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Lime Addition before Vacuum Carbon Deoxidation in Stainless Steel Manufacturing

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Abstract: ***This paper is regarding Stainless Steel manufacturing. The Previous process of Stainless Steel dealt with lime addition "AFTER" Vacuum Carbon Deoxidation whereas the Modified process deals with lime addition "BEFORE" Vacuum Carbon Deoxidation. The Modified process has an impact on Temperature drop, Oxygen consumed for blowing, Carbon drop, S drop, Refractory consumption, Electricity consumption and Electrode consumption. The whole process deals with the melting process at Ultra High Power Electric Arc Furnace, Oxygen blowing at Vacuum Oxygen Decarburization, Vacuum Carbon Deoxidation and Reduction. Further the liquid metal is cast into blooms in a bloom caster.***

Keywords: Scrap, Ladle, Furnace, VOD, VCD, Reduction, Tundish, AMLC, Stopper rod, EMS, Bloom, Nozzle, purging, porous plug, slide gate

1. Introduction

This paper deals with Stainless Steel making through the UHPF-VOD-LRF-BC route.

Scrap Yard

Scrap yard is the place where the raw material for the UHPF is stored. The main raw material used is the stainless steel scrap.

UHPF

The UHPF (Ultra High Power Furnace) is an electric arc furnace [1][2]. Here the inputs are SS (Stainless Steel) scrap, ferroalloys and lime. With the help of electrodes the charge is made molten. When the temperature reaches around 1630±10°C the liquid metal is poured into a ladle. This pouring of liquid metal into the ladle is known as tapping. There is a nonmetallic layer over the liquid metal in the furnace. This is known as slag. While tapping, the slag is not allowed to enter into the ladle. This is known as slag free tapping. The duration of the total furnace process is 60 minutes.

The furnace has a steel shell. In order to protect the shell of the furnace, there is brick lining and water cooled panels. The brick lining must be basic in nature because the slag produced in the furnace due to the reactions is basic in nature. Lime is the major content of the slag. Basicity is the ratio of CaO and SiO2 and the basicity of the slag must be greater than 2. The critical parameters that are monitored here are Electricity consumption, Electrode consumption, Refractory consumption and Oxygen consumption.

Here the production is done in batches. One batch is known as one Heat and the number of heats taken in the furnace is its life. The average life of the furnace is around 3000 heats.

VOD

The ladle is placed on a car for tapping. After tapping the ladle is shifted to another car which has a vacuum vessel. The ladle has a shell made of steel. Further, it has a basic lining because the slag generated in VOD (Vacuum Oxygen Decarburization) is basic in nature. VOD has a lance to blow oxygen. The lancing is done under vacuum. The main reaction that takes place during the lancing is,

$$\underset{(24\ kg)}{2C} + \underset{(22.4\ nm^3)}{O2} \leftrightarrow \underset{(56\ kg)}{2CO} + Heat$$

Here the product is a gas and it is continuously evacuated with the help of applied vacuum. The pressure is around 300mb. The starting carbon is about 0.50%. The calculated amount of oxygen is as follows.

The Carbon content in steel

= 0.50 x 45000/100
= 225 kg

The oxygen required to burn 225 kg of carbon

= 22.4/24x225
= 210 nm^3

Since the efficiency of oxygen is 60% only, the oxygen required

= 210/0.60 = 350 nm^3

This is blown with the help of an oxygen lance. Then vacuum carbon deoxidation is conducted under deep vacuum. At this stage the pressure is less than 2mb. The flow rate of oxygen is 10 to 11 nm^3/minute. Further, the reduction is conducted. During reduction lime is also added. The amount of lime is about 2000 kg for a heat size of 45000 kg. Then the ladle is taken out from the vacuum chamber. Later the temperature and the composition are

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checked. The critical parameters here are chemical composition, temperature, refractory consumption and oxygen consumption.

The duration of oxygen to be blown

= 350/11
~ 30 minutes

The duration of VOD is 30 minutes. The duration of VCD is 15 minutes. The duration of reduction is 5 minutes.

LRF

At LRF (Ladle Refining Furnace) [1] [2] final temperature and composition are adjusted. After achieving castable temperature and composition, the ladle is sent to the bloom caster. The critical parameters here are electrode consumption and electricity consumption.

BC

Bloom, in our case, is a piece of metal which has cross sectional area 250x250 mm2 and length around 4 m. At BC (Bloom Caster), from the ladle the hot metal is poured into another vessel called Tundish through the ladle nozzle. From the Tundish the hot metal is poured into two oscillating molds for continuous casting. There is a facility called AMLC (Automatic Mould Level Controller). Another facility is EMS (Electro Magnetic Stirrer). This is to homogenize the composition thereby avoiding segregation. Stopper rods are used to control the liquid metal flow through tundish nozzles.

Here the output is known as Bloom. They are initially water cooled and later air cooled. Further all the quality checks are done and delivered to the next internal customer mostly rolling mills.

The number of heats taken in a ladle is known as ladle life. The average life of a ladle was 10 heats before taking the trial. There is a directional porous plug in the bottom of the ladle for purging. Purging is required for achieving homogeneous temperature and composition. The medium used for purging is either argon or nitrogen. In nitrogen desired heats nitrogen is used as the medium and for others argon is used. Also there is a slide gate system to control the liquid metal flow from ladle to tundish. Tundish is a reservoir used between ladle and mould.

2. Experiment

Previous Process

In our plant, the heat size is 45,000 kg. The lime added during reduction is 2000 kg. Lime is more or less same in all the grades of stainless steel.

It was observed that, the temperature at the end of lancing was 1700±20ºC. It was also observed that the temperature after the reduction was 1540±20ºC. This means a temperature drop of 150±20ºC. The duration of VCD is 20 minutes and reduction is 5 minutes. The rate of temperature drop is 7°C per minute.

So the temperature at the time of lime addition is around 1600°C. The duration between end of lancing and reduction end is 20 minutes. Thus it is a massive drop of temperature and it causes a drastic thermal shock. This is the main reason for less ladle life, which means high refractory consumption. A detailed analysis revealed the following. For the entire duration of VCD there was no protection over metal matrix. This resulted in heavy radiation loss through the top of the metal.

It was also observed that the expected Carbon was not achieved after reduction. It was as high as 0.025%. We expect a carbon level less than 0.015% The analysis of lime lead to a breakthrough. The lime analysis report was as follows.

CaO= 93%
C= 0.50 – 0.80%
S= 0.06 – 0.07%

This means,

Carbon content in 2000 kg lime
= 2000x0.50/100
= 10 kg

Therefore the % of 10 kg carbon in 45000 kg metal
= (10/45000)x100
= 0.020%

Volume of Oxygen required to burn off 10 kg of Carbon
= 9.33 nm^3
~ 10 nm^3

Weight of 22.4 nm^3 of oxygen
= 32 kg

Weight of 1 nm^3 of oxygen
= 32/22.4
=1.43 kg

Weight of 10 nm^3 of oxygen
= 10x1.43
= 14.3 kg
~ 15 kg

15 kg Oxygen in ppm
= (15/45000)x1000000
= 317 ppm in steel
~ 300 ppm

The final observation was that the expected sulfur level was not achieved. It was as high as 0.021%. We expect it to be less than 0.010%. It is because the temperature drop is massive and the basicity of slag is very poor during VCD. When lime was added to improve basicity, the temperature was low. So effective duration of sulfur removal reaction was not taking place. Whenever an addition has to be made at VOD station, the vacuum need to be broken and kept the pressure at around 350 mb.

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Modified Process

As an experiment we added lime just before VCD. The vacuum level achieved for VCD is less than 2 mb. The lime here acted as a protective cover for the liquid metal for the entire duration of the remaining process. It takes care of the massive temperature drop and hence the thermal shock is minimized. In turn it takes care of the ladle life and refractory consumption. The temperature after lancing was 1700±20ºC. The same after reduction was 1630±20ºC. This means the temperature drop is only 70±20ºC as against 150±20°C in Previous process. This temperature drop is only one half as compared to previous process.

As the lime is added early, sufficient residual oxygen is available to burn off the Carbon in steel and lime. The oxygen required to burn off 10 kg Carbon is 9.3 nm^3. As the vacuum levels reached less than 2 mb there will be heavy turbulence which will enhance reaction at slag metal interface. Hence we could achieve carbon levels less than 0.015%.

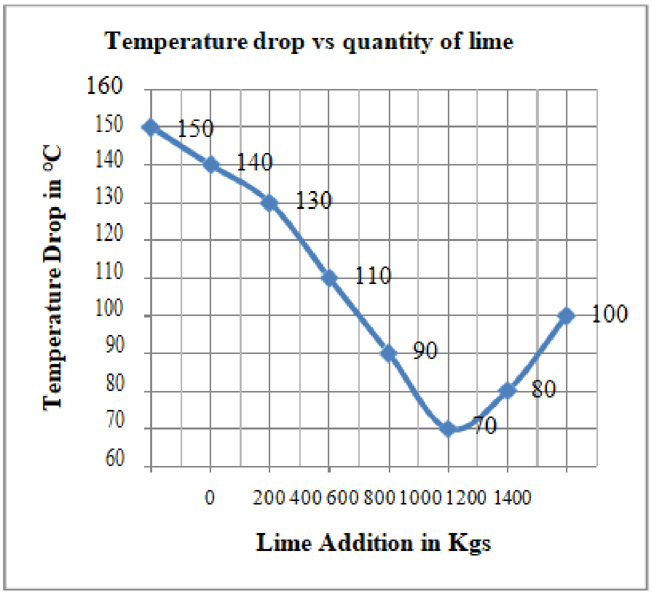
As the lime is added early, the required basicity can be developed right from VCD itself. Hence we could achieve a sulfur level less than 0.010%.

The mechanism of reaction is as follows. As the vacuum is dropped, the bath becomes agitated. This results in the formation of metal and slag droplets. This phenomenon increases the slag metal interface many folds. Slag droplets will go into metal matrix and metal droplets will go into slag matrix. A controlled trial was conducted and a graph was plotted. It was the temperature drop vs lime addition. The temperature drop was initially decreasing and later when the lime addition crossed 1000 kgs the temperature drop started.

3. Results

Previous temperature after reduction	: 1540±20°C
Modified temperature after reduction	: 1630±20°C
Previous C levels after reduction	: 0.025%
Modified Carbon levels after reduction	: 0.015%
Previous S levels after reduction	: 0.021%
Modified Sulfur level after reduction	: 0.010%
Previous electrode consumption at LRF	: 0.30kg/ton
Modified electrode consumption at LRF	: 0.10kg/ton
Previous electricity consumption at LRF	: 30KWH/ton
Modified electricity consumption at LRF	: 10KWH/ton

Previous Ladle life 10
Modified Ladle life 11



4. Cost Benefit Analysis

The main benefits are reduction in electricity consumption, electrode consumption and refractory consumption.

The average size of one heat = 45 tons

Number of heats produced per day = 8 heats
Number of heats produced per month = 8 x 30
= 240 heats

Number of heats produced per annum = 240 x 12
= 2,880 heats

Total tons produced per annum = 2880 x 45
= 1,29,600 tons
~ 1,00,000 tons.

4.1 Electrode Consumption

Previous average electrode consumption = 0.30 Kg/Ton

Modified average electrode consumption = 0.10 Kg/Ton

Hence Kg/Ton savings = 0.30-0.10
= 0.20 Kg/Ton

Hence savings in Kgs per Annum = 0.20 x 1,00,000
= 20,000 Kgs

Cost/Kg of electrode = Rs. 200

Hence savings in Rs./Annum = 20,000 x 200
= Rs. 40,00,000

Electricity Consumption

Previous average electricity consumption = 30 KWH/Ton

Modified average electricity consumption = 10 KWH/Ton

Hence KWH savings per ton = 30-10
= 20 KWH/Ton

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Hence KWH savings per annum = 20x1,00,000
= 20,00,000 KWH

Cost of one KWH = Rs. 7

Hence savings in Rs. Per annum = 20,00,000 x 7
= Rs. 1,40,00,000

Refractory Consumption

Previous average ladle life = 10

Total liquid metal weight = 10 x 45
= 450 Tons

Average net weight of ladle refractory = 17,000kg

Refractory per liquid metal ton = 17,000/450
= 38 kg/ton

Modified average ladle life = 11

Total liquid metal weight = 11x45
= 495 Tons

Refractory per liquid metal ton = 17,000/495
= 34 kg/ton

Refractory savings in kg/ton = 38-34
= 4 kg/ton

Average cost of refractory = Rs. 50/kg

Annual savings in money = 5x 1,00,000 x 50
= Rs. 2,50,00,000

Hence total annual saving in Rs.
40,00,000+1,40,00,000+2,50,00,000 = Rs. 4,30,00,000

5. Conclusion

Add an optimum quantity of 1000 kgs of lime, just before VCD of Stainless Steel process. It will have the following impact on the process. The affected parameters are thermal shock, Carbon level and Sulfur level.

Thermal shock:

The thermal shock must be minimum. In the controlled trial, as the lime is added as early as VCD start, it acts as a protective cover for the metal. This cover prevents the heat loss due to radiation. In this case the temperature drop is just the half which is 70°C as against 150°C in the previous process.

Carbon level:

We need to remove carbon as much as possible as carbon is not desirable in stainless steel. Carbon is present in steel as well as lime. So if the lime is added before VCD the residual Oxygen gets enough time to react with the carbon. The carbon level after reduction is 0.015% in Modified process as against 0.025% in the previous process. The favorable conditions for Carbon removal are higher residual oxygen, higher temperature, deep vacuum and agitated bath. All these conditions are satisfied here, but in the case of previous process, the effective carbon removal reaction does not take place as far as the carbon in lime is concerned.

Sulfur level:

Sulfur is also not desired in stainless steel. Favorable conditions for sulfur removal are higher basicity, higher temperature, deep vacuum and agitated bath. And all these conditions are satisfied here. The sulfur opening after reduction in the Modified process is 0.010% as against 0.021% in the previous process. In the Modified process the duration available for effective sulfur removal reaction is 20 minutes whereas, it is only 5 minutes in the case of previous process.

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[2] Electrometallurgy Part2 by F P Edneral

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