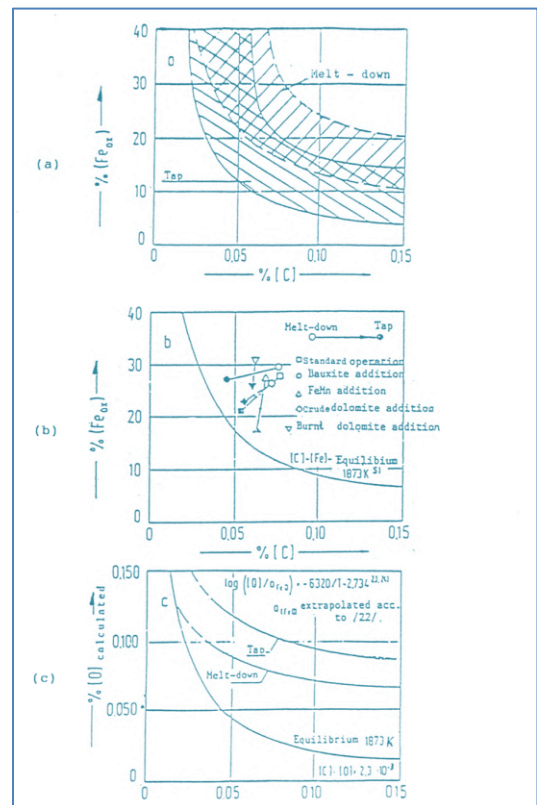


Figure 3. C, O, FeO relations at Liquid steel [1]

The level of dissolved oxygen in the steel not only affects the FeO, SiO₂, MnO, Al₂O₃ and Cr₂O₃ ratios in the slag and therefore the total amount of slag, but also determines the level of deoxidation that must be carried out in primary or secondary steel making.

In metallurgical out-of-equilibrium situations, the same liquid metal C level may correspond to different dissolved oxygen levels. The state closest to metallurgical equilibrium means the lowest oxygen level for a given carbon level. There is always a difference between the oxygen measurement value and the value calculated with thermodynamic data, this fact must be taken into account in advanced studies. The further away from equilibrium, the higher the dissolved oxygen and therefore the higher the FeO ratio in the slag for the same carbon value. Similarly, other elements in the furnace input will be exposed to oxidation at different levels and sequences. In other words, the level of use of chemical energy will directly affect the level of oxidation losses of all elements, including Fe.

The carbon removal process required for the desired/intended %C level; It should be carried out at an optimum dissolved oxygen level, taking into account parameters such as metallic productivity, yield, FeO concentration in the slag and the level of free oxygen that will have to be removed by deoxidation, thus minimizing the deoxidation products (inclusions) and affecting its composition. It is difficult to establish a direct relationship between steel cleanliness and liquid steel dissolved oxygen level. The use of ladle furnaces and tundish for residue flotation allows a significant portion of the deoxidation products to float, regardless of the amount, but it is clear that at the same flotation efficiency, a low initial deoxidation product concentration will ultimately result in a lower final product inclusion level. In addition, the higher the dissolved oxygen level at the beginning of deoxidation, the higher the amount of deoxidant required will be. This should be kept in mind as an important parameter in terms of ferroalloy efficiency. The high amount of FeO in the slag increases slag caused reoxidation in all liquid steel process steps, thus increasing inclusion formation due to reoxidation.

2. Operational results

2.1 Changes in CxO relations depending on absence of Chemical energy application at BDC melt shop.

The dissolved oxygen level in liquid steel is accurately measured with the Heraeus, Electro-Nite Celox disposable immersion sensor, which uses a special oxygen cell for extremely low oxygen activity levels with high sensitivity.

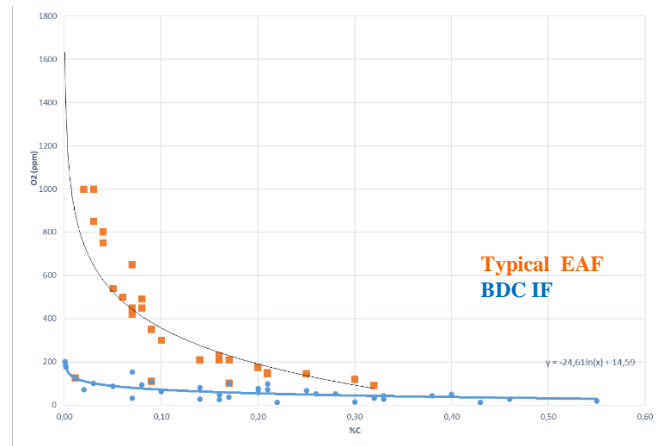
Process	CO value	Oxygen ppm at % 0,05 C
Q-BOP	15	300
LD top and bottom blowing	20	400
BOF	30	600
EAF	32	640
Oxygen rich EAF	40	800

Table 1. C&O&CO examples from different steel making processes.

As seen in the change in CO and dissolved oxygen values in different steelmaking processes specified in Table 1, there are oxygen levels varying between 800 ppm and 300 ppm in the process examples specified for 0.05% C value.

The BDC steelmaking process, which does not use any oxygen or chemical energy, is based on the use of only electrical energy due to the induction furnace. Carbon removal is possible with the partial oxidation environment obtained by adding certain proportions of mill scale to the scrap composition. Graph 1 shows the BDC and typical EAF CxO relationship graphs comparatively.

While BDC has a dissolved oxygen level of around 80 ppm at 0.05% C, typical EAF can reach 600-800 ppm.



Grafik 1. CXO relations at typical EAF and BDC conditions

There is an approximately 10-fold difference in dissolved oxygen levels between a melting process that uses 100% scrap, no chemical energy, and scale that uses 3-4% of the scrap composition, and an EAF melting process that uses nearly 50% chemical energy. Depending on these lower and upper values, EAF process cost and quality parameters will also vary.

3. Conclusion

While the fight against climate change changes the way we do business and our look at the world, the place of fossil fuels, which are the main GHG factor, in our civilization is heading towards phase out. Green electricity produced from renewable sources is also replacing classical fossil fuel-based energy uses.

The use of fossil fuel, which forms the basis of our industry due to its low cost, has become the most preferred type of energy in steel production, as in many other sectors, and the processes have been designed to take this fact into account. The world is at a turning point, and so is the steel industry. It should be taken into account that old rules and preferences are not absolute, and all process choices, especially those based on fossil fuels, must be questioned and changed.

The changes of the CxO relationship, which is the subject of our study, depending on the type of energy used in scrap-based steel production, provides very important inspirations;

- i. Scrap metallic yield is a function of the metallurgical process rather than scrap pollution; oxidation due to chemical energy use and oxidation due to the furnace atmosphere, is the main cause of yield loss. Losses that are known and considered unchangeable are not absolute. Oxidation severity directly affects the amount of slag and metallic yield.
- ii. Process development studies to reduce the severity of oxidation are the homework of metallurgists. Steel cleanliness affected by deoxidation can be reduced by changing the CxO relationship.
- iii. Chemical energy is the most inefficient type of energy, using all electricity is more correct alternative in terms of energy efficiency.
- iv. Ferroalloy efficiency depends on the CxO relationship.
- v. A very significant part of the EAF chemical energy input is thrown out of the system as flue gas, energy going to the increased amount of slag, and loss to water cooling systems.
- vi. We prefer to ask questions rather than propose a concrete metallurgical process and energy use.
- vii. There are no absolute rules, processes or truths in steel production other than thermodynamic laws.
- viii. While metal and energy efficiency should form the basis of any evaluation, it is clear that the current EAF process is not the most efficient process choice in either sense.
- ix. Every parameter, right and rule that we take for granted should be reviewed taking into account the new conditions.
- x. Digital twin, digitization, thermodynamic modelling, high efficiency, minimum loss and circularity are the new guidelines.
- xi. The decarbonization and EAF metallurgical process can be optimized with smart metallurgical software and online measurement systems and from a different perspective.

References

[1] Turkdogan, E. T. Et al, 1953

