Experience with long BOF Campaign Life and TBM Bottom Stirring Technology at Meishan Steel in China

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ABSTRACT

Meishan Steel in China is an integrated steelplant located close to Nanjing in Jiangsu province in China, 250 miles NW from Shanghai. The plant has a total annual capacity of 3.50m tons per year (tpy) supplying various steel grades including cold forming steel, structural steel, automotive structure steel, corrosion resistant structural steel, welding gas cylinder steel, checker plate, built welded line pipe steel and others.

Because of the iron ore source used hot metal Phosphorous content is rather high with 0.12 - 0.15%. To achieve low Phosphorous contents in the molten steel below 0.011 - 0.017% in 2002 the TBM (Thyssen Bottom Metallurgy) bottom stirring technology was introduced in the plant to improve the performance results. Since the vessel tap weight of 150 t/heat only is rather low, the downtime for BOF reline was reduced by increase of refractory lining life by introduction of slag splashing.

Over the last decade a combined technology of long BOF campaign live (10,000 heats and more) with performing TBM bottom stirring was successfully developed. This paper describes the operation technology applied at Meishan steel and demonstrates the benefits achieved by combined blowing technology.

INTRODUCTION

The 150t/heat BOF shop of Baoshan Iron & Steel Co. Ltd. (Meishan) was commissioned in 1995. The designed annual capacity is 3.5m tpy of continuous cast slabs. The process flow includes two hot metal submarine car re-ladling stations, a three stand co-injection HM-desulfurization station, three 150t combined blowing BOF vessel, three Ar-stirring stations, two ladle furnaces, two RH-degassers, one CAS station and two 2-strand slab CC-machines, **Figure 1**. The current production extends the designed capacity by 10%, in 2011 3.85m tpy of slabs were produced in the shop. The quality program of the shop includes basically carbon structure steel, tin plate, pipeline steel and some specialty steel grades.

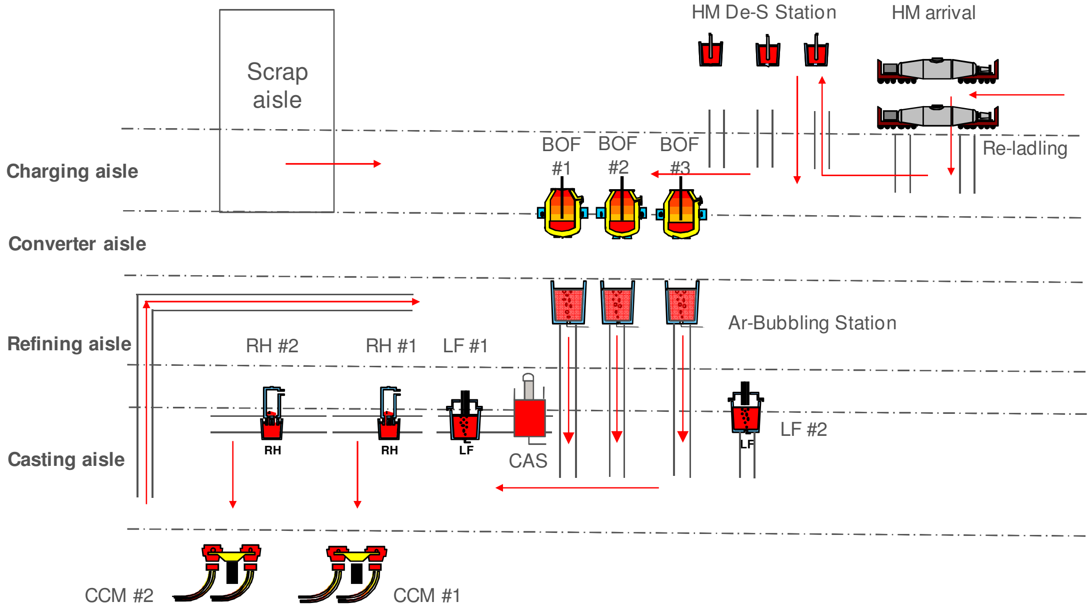


Figure 1: 150 t/heat BOF shop at Baoshan Iron & Steel Company (Meishan)

All three BOF converters are equipped with the TBM bottom stirring system. The inert gas used for bottom stirring is either argon or nitrogen. The minimum achievable [C]*[O] is 18. The slag splashing ratio is more than 95%, ensuring a BOF campaign of more than 10,000 heats with effective bottom stirring during the whole campaign which is at the most advanced level in China. The converters are equipped with sublance systems and automatic blowing control systems.

METALLURGICAL REQUIREMENTS OF MEISHAN STEELMAKING OPERATIONS

The production of ultra-low carbon grades requires that already at the BOF stage the heats are blown down to a Carbon level that allows the RH-degasser operations to be self-sufficient, i.e. without additional oxygen blowing. On the other hand too high oxidation in the BOF should be avoided to minimize iron losses and reduce alloy and de-oxidation agent consumption. Therefore at Meishan the heats are blown down to 0.040% in average, as shown in **Figure 2** on the left side.

The challenge for BOF operations at Meishan is the hot metal Phosphorus content, as shown in **Figure 2** on the right side. The Phosphorus in hot metal varies between 0.12 – 0.15% with an average of 0.137%. It has to be blown down in the BOF process to a level 0.017% in average to safely meet the specification of 0.020% in a single slag process. Very low Phosphorous specifications require a double slag process where slag is changed after approximately 5 - 6 minutes of the blow. In **Figure 2** also the Phosphorus content at the in blow sampling (TSC) is shown. It becomes clear that at this stage (1,616°C, 0.38% C) the Phosphorous still is at a level of 0.056% and must be blown down to the specification in the remaining two minutes of the blow. To ensure a good mixing of metal and slag during this critical phase of the blow, bottom stirring is the most useful method. At Meishan this is an important issue because tapping temperature with 1,676°C in average is rather high compared to other BOF shops producing the same steel quality program.

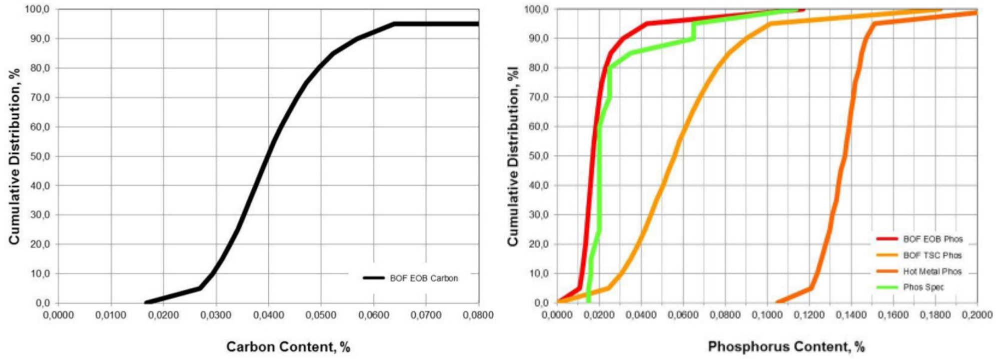


Figure 2: Carbon and Phosphorus Profile of Meishan BOF steel operations

BLOWING REGIME

The Blowing process is operated with a 5-hole 15.0° blowing lance tip with a blowing rate of 500 m_n^3/min. The lance was changed from former 17.5° angle to 15.0° angle because it became evident to reduce the oxygen wear attack to the lining while aiming for longer campaign life. Meishan aims for long lance tip life to minimize the long lance change out time of 60min by reducing the number of changes.

The heat starts with a fixed addition of 2t/heat of lime into the empty furnace, **Figure 3**. As the next steps the calculated amounts of scrap and hot metal are charged into the furnace. The oxygen demand is recalculated based on the real weights of the charge materials and the oxygen flow is started. After ignition of the melt, the fluxes (lime, dololime and MgO-pellets), iron ore and the BOF slurry pellets from the gas cleaning system are charged into the blowing furnace. It is target to finish all additions within 30-40% of the blow.

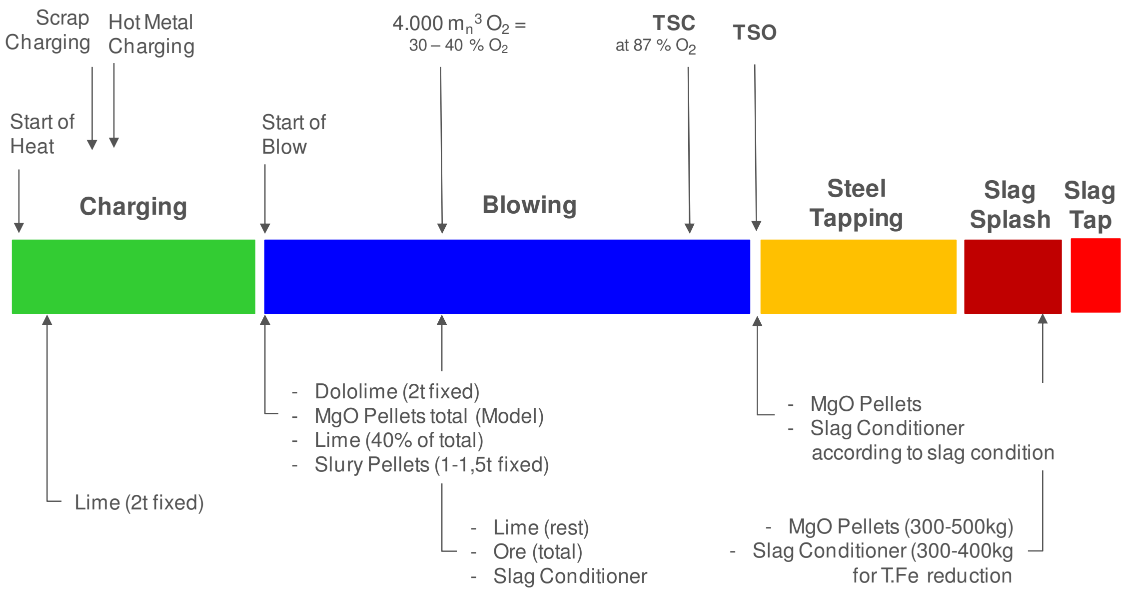


Figure 3: Blowing Regime of Meishan BOF steel operations

After start of the blow the lance is quickly lowered to a height of 180 cm above bath level and kept constant until the 11th min of the blow. Lance movements are done only limited and automatic in case of material additions to the furnace to keep the manual influence of the operators as low as possible. After a material addition plus a certain time the lance is automatically driven back to the original height in the pattern. Later the lance is lowered in two steps to 170 cm. The total blowing time is short with 14 min only.

After 87% of the blow the sublance is started for the first time and a TSC (temperature, steel sample) measurement is executed. This measurement also takes a sample from the blowing furnace. The oxygen volume is corrected based on the temperature result to hit the desired blow end temperature in the dynamic blowing mode. When the oxygen flow is stopped, after waiting for a period of 2 min, the sublance is operated the 2nd time for a TSO (temperature, steel sample, oxygen) measurement. After receiving the result from the laboratory for the steel analysis the heat is tapped.

After end of tapping the furnace is tilted back into vertical position, the slag is conditioned with MgO-Pellets and slag splashing is started. After a splashing period of 3 - 4min the remaining furnace slag is discharged into a slag pot. The splashing technique was optimized by using water model studies to evaluate optimum lance height and Nitrogen flow rate for the best available splashing results. Bottom built-up is controlled by different measures which will be explained later in the paper.

An important target to ensure a campaign life of 10,000 heats is, to keep the bottom wear in a range of 5mm per 100 heats. The initial bottom brick thickness of a new lining is 1000mm.

TBM SYSTEM INSTALLATIONS

The bottom stirring TBM system was installed in 2002 by Küttner from Germany. Two converters are working with 8 stirring elements arranged concentrically. The 3rd converter is equipped with 10 stirring elements arranged on an outer (6 stirring elements) and an inner circle (4 stirring elements). Normally the flow rate is kept constant for the whole blowing period at level of 8,5 m_n^3/min. It can be adjusted individually between 80% and 120% to control the individual wear of the stirring elements and their surrounding lining.

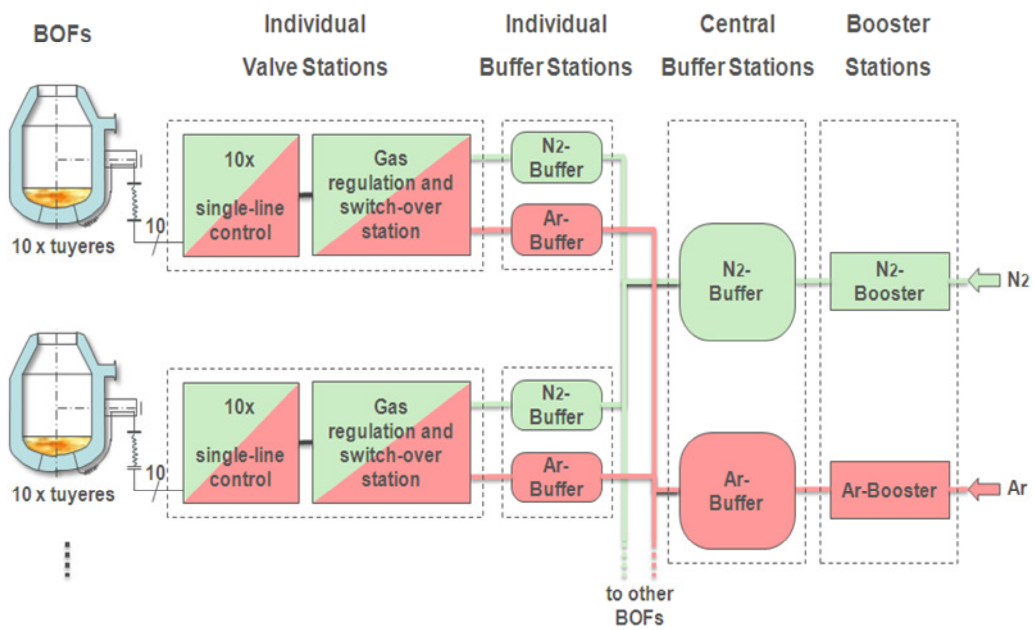


Figure 4: TBM system layout at Meishan BOF steel operations

The system is designed with an 8 respectively 10 line valve station for every furnace. The flow rate of each line is controlled individually, which is one of the major success factors of TBM, as it will be explained later. A set of Argon and Nitrogen booster fans and storage tanks guarantee the furnace operation to be independent from pressure deviations in the works grid. Argon and Nitrogen booster fans transform the inert gases from the grid to levels of 25 bars for Nitrogen and 30 bars for Argon. The pressure difference between Argon and Nitrogen is set to ensure that there is no risk of Nitrogen impurities in the Argon grid. The booster stations serve with big storage tanks for each medium. Close to the furnaces there are additional storage tanks for both types of inert gases. Since the normal blowing operation requires a max of 10 m_n^3/min which equals to 140 m_n^3/heat the system ensures that the furnaces could be operated successfully for several heats in case the inert gas supply of the works is down for whatever reason.

COMBINED BLOWING PROCESS RESULTS

The metallurgical results of the combined blowing (blow-stir) operation can be measured by various performance indicators. Performance indicators of importance to evaluate the efficiency of the process are:

- Oxidation degree of steel [%C][%O] and slag (%TFe) and (%MnO) contents,
- Phosphorus distribution factor L(%P_2O_5)/[%P] and slag (%P_2O_5) content,
- Slag (%CaO)´ saturation degree and
- Slag (%MgO)´ saturation degree

The results for these indicators are shown in the next few slides based on a data set representing the actual operation results from start of the last campaign in April 2011 to January 2012 of the #3BOF furnace in the shop. **Figure 5** shows the results for the [C][O] product, both resulting from the TSO end of blow sublance measurement.

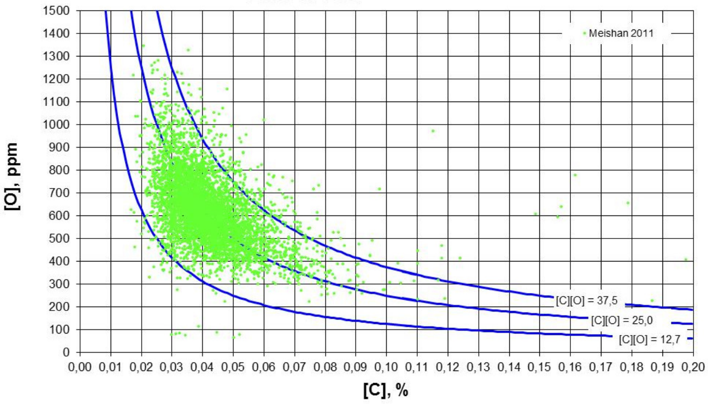


Figure 5: [C][O]-Product results in the recent #3 BOF furnace campaign at Meishan steel

It becomes clear that the majority of the results are in the range of 12.75 – 37.5 with an average [C][O] product of 24.6 which is a normal level for blow-stir combined blowing operations. This result ensures that with an average of 0.040% Carbon in the liquid steel, the average Oxygen content is 600ppm and will not exceed 950 ppm. Therefore the steel requires only limited consumption of de-oxidation agents during tapping and secondary refining.

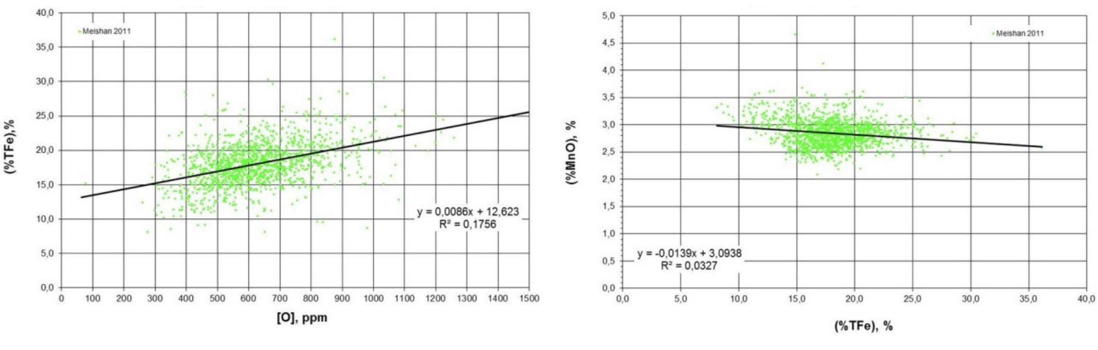


Figure 6: Slag (%TFe) and (%MgO) results in the recent #3 BOF furnace campaign at Meishan steel

The positive effects of the reduced Oxygen content in the steel on the slag parameters (%TFe) and (%MnO) are shown in **Figure 6**. Lower Fe-content in the BOF slag increases the furnace Fe-yield. Lower MnO-content in the BOF slag increases the furnace Mn-yield and saves expensive Manganese alloying agents to be added in secondary steel refining to meet the requirements of the steel specification.

The slag consistency parameters to be checked out for effective furnace operations are the CaO saturation degree and the MgO saturation degree of the slag. Adjusting the liquid slag near by the MgO saturation line ensures a operation with lowest possible war attack on the lining by the furnace slag. Operating at the CaO saturation line ensures the lowest possible MgO enrichment of the slag, as shown in **Figure 7**.

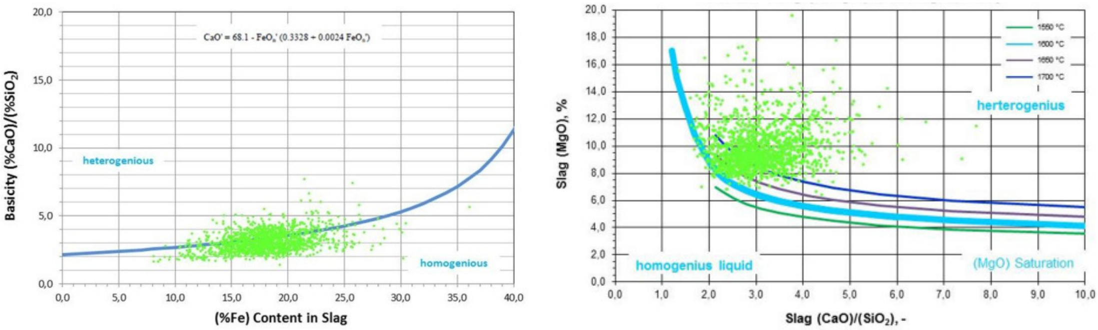


Figure 7: Slag (%TFe) and (%MgO) results in the recent #3 BOF furnace campaign at Meishan steel

It becomes clear that both parameters are controlled by Meishan steel intentionally. The slag basicity is increased with higher Fe-content of the slag and kept below the blue saturation index line. The MgO content varies at saturation obviously dependent from the aim steel temperature, but is also kept near the saturation lines. From this analysis it can be assumed, that in the furnace operations the slag in the vessel is always reactive and liquid which ensures proper de-phosphorization properties, **Figure 8**.

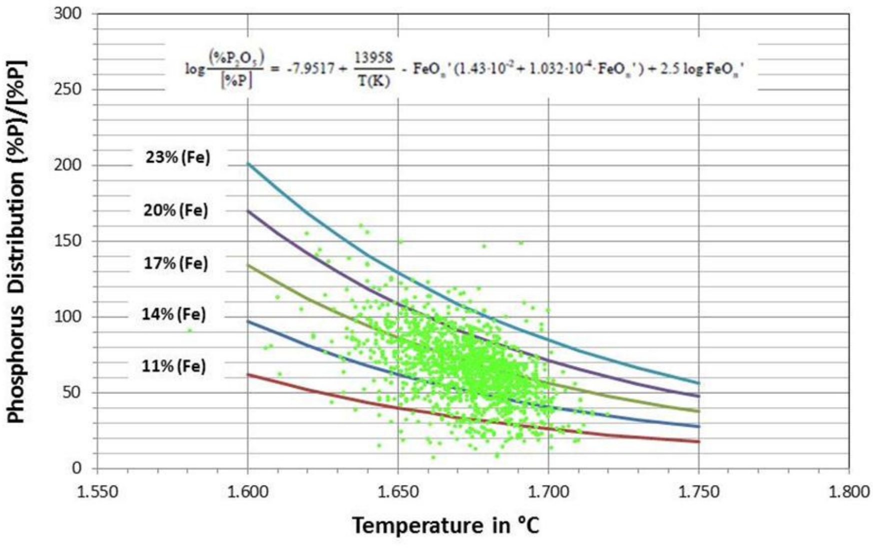


Figure 8: De-phosphorization results in the recent #3 BOF furnace campaign at Meishan steel

The average of the Phosphorus distribution (%P)/[P] of 70 at a operation temperature of 1,675 °C is exactly what can be expected in case of a blow-stir operation due to the formula given in the graph which was developed by Bannenberg et al. [….].

That these results are almost stable during the whole campaign life of the furnace is shown in **Figure 9** which shows the actual campaign line plots of the [C][O]-Product an L$(\%P_2O_5)/[\%P]$ levels and their frequency distribution.

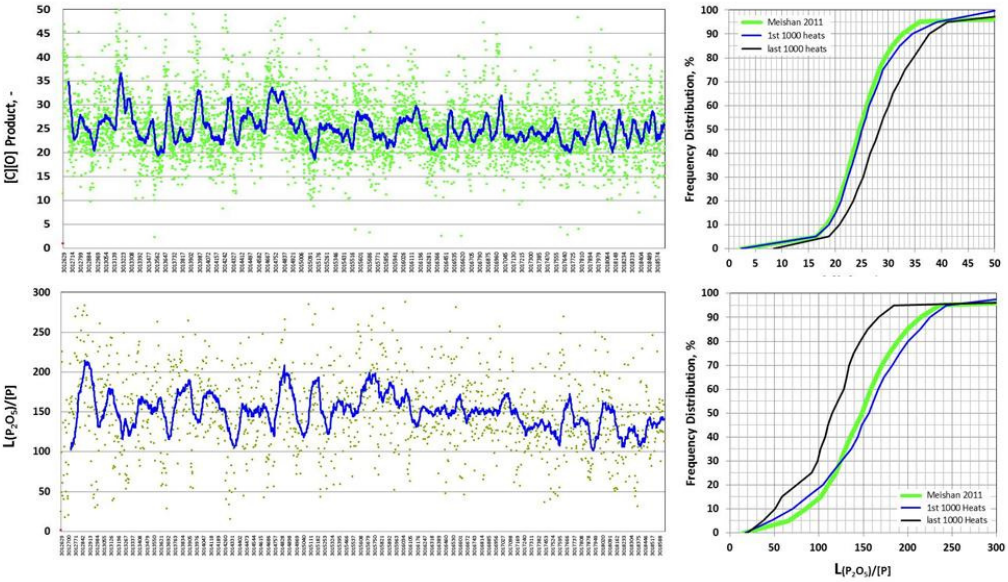


Figure 9: Metallurgical performance results in the recent #3 BOF furnace campaign at Meishan steel

The figure makes clear that the metallurgical performance obviously is controlled between certain upper and lower limits by intention. The frequency distributions were completed with the results of the last 1.000 heats of the previous campaign of the furnace and show that there will be a certain loss of metallurgical performance at the end of a campaign. This behavior clearly raises the question on the criteria to terminate a running campaign.

MAINTENANCE OF THE CONVERTER AND THE TBM SYSTEM

The deviation in the furnace metallurgical results leads the discussion to the furnace maintenance practice. As already mentioned before, slag splashing is the key to achieve long lasting furnace campaign life of 8,000 – 10,000 heats. This operation practice today is state of the art technology in many BOF shops worldwide. But none of the other shops in the world today is able to operate both: slag splashing and blow-stir operations simultaneously and with sustainable results. So what is the key success factor at Meishan steel that allows realizing the benefits of both operation standards?

The answer is a combination of different measures to keep the results within the desired limits. The key practice is that Meishan controls the bottom built-up unavoidable during slag splashing operation, mainly by adjusting:

- the individual flow rate per stirring element and
- the slag composition regarding (%MgO) and V-ratio (%CaO)/(%SiO_2)

In case the stirring element is free, the individual flow rate is reduced to 0.8 m_n^3/min, in case the stirring element is covered with slag, the individual flow rate is increased to 1.2 m_n^3/min. The adjustment of the individual flow rates is manifested in work flow instructions and is under responsibility of the shop supervisors on a daily business basis.

In addition, the slag chemical composition is changed based on the [C][O]-product performance results. Basically the slag (%MgO) content and the slag V-ratio are manipulated, see **Figure 7**. In case of high [C][O]-product results the slag(%MgO) content is reduced by a reduction of the of the MgO pellets charge. In case the [C][O]-product is low the slag (%MgO) is increased by using a higher amount of MgO-pellets in the charge. The [C][O]-product is controlled in the range of 20 - 30 (max. 35) as shown in **Figure 10**. It has to be mentioned that the slag for splashing is finally conditioned after end of blow.

Also the slag basicity and therefore the lime saturation index is manipulated intentionally to change the slag viscosity and to increase their capability to solute the built-up over a longer time period. By acting in this way early enough when the trend in the [C][O-product indicates the direction, it is possible to maintain not 100% of the blow-stir effect, but at least a remarkable advantage compared to the top-blow only operation.

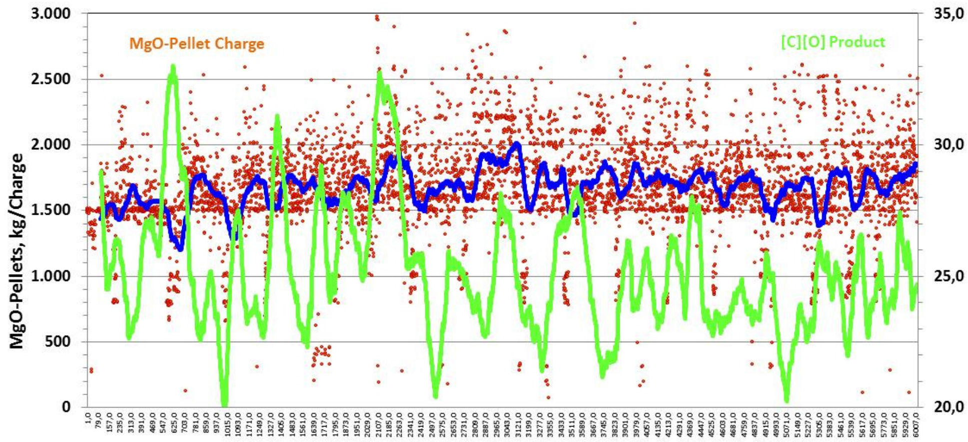
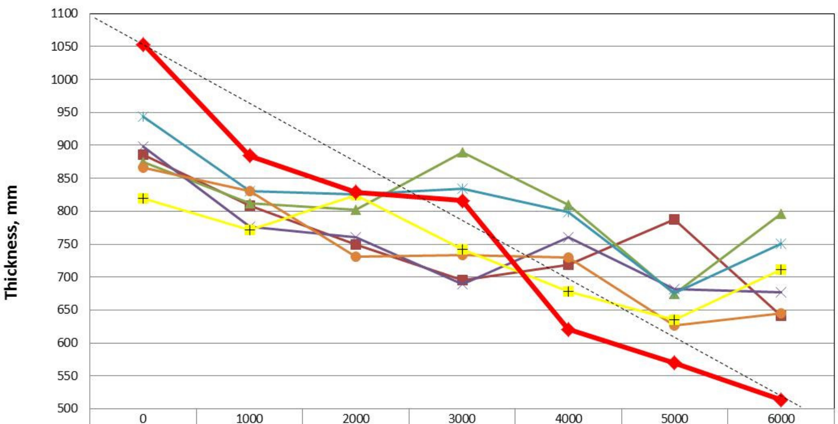


Figure 10: Slag composition variation during operations at Meishan recent #3BOF campaign

Figure 11 shows the summary results of the laser scans carried out on a regular base to check out the effects of the slag splashing maintenance and the slag composition countermeasures on the furnace lining wear. The scans are carried out on a regular base frequency of once per day (approximately every 25 heats) and summarized in the figure for milestones of every 1000 heats. It becomes clear that in the recent campaign the wear in the wall areas at the steel bath level around the inner contour of the furnace has almost stopped to zero while the wear in the bottom (red line) is controlled to be almost constant at 8.83mm per 100 heats. Continuing this wear rate trend will extend the recent campaign to more than 9,500 heats in total.



	0	1000	2000	3000	4000	5000	6000
前大面Charge Pad	886	808	750	695	719	788	641
后大面Tap Pad	875	812	802	889	810	675	796
前熔池Knuckle Charge Side	898	776	760	689	760	682	677
后熔池Knuckle Tap Side	943	831	825	834	798	676	751
东熔池Knuckle left Trunnion	866	831	731	734	730	627	645
西熔池Knuckle right Trunnion	820	771	824	742	678	635	711
炉底 Bottom	1053	884	829	816	621	570	514

Figure 11: Wear profile development in the recent campaign of #3BOF at Meishan steel

The figure also demonstrates that in the first 1,000 heats the built-up of the bottom is stabilized at a level of 50mm, which is the difference between the original brick length of 1,000mm and the average thickness measured in the scans with 1,050mm. Furthermore the figure shows that between 2.000 and 3.000 heats the built-up increased to almost 100mm, which was corrected within the next 2,000 heats to the original level. Figure 10 and 9 show for the first 3,000 heats of the recent campaign a higher [C][O]-product level as well as a much stronger deviation than for the second 3,000 heats. It has to be mentioned that the 500mm level was measured in the stirring element positions at 4:00 and 8:00 o'clock on the bottom from the hot face view. It can be summarized that also the wear profile results demonstrate the efficiency of the combined operations.

COMPARISON OF THE "TOP BLOW ONLY" AND THE "BLOW-STIR" PRACTICE

To indicate the benefits of the combined slag splashing and blow-stir operation the Meishan results were compared to the results of a top-blow only shop, **Figure 12**. It becomes clear the top-blow only shop [C][O]-product is strictly limited between 25 – 37.5, whereas the Meishan results vary from 20 - 30. This is an almost average 200ppm [O] saving in the steel, related to Fe- and Mn-yield increase and alloy and de-oxidation agent savings.

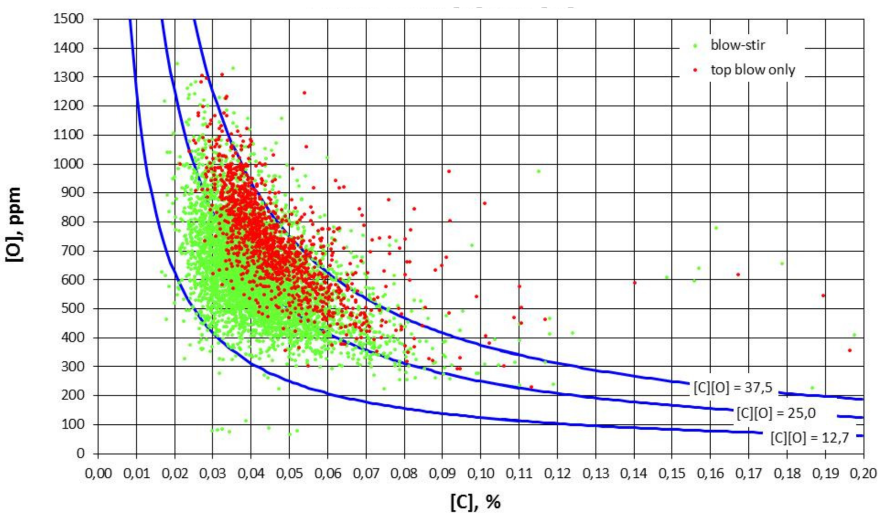


Figure 12: Oxidation degree of steel and slag in "top blow" and "blow-stir" operations

Regarding de-phosphorization from the frequency distribution comparison in **Figure 13** it becomes evident that the combined slag splashing and blow-stir operation results in higher slag (%P_2O_5) content, higher Phosphorus distribution factor L(%P_2O_5)/[P] and higher de-phos efficiency η[P].

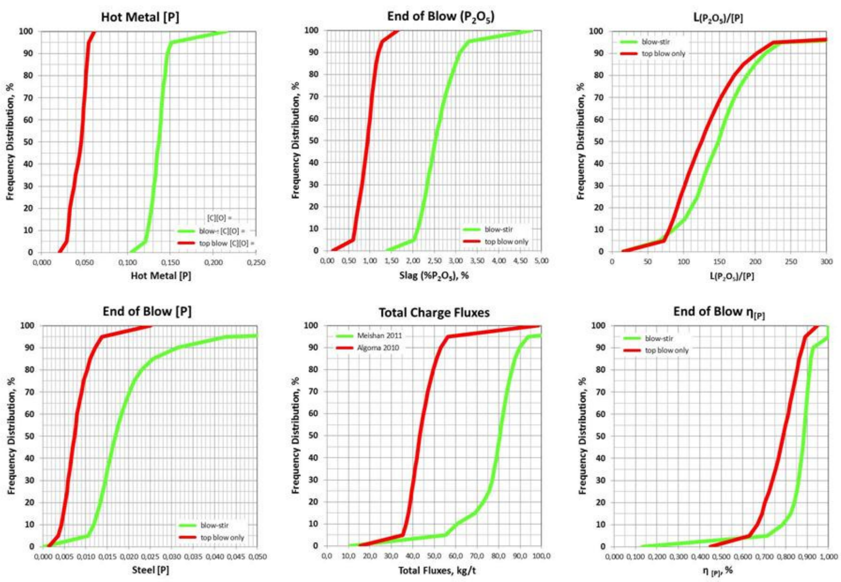


Figure 13: De-Phosphorization efficiency in "top-blow" and "blow-stir" operations

That in case of Meishan the steel end of blow Phosphorus content is significantly higher than in case of the only top-blown shop is not a consequence of the operation conditions, but of the quality program requirements. As already mentioned before also Meishan is capable to attain much lower Phosphorus levels, but this requires a double slag practice because of the initial hot metal Phosphorus of 0.137% compared to 0.043% of the only top-blown shop. This difference is also the reason why at Meishan the total flux consumption with 80.0kg/t is much higher than in the only top-blown shop with 43.0kg/t.

CONCLUSION

Bottom stirring is a BOF technology valuable to attain metallurgical benefits such as low oxidation degree of the melt and slag combined with low Fe-yield losses, low de-oxidation agent and alloying agent consumption. The second important field of benefits from bottom stirring is the intensifying of the slag metal reaction that is the base for sufficient de-phosphoriszation.

Slag splashing is a BOF technology valuable to achieve long lining campaign life related with higher availability of the furnace due to a low number of scheduled furnace operation downtime.

In this paper the operation results of Baoshan Meishan Iron & Steel Company Ltd. were presented, who operates both, bottom stirring technology and slag splashing in 8,000 – 10,000 heat campaigns successfully. The key for success is the operation of strong impulse stirring are the single hole stirring elements backed by a highly reliable pressurizing system of buffers and boosters ensuring a safe 24x7 operation of the stirrers. The TBM bottom stirring technology supplied from Küttner, Germany and a sophisticated operation & maintenance control model for the slag splashing, stirrer operation and slag chemical composition control allow earning benefits from a long BOF campaign life and simultaneous optimum metallurgical results.

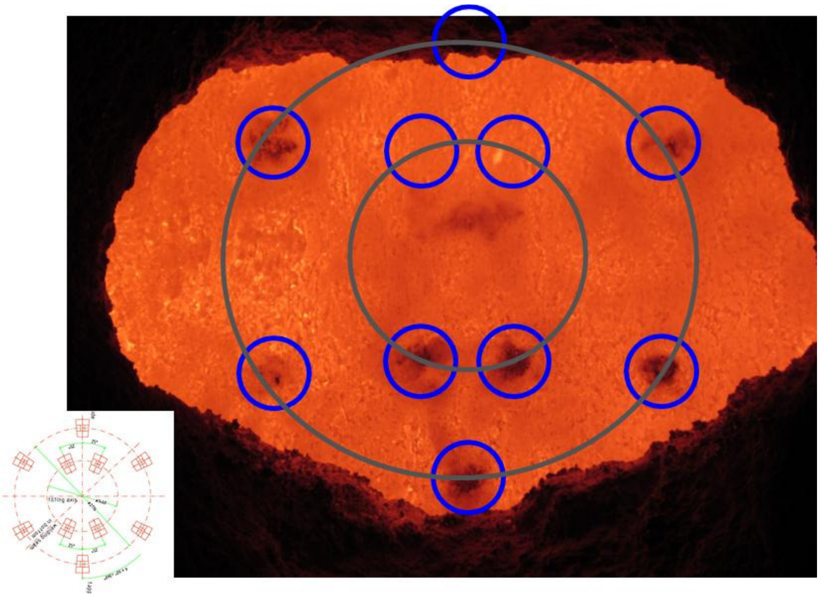


Figure 14: View into the Meishan #3 Furnace at 6.000 heats

All above mentioned factors in combination result in experience with long BOF campaign life and TBM bottom stirring technology at Baoshan Iron & Steel Company in China.

At the time of issuing this paper, Meishan is just starting up production in their newly built 2x 250t BOF shop. Meishan decided to continue the long lasting partnership with Küttner and again relies on the TBM bottom stirring system by placing the order for engineering and supply of the same with Küttner.

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