Pretreatment and Refining of Hot Metal – Efficient technologies to cope with today's Sulphur and Phosphorous challenges

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Summary

Pretreatment and refining of liquid hot metal (HM) are globally practiced ways to adjust the chemical composition of HM to the requirements of the final product or at least to the requirements of downstream operations. Sulphur, Silicon, Phosphorous, and Carbon are typically adjusted at pretreatment or refining facilities. In particular desulphurization of HM is a well accepted pretreatment technology used today by most of the steel plants worldwide. Desiliconization and dephosphorization of HM are other pretreatment processes which are a little bit outside of the main focus. For many years Phosphorous was not a major issue for many steelmakers due to the strategy of purchasing premium ore qualities. Limited resources and availability as well as highly volatile prices of these selective qualities has inexorably changed this situation since some years which lead to a growing demand to "pretreat" the HM prior to further processing or ingot casting. This development can be recognized not only in steel plants but also in other ferrous metallurgical facilities. Also these plants e.g. ferroalloy producers, are more and more battling with Sulphur and Phosphorous challenges and seeking for economic solutions.

This paper investigates the prevailing HM pretreatment and refining technologies, their constraints, and their typical applications. Today's conditions are highlighted and case examples are sketched how efficient technologies for pretreatment and refining of HM can help to cope with these challenges.

Key Words

HM, hot metal, pretreatment, refining, silicon, sulphur, phosphorous, desulphurization, desiliconization, dephosphorization, triple D process, clean steel

Introduction

Since the 80s it can be observed that the quality of raw materials and fuels used for iron and steel making has become continuously worse. As a result this global trend has led to a deteriorating hot metal quality in terms of higher contents of impurities. At the same time steelmakers have been faced with increasing requests to produce clean steel with low and ultra-low content of sulphur and phosphorous in particular.

Decreasing availability of premium high quality raw materials and fuels with low contents of unwanted and harmful elements and onwardly increased pressure to lower production cost by purchasing cheap raw materials have led to this doom loop. In the past generally the Western steelmakers responded this challenge by optimizing their facilities, improving the degree of automation, introducing bottom stirring in BOF converters, and to say by squeezing the productivity of their aggregates to ever new records. But these efforts have come to an end and further progress can be only attained with alternative concepts.

In contrast, the Japanese steelmakers went another very radical way and focused on intensive pretreatment of the hot metal taking advantage of the benefits of low treatment temperature. As a result they established a different but competitive way of steelmaking.

The authors of this paper think that it is the right time to call the concepts and results of hot metal pretreatment to mind and to investigate chances of applying these technologies to the conventional steelmaking route.

This paper gives a brief overview about the individual process steps and their application in the prevailing hot metal pretreatment processes used in industrial scale. Furthermore, the triple-D-process (De-S / Desulphurization, De-Si / Desiliconization, De-P / Dephosphorization) is sketched as it can be applied to steel plants using the conventional BF-BOF route. Two case examples of executed plants conclude this paper.

Hot metal desulphurization (De-S)

Sulphur in blast furnace (BF) hot metal is mainly coming from fuels such as coke, coal, and oil. With the exception of some very specific steel grades, sulphur is undesirable and has to be removed. Although the BF is a very efficient facility for desulphurization and able to remove typically 85 % of the total sulphur input, 15 % are remaining in the produced HM. This is still too much to satisfy the requirements of the steel grades. Therefore additional external desulphurization outside of the BF is required [1].

Today desulphurization of hot metal is carried out by the following methods:

- 1. Injection of De-S agents into torpedo ladles
- 2. Injection of De-S agents into open ladles
- 3. Addition of De-S agents into open ladles using the KR impeller stirring system
- 4. Desulphurization in the BOF converter
- 5. Desulphurization in the steel ladle

Table 1 shows clearly that desulphurization of hot metal is beneficial compared to an elevated effort to improve the desulphurization in the BF [2]. This topic has been discussed in detail in [4]. The BOF converter is the most expensive vessel to perform desulphurization and steel desulphurization should only be applied if necessary.

	Desulphurization (De-S)				
	in BF	of HM in ladle	in BOF	of steel in ladle	
Cost to remove 1 kg S, US\$	27	10.5	177	64	

Table 1: Cost to remove 1 kg sulphur by different procedures [2]

Hot metal desulphurization by injection technology is carried out by deep injection of powdery reagents like lime, calcium carbide, magnesium, soda ash, or mixtures thereof into ladles (torpedo ladles, BF transfer ladles, or BOF charging ladles). Refractory lined lances are immersed deep into the hot metal while the reagents are injected with high speed using mainly nitrogen as transport gas. Several pneumatic injection technologies like mono-injection, coinjection, or multi-injection are used depending on the selected reagents and operational requirements.

Efficient desulphurization requires intensive mixing of reagents, metal and slag. This can be achieved with a gas/solid mixture deeply injected into a ladle ensuring a minimum bath level of 1.5 m in order to maximize the residence time of the particles in the bath before they reach the surface. Therefore injection desulphurization in open ladles has a higher efficiency compared to torpedo ladles having an unfavorable shape. The consumption of reagents in the torpedo is approximately 15 - 25 % higher compared to open ladles.

Another possibility to achieve high mixing power is mechanical stirring with an impeller. This technique is used by SPCO's KR (Kanbara Reactor) system [3]. While a refractory lined rotating impeller is immersed into the metal and thus providing a good mixing of reagent, metal and slag, cheap coarse lime is fed by a vibration feeding system as De-S agent. The KR system achieves very low sulphur levels at comparably low reagent cost. Investment cost and other operating cost of the KR are typically higher compared to the deep injection technology.

Proper removal of the De-S process slag is in any case essential before the hot metal is charged into the BOF.

Hot metal desiliconization (De-Si)

The silicon in BF hot metal comes mainly from the ash of the BF coke and the BF operation. Silicon has a higher oxygen affinity than phosphorous and carbon. It is thus the first element to be oxidized during oxygen blowing in the BOF converter. The competitive reactions of phosphorous and in particular carbon will start with decreasing silicon content in the hot metal.

High silicon content in hot metal of more than 0.7 - 1.0 % leads to problematic oxygen blowing:

- increased consumption of lime in order to maintain a suitable basicity
- increased iron losses in the slag
- decreased BOF capacity due to increased slag amount
- increased oxygen blowing time and thus decreased productivity (sometimes even a double slag practice is necessary)
- increased danger of slopping (instable blowing process)

Therefore control of the silicon content below say 0.7 % is desirable and one of the benefits of hot metal desiliconization. Another reason is that a silicon content of less than 0.15 % is necessary before effective dephosphorization can start.

The process of hot metal desiliconization requires oxygen which can be supplied as gaseous oxygen or in form of iron oxides ("solid oxygen"). HM De-Si with solid oxygen is endothermic and drops the temperature by 10 °C per 0.1 % of removed silicon (using scales as source of solid oxygen). Including slag skimming this accounts for huge temperature losses in case of high initial silicon content in the hot metal. Desiliconization by means of gaseous oxygen is more effective compared to the addition of a De-Si agent. Assuming initial silicon content of 0.7 %, approximately 1.4 Nm² O₂ per ton per 0.1 % of removed silicon is required. Figure 1 compares the removal of silicon as a function of time for adding solid oxygen (here: scales), oxygen injection, and oxygen top blowing [5]. Blowing of gaseous oxygen for De-Si is exothermic and increases the temperature by approximately 27 °C per 0.1 % of removed silicon. The huge amount of generated slag makes it difficult to control this process in ladles.



Figure 1: Comparison of desiliconization behavior [5]

Figure 2 shows the temperature variation in case of solid oxygen addition (here: scales) and injection of gaseous oxygen as a function of removed silicon [5].



Figure 2: De-Si with gaseous and solid oxygen and variation of the hot metal temperature for De-Si [5]

High mixing power of the De-Si agents, metal and slag is required for efficient desiliconization. This can be achieved by several methods, e.g. natural flow, gas stirring by injection, mechanical stirring with an immersed impeller. In general, the De-Si efficiency of a process should be high enough to lower the silicon content to match with the requirements of proper oxygen blowing in the converter or to lower the silicon content to allow efficient dephosphorization. The following methods are applied in industrial scale:

- 1. Top addition of De-Si agents into the BF runner with or without slag separation by means of a skimmer blade. The natural flow of the hot metal is utilized to generate mixing power.
- 2. Injection of De-Si agents into torpedo ladles with or without simultaneous oxygen blowing.
- 3. Injection of De-Si agents into open ladles with or without simultaneous oxygen blowing.
- 4. Top addition of De-Si agents into open ladles using a KR impeller stirring system to provide mechanical stirring.

Method 1 is cheap and simple as less equipment is needed but efficiency and predictability are poor. An addition of 10 - 20 kg sinter dust fines per ton of hot metal achieves 30 % removed silicon. Injecting the De-Si reagents into the BF runner increases the desiliconization rate to 40 %. Nakasuga et. al. introduced a process using mechanical stirring with an impeller immersed in the hot metal runner. They report improved desiliconization rates up to 55 % compared with the injection method [6]. All these methods have fluctuations in the achieved silicon content, caused by varying temperature and varying flow velocity of the hot metal. The desiliconization rates obtained with these methods are normally sufficient to control the HM Si content below say 0.7 % making it suitable for oxygen blowing in the BOF converter. But desiliconization down to 0.15 % which is the precondition to proceed with dephosphorization requires methods according to 2 - 4.

Method 2 saves process time as the reactions can take place "on the road". Due to the shape of the torpedo it is difficult to remove the high amounts of slag completely. As a result, the torpedo capacity is decreasing with every treatment as accretions accumulate inside and at the mouth. Finally the cast house layout and its facilities are often limiting the application of this technology. Method 3 and 4 allow precise control of the final silicon content and adjustment of the temperature to certain extend. Furthermore these methods often allow usage of existing facilities already used for desulphurization.

Mill scale, magnetite fines, hematite fines or sinter dust are used as sources of solid oxygen in the De-Si agent with similar desiliconization efficiencies. Lime and silica are added to flux the slag, adjust the basicity and prevent excessive foaming.

Hot metal dephosphorization (De-P)

Phosphorous in the iron ore fed to the blast furnace is converted into the hot metal by a rate of > 90 %. The only possibility to limit the P-content of the hot metal is to use a low P-containing iron burden. It is thus clear, that higher P-content in hot metal requires higher efforts in steelmaking operations [1].

The BOF converter is a highly efficient facility to perform dephosphorization especially when equipped with strong bottom stirring [1]. Anyhow several limitations call for alternatives like hot metal De-Si and De-P. Applying HM De-P reduces the required slag amount during oxygen blowing, and ensures achieving consistently ultra-low phosphorous contents at end of blow. In this sense, HM pretreatment is of great help in reducing the metallurgical work load of the oxygen blowing process.

Basically hot metal dephosphorization makes use of the same agents as desiliconization. Oxygen in solid and/or gaseous form is needed. Iron oxides like mill scale, sinter dust fines, iron ore fines (e.g. magnetite or hematite fines), etc. are used as sources of solid oxygen.

Blowing oxygen onto or into desiliconized hot metal will initiate strong decarburization simultaneously. Due to the {CO} gas generation such a process is impossible to be managed safely in an open ladle. Therefore hot metal dephosphorization is done either in ladles with the sole use of solid oxygen or in a converter which provides enough space to handle the foamy slag.

Similar to desiliconization, also dephosphorization of HM requires high mixing power. A simple addition of the reagent on the surface of the metal results in unacceptable long treatment time and tremendous temperature losses. Application of gas stirring via bottom bricks in the ladle improves the situation only slightly. Only deep injection of the reagents or mechanical mixing with impellers provides sufficient mixing power.

The benefits of hot metal dephosphorization can be listed as follows:

- Dephosphorization is more effective at lower hot metal temperatures than at steel temperatures.
- A lean slag BOF blowing process for decarburization can be established.
- Slag from a BOF process using dephosphorized hot metal contains no free CaO and allows direct utilization as construction material e.g. for road layers, etc.
- Slag from a BOF process using dephosphorized hot metal can also be utilized for HM desiliconization.

Hot metal pretreatment

Process steps which are used to remove impurities from the hot metal can be summarized as hot metal

pretreatment. These process steps are inserted between the blast furnace and the BOF converter. Main objective is the adjustment and control of the hot metal composition by removal of unwanted impurities like sulphur (De-S), silicon (De-Si) and phosphorous (De-P) along with their undesired inclusions (oxides, borides, nitrides, carbides, and chlorides). This is a precondition to produce clean steel. Less than 100 ppm total impurities are standard requirement for quality steelmakers today.

Desulphurization of hot metal is a standard practice carried out in nearly all steel plants around the world while desiliconization and dephosphorization have not been in the main focus of the Western steelmakers. This was different in Japan, where the steelmakers investigated and developed hot metal pretreatment technologies already 30 years ago. A variety of hot metal pretreatment processes and technologies have been developed, applied, and reported in several papers during recent years. The following processes are the most common ones:

- SMP Slag Minimum Process
- SRP Simple Refining Process
- ZSP Zero Slag Process
- LD-ORP Optimized Refining Process
- LD-NRP New Refining Process
- Multirefining Converter Process (MURC)

All these processes use different vessels to carry out the metallurgical work of De-Si, De-P, and De-S. The main metallurgical vessels are:

- BF runner
- Torpedo ladle
- Open ladle (transfer or charging ladle)
- LD-Converter

All kind of combinations using different vessels and logistics have been tried and operated during the years.

One of the early pioneers was Nippon Steel, who developed and introduced the Slag Minimum Process (SMP) in 1983 as shown in figure 3. The main idea of this process is to separate the desiliconization reaction from the dephosphorization and the decarburization reactions and to separate the process slag. In industrial scale, this process consisted of HM De-Si in the ladle using a KR impeller system. The BOF converter is then utilized for De-P and De-C. Advantages compared to the conventional process using the BOF converter for removal of (sulphur), silicon, phosphorous, and carbon, were found in a reduced consumption of fluxes (mainly lime), a reduced slag amount, and an increased metallic yield. It is reported that the slag amount of this process for a hot metal silicon content of 0.15 % is half compared to the conventional process [7].



Figure 3: Process flow scheme of Nippon Steel's Slag Minimum Refining Process (SMP) [7]

Further investigations led consequently to technologies using the injection of suitable reagents into (oversized) torpedo cars. This operation procedure offered significant benefits in terms of "less slag" production, slag recycling, etc. but it had also some disadvantages due to the excessive handling requirements and the huge temperature losses. Nippon Steel installed and operated the torpedobased "Simple Refining Process (SMP)" for HM dephosphorization in their Kimitsu and Yawata works as shown in figure 4 [1].





Another Japanese steelmaker, Kawasaki Steel installed and operated similar processes in their Mizushima and Chiba works, also using the torpedo ladle as reactor for dephosphorization. They applied the intensive pretreatment operations in dedicated hot metal pretreatment centers located between blast furnace and steel plant. Chiba works firstly used gaseous oxygen blowing during dephosphorization in order to reduce the tremendous temperature losses. The process flow of Chiba's hot metal pretreatment process can be seen in figure 5 [8].



Figure 5: HM pretreatment process at Kawasaki Steel, Chiba works [8]

The huge slag generation due to blowing oxygen in the torpedo ladle during dephosphorization and a highly restricted scrap usage ratio, led Nippon Steel's Nagoya works to modify their BOF converter into a HM pretreatment converter for De-Si, De-P, and De-S. After tapping and separation of the slag the hot metal is then charged to another converter where De-C is executed. Figure 6 shows the flow diagram of this process, which was named "LD-ORP (LD – Optimized Refining Process)" [9].



Figure 6: Converter-based pretreatment process LD-ORP at Nippon Steel, Nagoya works [9]

The first HM pretreatment center using torpedo ladles for De-Si and open ladles for De-P and De-S was installed and operated at Nippon Steel Oita works. Figure 7 outlines their process which is completely based on the deep injection technology [9].



Figure 7: Ladle-based HM pretreatment process at Nippon Steel, Oita works [9]

The use of a turnable ladle turret with 4 treatment stations for sampling, deslagging (2x), and injection (De-P and De-S) is another highlight of Oita's hot metal pretreatment process.

NKK's Fukuyma works (today: JFE) operated a HM pretreatment process where the silicon content of hot metal from the blast furnace is already lowered to 0.2%. The HM is then sent to the De-Si station. where it becomes ultra-low silicon hot metal with a silicon content of less than 0.1 %. At the De-Si station, oxygen gas is used along with sintered iron ore (iron oxide) as reagents for De-Si. The reaction vessel is an open ladle, and the hot metal is vigorously stirred by injecting lime through an immersed lance. This method provides a highly efficient and stable supply of ultra-low silicon hot metal which improved the efficiency of lime for De-P significantly. As a result, the slag generation throughout the entire steelmaking process could be lowered to a minimum amount. Therefore NKK named this completely ladle-based process "Zero Slag Process (ZSP)" which is sketched in figure 8 [10].



Figure 8: Zero Slag Process (ZSP) at NKK's Fukuyama works [10]

A further development was the Multirefining Converter Process (MURC) which allows De-Si/De-P and De-C treatment in one vessel without tapping and recharging. The De-Si/De-P is carried with a low basicity slag, high (%T.Fe) and a hot metal without previous De-Si treatment. After De-P the P-rich slag is tapped and sent for dumping. The slag of the following De-C step is totally recycled as it remains as a hot feedstock in the converter for the next De-Si/De-P treatment as shown in figure 9 [11], [12].



Figure 9: The Multirefining Converter Process (MURC) at Nippon Steel [11] [12]

These converter-type hot metal pretreatment processes are today's standard operation practice in all works of Nippon Steel as summarized in figure 10 [12].



Figure 10: Overview of the hot metal treatment processes as applied at the different steelmaking works of Nippon Steel [12]

It has to be mentioned that there are a lot of processes in the secondary metallurgy in order to "fix" deficiencies of the produced steel and to ensure highest cleanness. Some of them are essential from a metallurgical point of view but some treatments applied to steel at high cost can be beneficially transferred to hot metal at lower cost.

Beside the ability to produce clean steel with low and ultra-low contents of sulphur and phosphorous, there are additional benefits of hot metal pretreatment.

Benefits of HM De-S regarding BF operation [1]:

- The BF can be released from some metallurgical work of De-S which increases BF productivity.
- Coke, coal, and flux charges to the BF can be reduced and the HM yield can be increased.
- The BF alkali balance can be improved due to operating at a lower basicity and a cost saving "lean slag" production becomes possible [4].

Benefits of HM De-Si and De-P regarding BOF converter operation:

- Reduced refractory attack by the less acid slag.
- Double slag technique, often applied in case of high silicon hot metal, can be avoided.

This shortens the tap-to-tap time and increases productivity.

- The slag generated during oxygen steelmaking using dephosphorized HM has a low P content which allows utilization of this slag in the sinter plant as part of the feedstock for the blast furnace. The recycling of BOF slag in the blast furnace without previous HM De-P is limited due to an enrichment of the P content in the HM.
- Low contents of silicon, phosphorous, and sulphur in the HM allow operating the BOF for more or less decarburization only with minimum slag (less than 1/3 of the standard amount) and thus minimizing lime consumption. Besides the obvious saving, the so reduced slag amount leads to a smoother blowing behavior, less slopping, and an easier control of the endpoint targets.
- Converter operation with minimum slag allows (partially) substitution of FeMn added at tap by much cheaper Mn ore. Due to the small slag amount the major portion of the manganese from the Mn ore is dissolved in the steel instead of being oxidized to the slag. This operation allows cost savings of several US\$ per ton.

Anyhow, the rather smart HM pretreatment technologies did not have a major breakthrough outside of Japan and some installations in Taiwan and South Korea.

Today conditions have changed and there is an increasing need for steelmakers to investigate opportunities to benefit from applying HM pretreatment steps into their existing conventional BF-BOF production route in order to release their aggregates from some metallurgical work.

Integration of hot metal pretreatment process steps into the conventional BF-BOF steelmaking route

In order to evaluate the technical feasibility and the economic benefits, an optimum sequence has to be defined. Table 3 summarizes favorable conditions for the individual hot metal pretreatment steps.

Figure	Hot metal De-S	Hot metal De-Si	Hot metal De-P
Process condition	Reducing	Oxidizing	Oxidizing
Oxygen activity	Low	High	High
Hot metal temperature	High	High	Low

Slag basicity (CaO/SiO2- ratio)	High	High	High
Hot metal silicon content	High	-	Low (< 0.15 %)
Hot metal carbon content	High	-	-
Mixing power of metal and slag	High	High	High

Table 3: Favorable conditions for the single hot metal pretreatment steps

Considering this and the typical logistics of the conventional BF-BOF steelmaking route, the following process flow as shown in figure 11 can be realized with little modifications.



Figure 11: Possible process flow of HM pretreatment within the conventional BF-BOF route

De-Si is executed in the BF runner with separation of the De-Si slag during pouring into a torpedo ladle by means of a skimmer blade. This is followed by De-P based on injection of De-P agents into the torpedo ladle. After reladling into the BOF charging ladle, the De-P slag is skimmed off. Then desulphurization is carried out by means of injection technology or a KR system. After the De-S slag has been removed, the hot metal is charged into the BOF converter and the decarburization process is executed by means of oxygen blowing. It is known that during De-Si with a proper De-Si agent also a certain amount of sulphur is removed. This advantage can be utilized when De-Si is carried out before De-S.

Although this sequence is a "natural" sequence taking advantage of the "low cost" possibility to desiliconize in the BF runner as the first step, another sequence is often more advantageous from a thermodynamic point of view. De-S as well as De-Si, both favor high temperature. In opposite, De-P favors low temperature. Considering this, the sequence shown in figure 12 is preferable.



Figure 12: Alternative sequence of HM pretreatment process step within the conventional BF-BOF route

Summarizing it can be said that an optimum sequence has to be selected for each installation individually depending on available facilities. In particular, existing vessels for De-S treatment, metallurgical targets, and last but not least the HM temperature need to be considered.

Many De-S stations for open ladles and torpedo ladles are in operation worldwide based on either injection technology or mechanical stirring technology (KR systems). Very often these existing stations can be easily extended to HM pretreatment stations, providing De-Si and De-P additionally to De-S when needed and beneficial.

The major reasons why HM De-Si and De-P in open ladles didn't have a real push through in the international iron and steel industry are:

- Limited capacity of treatment facilities: Existing treatment facilities especially for De-S are normally sized to meet the requirements of the converter cycle. Additional treatments in these facilities lead to an increased load and thus the converter cycle can no longer be met.
- Huge temperature losses: Every treatment step causes a temperature drop of the HM: De-S injection, slag skimming, De-Si injection, slag skimming, De-P injection, and again slag skimming. In total this accounts to more than 100°C which often impedes execution of all steps due to a too low final HM temperature for the following converter process. In particular the last De-P step can often not be executed due to this reason.

Oxidation of carbon in a ladle process is especially critical due to the generation of {CO} gas and the excessive foaming of the slag. Therefore the oxidation of carbon during desiliconization and dephosphorization has to be limited and controlled to the best possible extend.

Küttner has designed a process for De-Si and De-P of HM which overcomes the drawback of huge temperature losses using chemical heating with gaseous oxygen. The generated heat is taken from the exothermic reaction of silicon with gaseous oxygen in contrast to the endothermic reaction of silicon with iron oxides. In order to control the temperature increase during the removal of silicon to the desired extend, a balanced supply of gaseous oxygen and injected solid oxygen from iron oxides deep into the ladle is used. As the silicon has to be removed anyway for De-P this effect can be utilized to compensate the temperature losses at least to some extend as shown in figure 13.



Figure 13: Compensation of temperature losses by the Küttner process

This process requires the injection of a mixture of CaO, iron oxide. Some additives are used to control slag composition and excessive slag foaming. The required reagents are injected as a premix in mono-injection mode or as single components using co- or multi-injection systems. At an incoming silicon content of 0.5 % and 1323 °C, the consumption of De-Si agent to achieve 0.15 % [Si] is approximately 20 kg/t.

Phosphorous removal requires a very high mixing power density to achieve a low phosphorous content. A dephosphorization rate of 70 % (e.g. P reduction from 800 ppm to 250 ppm) is achieved by injecting approximately 22 kg/t of a De-P agent. As it is nearly impossible to achieve sufficiently high mixing power with top addition and lance stirring or bottom plug stirring, injection of solids or mechanical stirring by an impeller are the preferred methods for HM De-P.

The following two figures 14 and 15 give key figures of executed Hot Metal Refining Plants.



Figure 14: Hot Metal Refining Plant (under commissioning)





Summary and conclusions

Production of clean steel requires removal of all undesired impurities especially sulphur and phosphorous. The removal of sulphur from hot metal is already used by most of the steelmakers but dephosphorization is traditionally carried out in the BOF at least by Western steelmakers. As this process is often already optimized to its limits, additional incoming phosphorous contents can only be handled by paying a penalty in terms of increased production cost and reduced productivity. Purchasing premium iron ores with low phosphorous contents is often the only way to avoid these problems.

On the other hand, premium low phosphorous iron ores are significantly more expensive than ores with higher phosphorous contents. Therefore economic benefits can be gained by introducing selected HM pretreatment steps before charging the hot metal into the BOF converter. With respect to De-Si and De-P, small investments are often very profitable due to short payback periods.

By blowing pretreated low P HM in the BOF converter, ultra low phosphorous steel grades with contents of less than 50 ppm can be easily achieved.

Another benefit arises from a lean slag BOF operation which allows partial substitution of FeMn with many times cheaper Mn ore. Savings of several US\$ per ton of steel can be achieved. Furthermore the generated BOF slag can be utilized as De-Si agent or BF feedstock.

Pretreatment of HM means basically shifting of anyhow necessary process steps from the steel phase (BOF converter or secondary metallurgy) to the thermodynamically more favorable hot metal stage.

As many already existing De-S stations based on injection technology or mechanical stirring (KR) are suitable to be used also for De-Si and De-P, extension of De-S to triple-D is often just a short step.

The main drawback of the ladle-based HM pretreatment technologies is the huge temperature drop of the HM with the already discussed negative effects on the downstream operations. A process concept has been described which utilizes the exothermal oxidation of silicon with gaseous oxygen in order to generate heat required to compensate the temperature losses at least partially. This process can be adopted into the production sequence of nearly all plant concepts and layouts and thus helps to create capabilities of processing cheaper raw materials.

References

- Huesken, R., Cappel, J., Fechner, R.: Iron & Steel Technology; November 2011; Use of Hot Metal with High Phosphorus Content in Combined Blowing BOF Converters; page 46-57
- [2] Yin, R.: Metallurgical Industry Press; 2011; Metallurgical Process Engineering; page 222
- [3] JP Steel Plantech: Product Information; 2015; KR Hot Metal Desulphurization System; page 18
- [4] Huesken, R., Cappel, J.: MPT International; 05/2012; Desulphurization Strategies in Oxygen Steelmaking; page 42-49
- [5] Kawauchi, Y., Maede, H., Kamisaka, E., et al.: ISIJ; 1983; Metallurgical Characteristics of Hot Metal Desiliconization by Injecting Gaseous Oxygen; page 1730-1737
- [6] Nakasuga, T., Kimura, S., Uchida, N.: AISTech 2012 Proceedings; Reaction Analysis of Continuous Desiliconization and Desulfurization in the Hot Metal Runner at Kobe No.3 Blast Furnace; page 439-447
- [7] Itoh, Y., Satoh, S., Kawauchi, Y.: Transaction ISIJ; Vol. 23, 1983; Development of Slag Minimum Refining Process by Desiliconization of Hot Metal
- [8] Nabeshima, Y., Taoka, K., Yamada, S., et al.: Kawasaki Steel Technical Report No. 24; April 1991; Hot Metal Dephosphorization Treatment in Torpedo Car; page 25-31

- [9] Endoh, K.: Nippon Steel Technical Report No.
 61; April 1994; Recent Advances and Future Prospects of Refining Technology; page 1-8
- [10] Tanabe, H., Nakada, M., el al.: NKK Technical Review No. 88, 2003; Steelmaking Technologies Contributing to Steel Industries; page 18-27
- [11] Sasaki, N., Mukawa, S., Ogawa, Y., Miyamoto K.-I.: Nippon Steel Technical Report No. 104; August 2013; Improvement of Mot Metal Dephosphorization; page 26-32
- [12] Kumakura, M.: Nippon Steel Technical Report No. 104; August 2013; Advances in Steel Refining Technology and Future Prospects; page 5-12