Methods of steel manufacturing - The electric arc furnace

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Abstract. Initially, the carbon content was reduced by mixing “the iron” with metallic ingots in ceramic crucibles/melting pots, with external heat input. As time went by the puddling procedure was developed, a procedure which also assumes a mixture with oxidized iron ore. In 1856 Bessemer invented the convertor, thus demonstrating that steel can be obtained following the transition of an air stream through the liquid pig iron. The invention of Thomas, a slightly modified basic-lined converter, fostered the desulphurization of the steel and the removal of the phosphate from it. During the same period, in 1865, in Sireuil, the Frenchman Martin applies Siemens’ heat regeneration invention and brings into service the furnace with a charge composed of iron pig, scrap iron and iron ore, that produces a high quality steel [1]. An act worthy of being highlighted within the scope of steelmaking is the start-up of the converter with oxygen injection at the upper side, as there are converters that can produce 400 tons of steel in approximately 50 minutes. Currently, the share of the steel produced in electric arc furnaces with a charge composed of scrap iron has increased. Due to this aspect, the electric arc furnace was able to impose itself on the market.

1. Introduction:
The development of our century’s technology is based, to a great extent, on the usage of steel, which must comply with conditions very diversified and, in some cases, very arduous.

Inclusions are, widely, defect which lead to the discarding of a casting or forging. These are found in the molten steel under various forms and impact in a negative manner the physicochemical properties of steels.

The production of steel has ceaselessly increased, as a result of the growing requirement for metallic materials. This increase also led to amendments regarding the quality of the steel produced and the elaboration technologies.

Constructional, technological and functional modernizations of the EAF improved this aggregate’s performance and yield. The primordial objective of the modernizations was the achievement of high productivity with minimal costs. For the accomplishment of the aforementioned, the following conditions must be met:

- The rigging with a performing installation of oxy-fuel burners, for the rapid melt of the charge;
- The optimization of the charging networks, which would lead to acquiring the desired chemical composition at the end of the melting;
- High melting speed through: the charge’s preheating, maximum electrical output and additional technical input;
- The abridgment of the post-melting period;
- Minimum periods of standstill. The growth related to the productivity and energo-
technological yield of the elaboration of electrical steel is subordinated to the main
constructional, technological and functional modernizations of the EAF.

2. The “Héroult” type Electric Arc Furnace
The electric arc furnace in which the steel is elaborated uses three-phase alternating current, the
electric arc being formed between the three electrodes and the metallic charge. In view of this, it is
named furnace with direct action arc

It receives the electricity from the high-voltage grid (6-110 MV), by the agency of a transformer
that supplies the furnace with current at variable voltages - between 90 and 350 V [1].

The furnace (Figure 1) is composed of: the body of the furnace, the roof and the rocker. The body
of the furnace, with a cylindrical shape, in the form of a spherical cap or truncated cone, is built of a
shell made of thick steel plate, lined at the interior with basic refractory material (magnesite bricks or
blocks of stabilized dolomite) or acid refractory material (silica bricks). To reduce the heat losses, an
insulating layer is interlaid between the metallic shell and the refractory masonry. There are two holes
within the the body of the furnace: the steel purging outlet, equipped with a cradle, and the furnace’s
operating door .The body of the furnace is fitted on a sledge (two runners) with the aid of which it can
be tilted towards the steel’s purging outlet with up to 45° and towards the operating door with up to
15° [2].

![Figure 1](image-url)

Figure 1. The drawing of the electric arc furnace: 1-the body of furnace; 2-roof; 3-sledge; 4-
purging cradle; 5-operating door; 6-electrodes; 7-water-cooled copper rings; 8-roker

At the upper side of the Heroult type electric arc furnace, the body of furnace is covered by a
detachable roof, made of silica bricks or chrome-magnesite bricks which are resting, by the agency of
a ring, on the metal jacket. Within the furnace’s roof there are three holes, disposed in the shape of an
equilateral triangle and through these holes are inserted 6 electrodes that are supported by seven water-
cooled copper rings. The electrodes are made of graphite or graphite carbon and have threaded holes at
their ends.
The rings are positioned at the ends of some horizontal arms and are supported by vertical masts fitted on the tilting sledge in such a way that the electrodes tilt over together with the furnace. The arms that support the electrodes can move both upwards and downwards on the supporting masts, the movement being automatically controlled for the purpose of maintaining the electric arc [1]. The electric current is supplied for the transformer to the electrode’s support arm with a flexible cable and, alongside the cable, with a copper rail to the electrode’s clamp, which also performs the function of conveying the electricity to the electrode [1].

The Girod type electric arc furnace (Figure 2) represents a version of the Héroult type furnace and it is used for the elaboration of metals or alloys, especially for steelmaking, the electric arc being produced between the electrodes mounted within the roof and the furnace’s hearth. For the single-phase alternating current the furnace was equipped with one graphite electrode fitted in the roof and two metallic water-cooled electrodes in the hearth. In the case of the three-phase alternative current are used three graphite electrodes mounted in the roof, similarly to the Héroult type electric furnace, however, with a hearth that is a good conductor of electricity. At present, these furnaces are seldom used [1].

![Figure 2. Girod type electric arc furnace [2]](image)

3. The production of steel using electricity

The steel produced by using electricity as an energy source, hence, within the Electric Arc Furnace, fills the second place of the worldwide ranking of the most important routes of steelmaking.

The steel manufacturing method by means of the electric arc furnace is the main technological route of recycling the iron scrap.

Process modelling and simulations contribute to a thorough apprehension of the energy and mass transfers during the melting process and may be applied to investigate new control strategies, possibilities of recovering the residual heat or to support the operator. The EAF off-gas especially offer development potentials, due to their energetic capacity, which represents approximately 20 - 30% of the total absorption of energy, and the possibility of process control by means of the measurements performed on them [3].

The EAF off-gas, with its energetic capacity representing up to 30% of the total absorption of energy, is in the forefront of current and future developments, for the effective enhancement of the melting process within the EAF regarding the energy and resources [4-7]. Therein, the residual energy recovery systems, by means of steam generation and the enhanced process control, by means of off-gas measurements, can contribute to the optimization of the EAF process efficiency and to remaining competitive during period of rises of the energy prices and stricter environmental protection norms.

The comprehensive process simulations of the melting process and the off-gas treatment system are capable of improving the EAF’s control and to provide aidful information, for a better understanding of the energy and mass transfers. EAF’s process modelling and simulation has strongly developed
recently, due to its diverse possibility of application and the enhanced computing capacity. Several numeric models were developed for the improvement of the melting process, the enhancement of the process control through the analysis software programs or assistance to the plant’s automatization with only limited consideration of the exhaust model [3].

Regarding the EAF a comprehensive, fast and easily adjustable model of the dedusting system can contribute, when applied, to the optimization of the control strategies, the decrease of the output energy and the improvement of the residual heat.

The development of the current century’s technology is based on the use of steels, which must meet a spectrum of conditions, in some cases very difficult.

Inclusions are, widely, defect which lead to the discarding of a casting or forging. These are found in the molten steel under various forms and impact in a negative manner the physicochemical properties of steels [8], [9].

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**Figure 3.** Al$_2$O$_3$ indogenous inclusion [8]

**Figure 4.** Al$_2$O$_3$ · CaO exogenous inclusion [8]

Quality steels must have a high degree of purity in non-metallic inclusions and gases to be insensitive to the formation of flakes, to overheating and to possess a high tenacity, properties that must be regularly acquired. Thus, the production needs to be uniform in time.

The amount of oxide inclusions present in each ton of steel is of the order of 1012…1015 inclusions, considering a molten steel which contains 100 ppm oxygen that was advancedly deoxidized with the aluminum, forming spheric particles of Al2O3 with $\rho=4g/cm^3$. Thus, depending on the diameter from Table 1, the following distribution of the number of inclusions is acquired.

**Table 1.** The distribution of the Al$_2$O$_3$ inclusions depending on their diameter in steel with 100 ppm and oxygen.

| The inclusion's diameter in μm | No. of inclusions/ton of steel | Steel Volume/inclusion | Minimal distance between the inclusions |
|-------------------------------|--------------------------------|------------------------|----------------------------------------|
| 1000                          | $10^5$                         | 1,3 cm$^2$             | 1,1 cm                                 |
| 100                           | $10^8$                         | 1,3 mm$^2$             | 1,1mm                                  |
| 10                            | $10^{11}$                      | 1,3·$10^6$μ$^7$        | 110 μ                                  |
| 1                             | $10^{14}$                      | 1,3·$10^7$μ$^7$        | 11 μ                                   |
| $10^{-1}$                     | $10^{17}$                      | 1,3 μ$^7$              | 1,1 μ                                  |
| $10^{-2}$                     | $10^{20}$                      | 1,3·$10^{-2}$μ$^2$     | 0,11 μ                                 |
Aside from the inclusions, significant amounts of hydrogen (derived from the dissociation of the water vapors) and nitrogen (originated from the atmosphere) are dissolved in the steel. These gases generate deficiencies, if they remain within the steel.

Within the steel, during the elaboration, excepting the non-metallic products (inclusions) resulted pursuant to the elaboration processes and the casting conditions, are dissolved substantial amounts of hydrogen (derived from the dissociation of the water vapors) and nitrogen (originated from the atmosphere).

If they remain within the steel these gasses cause defects: the hydrogen induces intercrystalline fractures, known as flakes, or structure deficiencies - shadow lines, and the nitrogen increases the steel’s tendency to age.

![Hydrogen solubility in iron depending on the temperature](image)

**Figure 5.** Hydrogen solubility in iron depending on the temperature [9]

Over the last two decades significant amendments intervened in the design and organization conception of the high capacity modern steel plants, by the emergence of the “ladle metallurgy”, which consists in the fragmentation of the elaboration technology in two major phases.

During a first phase, also named as “primary elaboration”, which takes place within a classic metallurgical aggregate (electric arc furnace), an intermediate liquid product is obtained (crude steel), as a result of the melting and stirring. This product is then subjected to several refining and alloying operations, which constitute the secondary elaboration phase, outside the elaboration aggregate, both in the casting ladle and some specialized aggregates.

4. **Conclusion**

The steel produced by using electricity as an energy source, hence, within the Electric Arc Furnace, fills the second place of the worldwide ranking of the most important routes of steelmaking.

The steel manufacturing method by means of the electric arc furnace is the main technological route of recycling the iron scrap.

The EAF off-gas is in the forefront of current and future developments, for the effective enhancement of the melting process within the EAF regarding the energy and resources.

The comprehensive process simulations of the melting process and the off-gas treatment system are capable of improving the EAF’s control and to provide aidful information, for a better understanding of the energy and mass transfers.
A comprehensive model, fast and easily adaptable to the dedusting system when it is applied, can contribute to the optimization of the control strategies, the decrease of the output energy and the improvement of the EAF’s residual heat.

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