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LF Refining Process Optimization Strategy

Xuanwu Guan, Zhong Yan*, Jinghui Zheng, Chaoguang Liang, Huiyong Li, Pengfei Zhang, Xiangyang Lu

Second Steelmaking Plant, Hesteel Group Wuhan Steel Company Henan, Pingdingshan, 462500, China

**Corresponding author: 15799104572@163.com*

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Abstract: Optimizing refining processes is crucial for the advancement of steel mills. This study provides a comprehensive overview of historical LF methods, examining their strengths and weaknesses. By comparing and analyzing various refining processes, it highlights the advantages of the LF refining process, including its low equipment investment cost, suitability for smelting multiple steel grades, and compatibility with other refining methods. Whether establishing new lines or upgrading existing ones, the LF process offers high cost-effectiveness. Strategies such as phased aluminum calcium line feeding and the use of new refined slag to replace fluorite have been successfully employed to enhance the LF refining process, yielding significant results in practical applications. This study serves as a technical reference and offers development insights for refining process optimization in steel plants.

1. Introduction

The basic definition of the boundary between steel and iron in the study of steelmaking processes should be clear. In the oxygen blowing steelmaking process, the carbon content in the metal melt or iron solution is constantly changing. Steel and iron are defined according to the carbon content in the austenite of the iron solution: a carbon content of w[C] = 0.007% to 2.11% is called steel, w[C] = 0% is called chemical pure iron, w[C] = 0 to 0.007% is called industrial pure iron, and w[C] = 2.11% to 4.5% is called industrial pure iron[1].

The traditional steelmaking process consists of two steps: primary refining and secondary refining. Electric arc furnace (EAF) or basic oxygen furnace (BOF) [1], collectively referred to as the primary refining furnace, where melting, dephosphorization, decarburization, and alloying of the charge take place in an oxidizing atmosphere. Secondary refining, also known as secondary refining (or multiple refining based on the number of refining cycles), involves transferring the initially refined steel from the converter (or electric furnace) to another reactor for refining. Steel ladle refining (LF) or RH (named after the first letters of Ruhrstahl and Heraeus, the companies that jointly developed it) involves deep decarburization, degassing, deoxygenation, desulfurization, removal of inclusions, and inclusion modification treatment under vacuum, blowing inert gas (usually argon), adding various fluorites, alloys, lime, aluminum calcium wires, aluminum grains, or under controlled atmosphere conditions, adjusting composition, and controlling the temperature of the steel, thereby optimizing the process and product structure, developing high-value-added products, saving energy, reducing consumption, reducing costs, and increasing economic benefits [2].

Although LF technology has been widely adopted in numerous steel mills across China, it is not without its drawbacks. For instance, a study conducted at the first steel plant of Henan Jiyuan Iron and Steel Co., Ltd., by scholars Chao Xia and Sheng Guoxiang, highlighted the significant erosion of refractory materials in the steel ladle during the refining process outside the furnace [3]. Additionally, various scholars have pointed out limitations of LF equipment in smelting specific steel grades. Deng Jidong and Qian Xiaolong noted that the conventional LF refining process, which relies on manual control of argon blowing, is susceptible to external environmental factors such as pressure and temperature fluctuations, as well as issues like steel brick blockage and pipeline leakage in the ladle, often resulting in erratic flow rates [4]. Achieving precise control of argon gas flow rate, particularly in challenging working conditions with stringent production requirements, remains a significant challenge. Furthermore, scholar Meng Jingsong raised concerns about deep desulfurization during the smelting process of petroleum pipeline steels GR653 and GR535 in the 180TLF furnace at the second steel plant of An steel in the northern region [5].

With the high-quality development of various industries in China, the development trend of new steel materials is ultra-clean, high uniformity, and microstructure control. The secondary refining process of the steel plant is an important process to ensure the quality of the molten steel, expand the product range, and ensure energy saving and environmental protection. Therefore, the optimization of the refining process is of great importance for the steel plant to form new quality productivity, open up the market, and achieve self-development.

2. Comparison of Process Characteristics of Different Refining Equipment

According to the different types of steel produced, secondary refining technologies such as RH, CAS (Caustic Arc Stirring), KIP (Kimizu Injeet Procass), LF, DH (Dortmund Horder) followed by VOD (Vacuum Oxygen Decarburization) or VAD (Vacuum Arc Degassing) for vacuum treatment are used. DH is mostly used in Japan, while most steel plants in China use RH and LF for single or multiple combined cross treatments. Table 1 provides a detailed introduction to the refining methods and purposes currently in use.

The main part of the RH refining unit includes the steel ladle and the vacuum chamber, with a dipping tube installed at the bottom of the vacuum chamber. During vacuum treatment, the vacuum chamber is lowered or the steel ladle is lifted to insert the dipping tube into the molten steel to a certain depth. At this point, the vacuum pump system above the vacuum chamber is activated. Under the pressure difference, the molten steel will flow through the dipping tube into the vacuum chamber and occupy the lower part of the chamber. Meanwhile, gas (usually argon) is introduced into the nozzle of the upriser, and the molten steel in the ladle is propelled by the buoyancy of the bubbles into the upriser, forming bubble nuclei in the steel. The gas in the molten steel diffuses into the bubbles, causing them to expand rapidly. The molten steel first sprays into the vacuum chamber in a jet-like fashion, where degassing reactions take place. Then, under the force of gravity, the molten steel flows back into the ladle through the downcomer, achieving the purpose of refining the molten steel through multiple continuous cycles. The technical characteristics of RH refining are strong decarburization capability; effective degassing, effectively controlling the hydrogen and nitrogen content in the molten steel; suitable for large-scale molten steel treatment, with the vacuum pump circulating the molten steel, unrestricted by the conditions of the steel ladle, and having a short treatment cycle; the temperature drop during the treatment process is small; additionally, alloys can be added in the vacuum chamber to accurately control the composition of the molten steel[4-5].

Table 1: Parameters and Characteristics for Different Refining Technological [3]

Number	Name	Refining Techniques			Main Metallurgical Functions									
		Slag formation	Vacuum	Agitation	Injection	Heating	Degassing	deoxidation	Inclusion removal	Control of inclusion morphology	Alloying		Temperature adjustment	
1	DH		√				√							
2	RH		√				√							
3	**LF**	+	○	√		√	○	√	√		+	√	√	
4	**CAS-OB**			√	√	√		√	√			√	√	
5	**VAD**	+	√	√	+	√	√	√	√		+	√	√	+
6	**VOD**		√	√	√		√	√	√					√
7	**Argon stirring in steel ladle**			√					√				√	
8	**CAB**	+		√				√	√		+	√		
9	**ASEA-SKF**	+	√	√	+	√	√	√	√		+	√	√	+
10	**RH-OB**		√		√		√							√
11	**AOD**				√		√							√
12	**TN**				√			√			√			
13	**SL**				√			√		√	√	√		
14	**Wire feeding**							√		√	√	√		
15	**synthetic slag washing**	√		√				√	√	√	√			

Notes: "+" Indicating that better metallurgical functionality can be achieved by adding other facilities; "○" After adding a vacuum device, LF is called LF-VD and has the same refining function as ASEA-SKF.

The CAS equipment can be divided into five systems and one operation center, namely: (1) bottom blowing argon system, including argon supply pipeline network, argon flow and pressure detection and control device, ladle bottom blowing argon device, and replacement device; (2) CAS hood system, including lifting device and hood replacement device; (3) Alloying and composition fine-tuning system, including material silos (commonly used alloys, cooled scrap steel, heated aluminum, and synthetic liquor), alloy weighing and fine-tuning weighing devices, feeding chutes, etc; (4) Temperature measurement and sampling system, including mechanical temperature measurement and sampling devices, instruments for recording and analyzing temperature, pneumatic sample delivery devices, etc; (5) Dust removal and exhaust system, including smoke exhaust ducts, dust removal devices, devices for extracting and guiding smoke, etc; (6) The operation center consists of a primary and secondary computer system for the operation, management, and data collection of the five systems mentioned above. The main equipment components of CAS furnace are as follows: refining ladle and ladle car; Immersion cover and its lifting mechanism protected by special refractory materials (such as corundum); Dust removal system; An alloying system with storage bags, weighing, conveying, and vibrating chutes; Temperature measurement, sampling, oxygen activity measurement device, and slag cleaning device. The bottom blowing argon control system, as well as computer and automated detection control systems.

LF refining furnace, also known as ladle refining furnace, mainly includes furnace body, top cover, heating electrode, and feeding pipeline. Due to its simple equipment, low investment cost, rich functionality, and good refining effect, it is widely used in most steel mills in China. In the LF refining process, the steel liquid that has been preliminarily smelted by the converter or electric furnace is poured into the ladle to complete a series of operations such as deoxidation, desulfurization, alloy composition adjustment, and heating. Most LF furnaces use three graphite electrodes and electric arc to bury slag for heating, which can effectively increase the temperature of the steel liquid, compensate for the heat loss during the steel refining process, and have high heating efficiency while also protecting the furnace lining. In addition, the oxygen content in the steel after converter blowing is relatively high. By adding deoxidizers and alloys such as aluminum particles and aluminum calcium wires, precipitation deoxidization, diffusion deoxidization, and composition adjustment of the steel can be achieved. At the same time, a slag making agent is added to modify the highly oxidizing slag in the converter into reducing slag. Argon gas is blown at the bottom to ensure the reducing atmosphere in the furnace. Under the reducing atmosphere, the slag steel reacts. In this process, the role of bottom blowing argon in the ladle is particularly prominent. By stirring the steel liquid with bottom blowing argon gas, the slag steel reaction rate is accelerated, allowing inclusions such as MnO, SiO, and Al_2O_3 in the steel liquid to fully float and react with reducing slag[6]. This stage is also known as white slag refining, abbreviated as making white slag. White slag refining can effectively reduce the content of oxygen, sulfur, and inclusions in steel, thereby producing steel with very low impurity content.

The production process of bearing steel at NKK Jingbin Iron Works in Japan includes blast furnace - hot metal pretreatment - converter - vacuum slag removal, ladle refining - (including powder injection, gas stirring, alloying, slag refining) - RH-CC[7]. Datong Zhiduo Plant will combine RH-LF, Sumitomo Industrial Company's converter slagging RH PB CC Wakayama Plant in Japan, as well as Nagoya Steel Plant's pipeline steel, Japanese production process and domestic Baosteel RH refining process, RH mass spectrometry online analysis, and Fujii model Chamois Model and Bacchus. The three models, as well as the production process time, quality, composition, inclusion temperature, and time of Ansteel's ultra-low phosphorus steel pipe line and heavy rail steel, were compared and analyzed with the LF method used by Wugang South Steel and others for new construction. Based on the comprehensive analysis of equipment cost, maintenance process, and new process development, it can be said that using optimized LF refining to produce clean steel is more cost-effective for new steel mills in the future, and for steel mills that already have LF equipment, the clean steel production process is more research-oriented. Therefore, optimizing the clean steel production process of LF has great prospects and research and development significance.

3. LF Case analysis of advantages and disadvantages of LF process

For the LF refining mentioned above, compared with CAS and RH in terms of comprehensive performance including the reduction of inclusions by argon blowing, slagging function, heating function, and the matching function of upstream and downstream processes on site, LF refining offers the highest cost-performance ratio. Therefore, a brief description of the LF process optimization measures that can be implemented in most domestic steelmaking plants will be provided.

3.1 Practice of LF Refining Furnace Process in the Steelmaking Plant of Shanxi Xinlin Steel Co., Ltd

In August 2005, the 30tLF steelmaking plant of Shanxi Xinlin Steel was put into operation for hot testing. The process flow was as follows: converter → 2 × LF furnace → continuous casting. The refining cycle is about 22 minutes, and in a short period of time, the refining furnace has played a good role in refining deoxygenation, effectively controlling the temperature of the molten steel, reducing some inclusions, and improving the internal quality of the molten steel. The short refining cycle is advantageous for the overall production of steel, but it also makes the LF refining slag making process difficult.

3.2 Huaigang Steel Co., Ltd. LF Ladle Refining Furnace

The refining process of Huaisteel 90tLF ladle is as follows: the pre blowing argon gas flow rate is controlled at 350-500NL/min, and adjusted according to the steel liquid level to meet the following process requirements. (1) After pre blowing argon for 3 minutes, measure the temperature and take a sample. (2) Turn the ladle to the heating position, lower the furnace cover, adjust the argon gas flow rate, and perform the power transmission operation. (3) First, use the arc voltage to current the slag shell, then add slag to the furnace for slag making. Add an appropriate amount of lime to each furnace and add corresponding fluorite. To ensure rapid slag melting, various slag materials should be added in batches as early as possible. (4) Ensure that liquid white slag is formed within 15 minutes of power supply, and maintain the white slag for no less than 10 minutes. (5) Add an appropriate amount of deoxidizer (silicon powder, calcium carbide, aluminum particles) to the slag surface, and close the observation door. （6） After slag making is completed, raise the electrode and cut off the power for temperature measurement and sampling. The slag making process is easy to control and adjust, but the flow valve of the argon gas meter is difficult to control. The detailed process requires manual control and calculation, which is prone to human errors. Various equipment conditions require strict requirements and require constant maintenance and repair. The inability to execute the process can easily lead to quality problems.

3.3 Han Steel and Ansteel LF Large Ladle Refining Furnaces

After the initial smelting of the 120T ladle refining furnace in Han Steel and the 100T refining furnace in Angang, the ladle containing molten steel enters the refining process. After connecting the quick ammonia blowing joint at the bottom of the ladle, the ladle is transported to the heating station by the LF furnace ladle car. Lower the ladle cover of the LF furnace, and at the same time, perform timely electric arc starting operation to heat the molten steel and flux. After melting, the flux should be maintained for a certain period of time to facilitate the removal of P and S inclusions. The bottom blowing of argon throughout the entire process of the LF furnace is beneficial for heating and uniform composition, as well as for desulfurization and removal of impurities. Blowing argon bricks is prone to lack of air permeability, resulting in secondary refining. The degree of automation is low and requires a lot of manual labor.

3.4 Operating process regulations for a 100t LF furnace in a certain steel plant

Molten steel entering the station - connecting to the bottom argon blowing pipe - entering the working position of the ladle - temperature measurement and sampling (oxygen determination) - heating and slagging, and adjusting the composition—Temperature measurement and sampling (fixed oxygen) - wire feeding - static blowing - temperature measurement and sampling - molten steel to non working position - adding insulation agent (rice husk) - hanging ladle - continuous casting. The desulfurization and deoxygenation effect is significant, and the amount of impurities floating on the slag is reduced, ensuring quality and controllable temperature. However, there are certain requirements for the raw material conditions, such as the clearance of the initial steelmaking furnace, the thickness of the slag layer, and the content of components such as P, S, and C, making it difficult to control the argon blowing intensity. [8-9]

In short, The LF (Ladle Furnace) process offers several advantages in steel refining, including its capability for precise composition adjustments, reduction of non-metallic inclusions, and superior temperature control, contributing to enhanced product quality and energy efficiency. However, challenges exist, such as rapid refractory wear necessitating frequent maintenance, reliance on manual operation leading to potential process inconsistencies, and susceptibility to environmental factors affecting stability and control. Additionally, LF furnaces have limited capacity compared to larger vessels, and achieving deep desulfurization may require additional steps or modifications, adding complexity and cost to the process. Therefore, it is of great significance to find optical method for LF refining process.

4. LF Optimization strategy for LF refining process

Optimization has been carried out from different perspectives for LF ladle refining furnaces, but both equipment and individual process and process improvements are closely related to the process.

4.1 Optimization of deoxygenation process

Through extensive practice, it has been proven that the deoxidation of LF furnace can be controlled from the previous process, namely the initial refining furnace. Secondly, the reduction of endpoint oxygen content in molten steel should be controlled within a reasonable range. Thirdly, steel alloying is achieved by adding an alloy when a quarter of the molten steel is poured out. After adding the alloy, 2kg/t of lime top slag is added to achieve pre slag formation and slag washing of the molten steel Optimization of supplied materials from manufacturers: Introducing new types of deoxygenation materials such as aluminum calcium composite deoxygenation slagging agents, which contain small flakes of aluminum scattered in deoxygenation balls, can improve the deoxygenation efficiency of steel slag and reduce the waste of aluminum sheets caused by dust removal. Using a flow rate of 100-300 L/min to ensure the molten steel is not exposed during the process; So as to improve the floating rate of non-metallic impurities and quickly fuse with the top slag, improve the purity of molten steel to ensure quality, and reduce smelting time. (2) Using a speed of 300-600 L/min as the stirring speed for electric heating and equal intensity, to ensure the effect of submerged arc and uniform steel temperature; (3) Improve smelting rhythm and efficiency with a strong stirring speed of 800-1000L/min for deoxygenation and desulfurization.

4.2 Optimize smelting process

In order to optimize the smelting process, a composite deoxygenation slag making agent was tested to adjust the content of steel slag, improve the adsorption level of inclusions, and enhance its liquid fluidity. Furthermore, for the deoxidation of steel slag, a new type of aluminum calcium composite deoxygenation slag making agent material can be used to improve the formation rate of white slag.

It is necessary to adjust the overall material composition of the slag material, replacing the expensive and easily causing a sharp temperature drop fluorite with a cheap powder containing a high calcium fluoride slag agent and powder like fluorite powder. This can reduce temperature drop losses and improve the viscosity of the steel slag Disposable aluminum feeding deoxygenation process: during the deoxygenation of molten steel, aluminum is fed in one go. By adjusting the steel grade, the number of times the aluminum wire is fed is reduced. By feeding the aluminum wire in one go, the w (all aluminum sample Als) in the steel is $\geq 230 \times 10\text{-}6$, which reduces the frequency and repetition of adding aluminum, improves the efficiency of refining deoxygenation, helps inclusions float, and helps improve the quality of molten steel.

The composite calcium aluminum cored wire, which uses a new type of steel shell wrapped with aluminum particles and high-pressure hot drawn pure calcium ingots, has the characteristics of small temperature drop before and after wire feeding, short wire feeding time, low wire feeding amount but high yield.

The clearance height of steel is closely related to the casting allowance, ladle age, and converter steel output. The distance between the steel slag interface and the wire feeding guide is affected by the clearance of the ladle, which can lead to a shallower depth of the calcium wire and cause severe flipping, reducing the absorption rate of the calcium wire. Therefore, it is necessary to use a new type of wire feeding guide to change the position of the guide in space.

5. Conclusion

This article summarizes the characteristics of different refining processes through literature collection, analyzes the optimization strategies of LF refining processes, and draws the following conclusions:

Firstly, by using fluorite powder and slag dissolving agent instead of fluorite, the rate of temperature loss is accelerated and reduced. The optimization measures of the smelting process increase the rate of inclusion floating in the molten steel, increase the adsorption capacity of inclusions, improve the rate of slag reduction in the LF ladle refining process, reduce the oxide content, and improve the purity of the steel, reducing the cost of deoxygenated raw materials in the refining process.

At the same time, by optimizing the LF ladle refining process, enterprises can reduce costs, achieve fast slag making, good deoxygenation and desulfurization effects, improve steel quality, and reduce manual labor. It is an important process for modern enterprises to achieve high-quality and green development, and also has research significance for scientific research.

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