Desulfurization Strategies in Oxygen Steelmaking

Over the last three decades, steel producers around the world have been faced with two major trends:

1. Continuous price increases for raw materials like coal, coke, iron ore, scrap and others.
2. A continuous requirement for steel property improvements that led to very low specifications for carbon, oxygen, silicon, phosphorus, nitrogen, tramp elements (Cu, Cr, Ni, Mo) and sulfur.

Especially in the case of steel products to be operated in high-pressure applications at very low temperatures, i.e., line pipe steel and steel for large-diameter, long-distance pipelines, ultralow sulfur (ULS) specifications require the sulfur levels to be adjusted < 5–10 ppm. On the other hand, it is well known that sulfur in steel increases the crack sensitivity. Therefore, to avoid crack formation in continuous casting for high-strength low-alloy (HSLA), and peritectic steel grades, low sulfur contents of < 30 ppm are beneficial. A sulfur content limitation of < 60 ppm in steel results in an intensive treatment of the liquid in the secondary refining stage with a positive impact on deoxidation degree and cleanliness. Although most other steel grades don't have special requirements on sulfur specification, low-carbon (LC), ultralow-carbon (ULC), electrical steel and tinplate are limited to < 120 ppm, and even simple grades like sections, rebar or wire are limited at < 250 ppm.

Since the sulfur input in an integrated iron and steel plant is generally much higher than the steel product specification, desulfurization (De-S) technologies are required. The sulfur source basically results from processed primary fuel, but also from the recycled scrap. Once the de-S technologies are implemented in a steel plant, they can also be used as a flexible completion of the overall operation's cost-minimizing strategies.

This paper will discuss the sulfur path during the single steelmaking process steps, based on the example of the operation practice of Iskenderun Demir Ve Celik A.S., a major Turkish steel producer.

Sources of Sulfur in Iron and Steelmaking

Sulfur in liquid hot metal (HM) is included in burden materials like limestone and ore, and primary fuel such as coke, oil and pulverized coal used in the blast furnace (BF) for ironmaking (Table 1).[6]

Coke and oil are by far the largest sources. Coke and coal contain approximately 0.8–1.2%

This paper explains the control of hot metal sulfur coming in high levels from the blast furnace during steelmaking by the combined technology of hot metal and steel desulfurization. The benefit sharing between the BF and the BOF shops will be recognized, and the requirements of high-quality steel products on sulfur control will be reviewed.

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sulfur, depending on the mine source. Oil and heavy oil contain 1.3–2.0%. This adds up to a sum of 95% of the total input. Due to the reducing atmosphere in the ironmaking process in the BF, more than 80% of the total input is removed through the slag, so that there is only a balance of approximately 12%, which remains in the liquid hot metal. In the balance in Table 1, this equals to a hot metal sulfur content of 0.055%.

Table 1

Sulfur Balance of a German Blast Furnace[6]

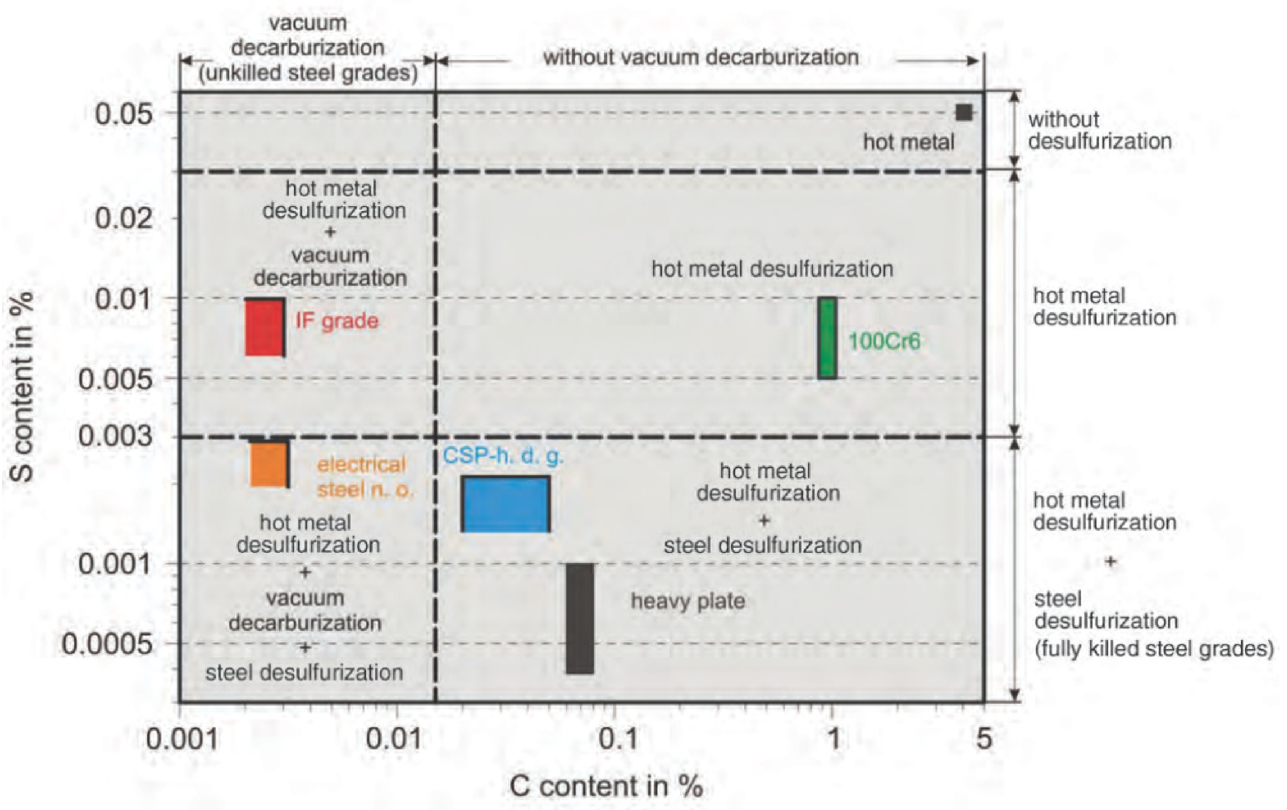
S input (4.40 kg/tHM) %			S output %	
Sinter	5.1	6.2 (sum of sinter, pellets and additives)	Slag	82.4
Pellets	1.0		Hot metal	12.6
Additives	0.1		BF top gas	3.6
Coke		60.2	BF dust	0.7
Oil		33.6	BF sludge	0.5
Total		**100**	Casthouse dust	0.2
			Total	**100**

Sulfur Requirements in Steel

Sulfur in steel is commonly considered to be a harmful impurity because it negatively influences steel properties like ductility, impact toughness especially at low temperatures, corrosion resistance and weldability. Therefore, sulfur is limited in almost all types of steel, but on different levels. For plain carbon steel like rebar, sections and wire, < 200 ppm is the normal specification. For special steel grades like LC, ULC, electrical steel, tinplate and most long products, the specifications are in the limits of < 50–100 ppm. In the case of ULS steel, the specifications require < 10–20 ppm. These grades are basically hydrogen-induced cracking (HIC) steel grades and high-strength steel for armor plates, liquefied natural gas (LNG) tanks, etc.

Another effect in secondary steel refining related to De-S treatment (in the case of slag-metal reaction) is that the deoxidation degree of the steel and slag is very high (i.e., very low oxygen contents) and the cleanliness of the steel is excellent. Therefore, a sulfur limitation of < 60 ppm in the internal specification of the steel plant is often used to guarantee high

Figure 1



Carbon and sulfur requirements for different steel grades.[8]

cleanliness performance. Due to the negative impact on ductility, the sulfur content in high-strength steel, HSLA and peritectical steel (0.09–0.12% C) is limited at < 30 ppm to avoid crack formation during bending and unbending in continuous casting.

Figure 1 shows a schematic of steel quality requirements on carbon and sulfur for five different steel grades. Interstitial free (IF) steel is a type of ULC steel used basically for deep drawing applications. In most applications, IF steel is surface coated (galvanized), which is best known in automotive construction. The most critical application of this steel is automotive exposed parts. Electrical steel is another ULC steel type used in transformer and generator fabrication. Due to its elevated silicon content, the electrical losses of its application can be minimized. Continuous strip production (CSP) steel is basically low-carbon steel for construction applications such as wheels, cylinders, welded pipes, agricultural, etc. In this case, heavy plate is HIC-resistant steel for large-diameter pipeline tubes, and 100Cr6 is the classic high-carbon, high-strength steel used for roller bearings. In order to improve machinability of this steel, the sulfur content is controlled at a certain range.

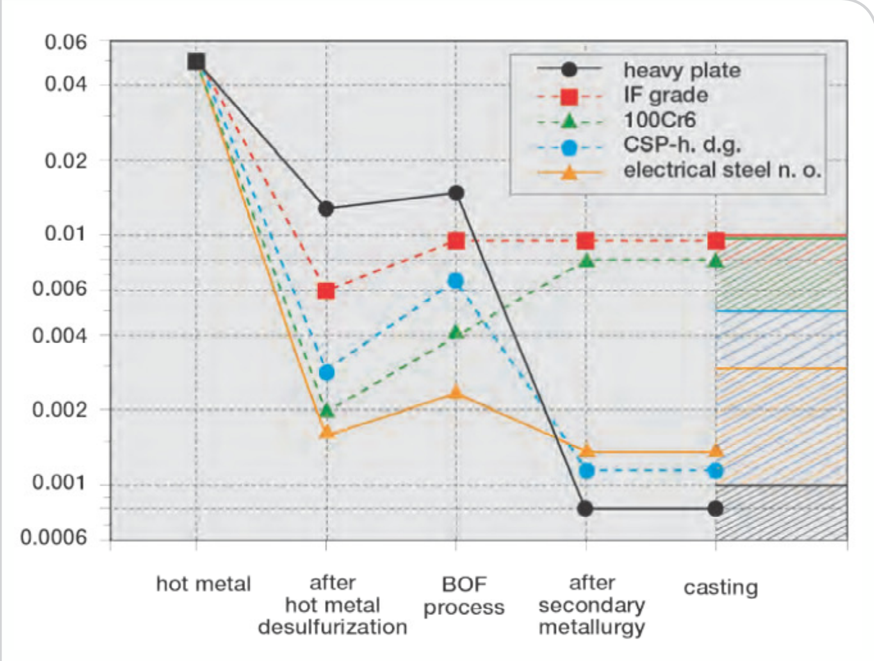
It becomes clear that all steel types are on a different sulfur level and require special treatments according to their specifications.

In Figure 2, the desulfurization strategies of different grades are demonstrated. The total De-S required is split between the different product stages during liquid steel production, which are:

- Hot metal desulfurization.
- Basic oxygen furnace (BOF).
- Secondary metallurgy.
- Casting.

As one can understand from the figure, the main goal is to guarantee that, after release of the liquid steel to the caster, the desulfurization reaction must be completely stopped. This is because, in the combined reaction of sulfur, lime and alumina according Formula 1, metallic aluminum is required to crack the lime to make the calcium available to react with the sulfur. But this forms alumina particles as byproducts, which are distributed in the melt and cannot be floated out in the remaining time to solidification.

Figure 2



Course of sulfur in steel processing for different steel grades.[8]

$$3[S] + 3(CaO) + 2[Al] \rightarrow 3(CaS) + (Al_2O_3) \quad \text{(Eq. 1)}$$

During secondary refining, the HIC-resistant steel, CSP and electrical steel are desulfurized at different levels, depending on the final specification to be achieved. As one can also estimate from the figure, the lowest possible content after the BOF with 25 ppm, in the case of the electrical steel, still requires desulfurization. Since it is more difficult to reduce sulfur from a low to an ultralow level, because of chemical reaction kinetics, in the case of the heavy plate, the huge De-S force from the high level of 150 ppm is successfully used to achieve ultralow contents. Because of this effect, only a medium level of hot metal De-S is required.

This is much different in the production routes of the LC, ULC and electrical steel grades. On the one hand, to achieve low final sulfur content or, on the other hand, to avoid the impact of steel De-S completely, hot metal De-S is applied. Especially in the case of IF steel grades, this is necessary because the side effect of steel De-S always is a silicon pickup (in the case of metal slag reaction and CaSi injection) or a carbon pickup (in the case of CaC_2 injection). Both effects are critical because IF steel is limited in carbon

Table 2

Model Factors to Calculate the Sulfur Content in the Blast Furnace[11]

Parameter	Base value	Correlation factor	
Hot metal temperature	1,491°C	–0.0025%	+10°C
Slag volume	327.0 kg/tHM	–0.0004%	+10 kg/tHM
Slag V-ratio	1.24	–0.0070%	+0.1
Slag (%MgO)	5.4%	–0.0017%	+1.0
Mn in Burden	7.9 kg/tHM	–0.0010%	+10 kg/tHM
Hot blast pressure	2.94 bar	+0.0005%	+0.1 bar
Productivity	1.80 t/(m^3 x 24 hours)	+0.0013%	+0.1 t/(m^3 x 24 hours)
Slag (%Al_2O_3)	14.8%	+0.0014%	+1.0%
%S in coke	0.48%	+0.0036%	+0.1%
%S in auxiliary fuel	0.65%	+0.0005%	+0.1%
Coke rate	473.0 kg/tHM	+0.0004%	+10 kg/tHM
Auxiliary fuel rate	57.0 kg/tHM	+0.0006%	+10 kg/tHM

for low strength and silicon for good surface coating properties.

An exception in the treatment is bearing steel. Since the grade has a controlled elevated sulfur content specification, the process strategy is to desulfurize the hot metal below specification, and after to elevate the content into specification by adding FeS alloying agent into the steel.

Desulfurization Technologies

Desulfurization in the BF is at a high level of 85–90%, as shown in Table 1. It can be influenced to an even higher efficiency by various parameters, as shown in Table 2. But as the table shows, most of the measures are related to higher coke consumption in the furnace or even lower productivity. The increase in the slag basicity helps, but has a strong negative impact on the alkali balance. This problem is one of the most critical in BF operations because it can result in a collapse of the whole furnace heat balance and cause a freezing of the furnace. All measures in the BF always impact the whole amount of hot metal being produced, while other technologies utilize the freedom of batch processing.

In steelmaking, various possibilities for De-S are available during processing (Figure 3). Sulfur can be removed in all different stages of operations, based on different efficiency levels. The so-called desulfurization efficiency, η_S in Equation 2, summarizes the process results and allows for benchmarking.

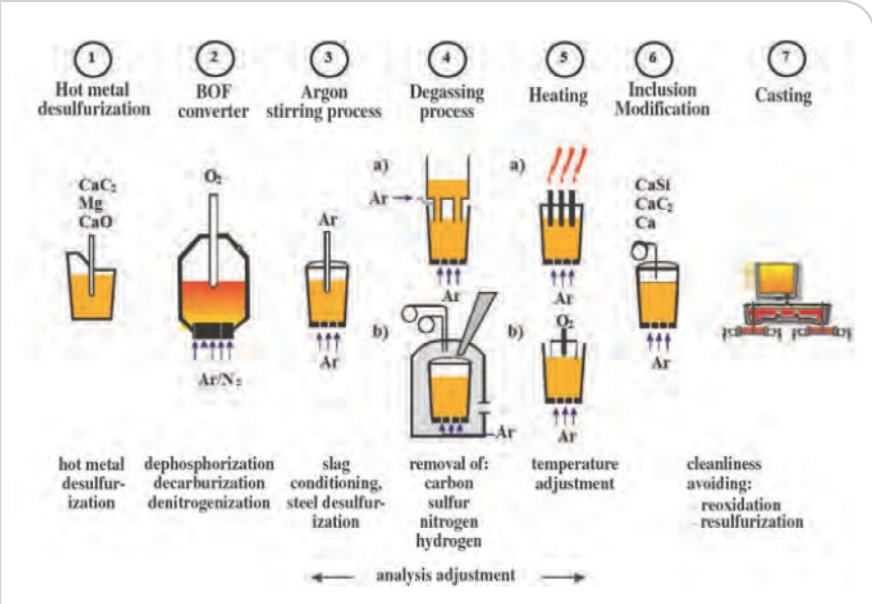
$$De\text{-}S\ degree = \eta_S \frac{\left(S_{initial} - S_{final}\right)}{S_{initial}} * 100\% \quad \text{(Eq. 2)}$$

where

$S_{initial}$ is the initial sulfur content in HM or steel before treatment and
S_{final} is the final sulfur content in HM or steel after treatment.

Hot Metal Desulfurization — One of the most common batch technologies applied in integrated steelmaking is hot metal desulfurization. In this case, the hot metal is treated in the charging ladle by using various agents and technologies. Common agents are powdered lime, powdered CaC_2 and metallic magnesium granules. Common technologies are tapping stream turbulence stirring, mechanical stirring and pneumatic powder injection. Desulfurization with liquid slag would be possible as well, but it is difficult to melt fluxes at the rather low hot metal temperatures; and, because of the necessity to deslag the hot metal ladle after De-S properly in order to avoid reversion in the BOF, the slag volume shall be kept low. Wire injection of CaSi or CaC_2 powder-filled wires will not work because the steel wire will not melt in the hot metal within a short time. The final results range in the η_S from 70 to 95%. It is possible to achieve final sulfur contents of 20 ppm in standard operations.

Figure 3



Course of sulfur in steel processing for different steel grades.[8]

Desulfurization in the BOF — Due to its oxidizing operation conditions, the η_S is rather low (20–50%), although basic slag is used for refining. Table 3 gives a sulfur balance of the process. It becomes clear that the sources for sulfur are hot metal, scrap and lime. The output is split between liquid steel, slag and dust, with 56% of the initial sulfur remaining in the steel. The possibilities to increase the De-S efficiency are rather limited. The most effective measure applied in operations is a limitation of the sulfur input with the scrap, by using special prepared and sorted scrap in the case of production of low-sulfur steel grades. It must be stated that, usually in the case of intensive hot metal desulfurization, even a sulfur pickup must be faced due to the sulfur content of scrap and lime and sulfur reversion from improper hot metal De-S slag removal, as shown in Figure 2.

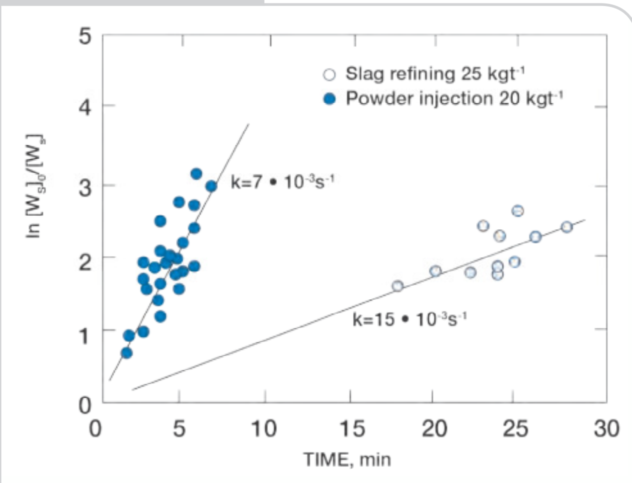
Desulfurization of Liquid Steel — A common technology that is applied worldwide is the desulfurization of liquid steel. The technological principles used are slag metal interface reaction, powder injection and wire injection. The technologies used are strong stirring, vacuum treatment, powder injection and wire injection. The agents used are high basic liquid slag based on lime flux additions into the ladle, CaSi or CaC_2 powder, and CaSi wire. The efficiency of the process is as high as for hot metal desulfurization, at 70–95% (98% when vacuum tank degassing is applied). The pre-condition for high efficiency, in the case of steel desulfurization, is deep deoxidation of the steel and melt, as mentioned earlier. The main reaction is given in Equation 1, with lime as the agent. It becomes clear that this principle can be used in Al-killed steel only, because Si-killed steel will produce

Table 3

Sulfur Balance of a German BOF Shop[9]

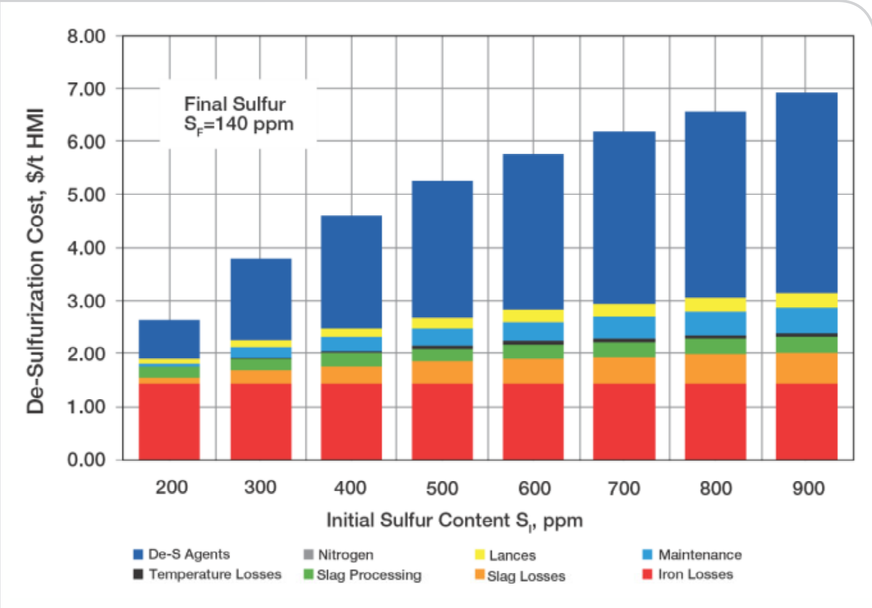
S input (0.54 kg/t_{CS})			S output	
	kg/t_{CS}	%		%
Hot metal (830 kg with 0.055% S)	0.46	85.3	Crude steel (1,000 kg)	56.7
Scrap (270 kg with 0.025% S)	0.068	12.5	Slag (110 kg)	37.3
Lime (60 kg with 0.020% S)	0.012	2.2	Dust (50 kg)	6.0
Total		100	Total	100

Figure 4



Efficiency of different steel De-S technologies.

Figure 5



Hot metal desulfurization operation cost structure.

silica during deoxidation and reduce the free lime available for desulfurization. Additionally, the final oxygen content in steel in the case of Si-killing is much higher.

Powder or wire injection at LF installations is a common method for steel De-S operations. Figure 4 shows the efficiency of both technologies. Since the aim of the injection technology is to achieve results with an agent-metal reaction without participation of the slag, a critical issue is the floating out of the reaction product, CaS. Furthermore, the use of CaSi or CaC_2 is always related with a silicon or carbon pickup in the steel, which might be critical for some steel grades.

In fact, the slag-metal reaction is facing the same issue. Due to the overdose of the aluminum required for deep oxidation, the ladle slag is reducing itself. That causes a reversion of silicon and phosphorus, and chromium and titanium. Due to the strong impact of the stirring treatment, carbon from the refractory will be solute in the melt and might cause problems, in the case of ULC steel grades.

As mentioned earlier, there are some side effects of steel desulfurization to be mentioned. First is the effect that De-S below a certain limit by metal slag mixing significantly improves steel cleanliness. An internal sulfur limitation of < 60 ppm, therefore, is beneficial. On the other hand, it is very important that the De-S reaction has stopped at the ladle's release to the caster. The reason is that, according to the De-S reaction, finely distributed alumina is produced that cannot be floated out from the melt and will cause clogging effects during casting.

Desulfurization Cost

The desulfurization costs were calculated many times for single operations. Figure 5 shows an example for hot metal De-S. Generally, the cost increases with increasing the hot metal initial sulfur S_I. This is basically caused by the consumption of De-S agents, but all other parameters like maintenance, lances and nitrogen increase as well. It can be estimated that temperature losses, slag (%Fe) losses and slag processing costs increase as well. Only the skimming losses for iron remain constant in operations. They are more related to the efficiency of the deslagging process than to the sulfur level in the hot metal.

The total cost for hot metal desulfurization from the blast furnace level of 0.060% down to 140 ppm are at almost $US6.00/tHM with 50% being the De-S agents, 25% being the skimming losses and 25%

Table 4

Desulfurization Cost Benchmark for 100 ppm of Sulfur

Parameter	Blast furnace (US$/t)	Hot metal desulfurization (US$/t)	Steel desulfurization (US$/t)
Fluxes	0.48	—	—
Fuel	1.01	—	—
Granulated BF slag	–0.05	—	—
De-S agents	—	0.48	—
Consumables	—	0.07	—
Maintenance	—	0.07	—
Transport	—	0.066	—
Slag and yield losses	—	0.129	—
Argon stirring	—	—	0.48
Aluminum consumption	—	—	0.12
Total	**1.44**	**0.82**	**0.60**

Figure 6

Hot Rolled

- Low-carbon unalloyed mild steels for cold reducing
- Hot rolled steels for cold reducing and galvanizing by hot dip process
- Medium carbon for cold reducing
- Low-carbon drawing quality steels for immediate cold forming
- Low- and medium-strength carbon steels for general purposes
- Steels for pipe and profile production
- High-strength steels with improved formability for automobile structural uses
- High-strength, low-alloy steel with improved formability
- Steels for LPG
- Steels for elevated temperature and pressure purposes
- Fine-grained, normalized steels for pressure purposes
- High-strength hull structural steels for shipbuilding
- Non-alloy structural steel
- Non-alloy carbon steels of structural quality for general purposes
- Steels for wheel production
- Boron-alloy steel plates for quenching and tempering steel for casing and tubing in the oil and natural gas industry. Petroleum line pipe steels suitable for use of conveying gas, water and oil in both oil and natural gas industries API

Billets for Merchant Bar, Rebar

- Non-alloyed, high-strength steels
- Structure steels for angle iron and profile production
- Steels for ship profile production
- For deformed reinforcing steel bar
- Seamless pipe steels

Wire Rod

- Carbon steels for thin-wire-drawing
- Electrode steels
- Screw steels
- Bolt steels
- Non- and micro-alloyed high-strength steels for springs
- Typed cord steels

Process flow and metallurgical facilities at Isdemir.

other cost factors. A cost addition of approximately $US2.50/tHM for labor; services; selling, general and administrative expenses; and capital cost has to be taken into account on top of that.

A benchmark comparison of blast furnace, hot metal and steel desulfurization is given in Table 4 for a sulfur decrease of 100 ppm in the hot metal or steel.

In the case of the blast furnace, the De-S will be achieved by increasing the basicity and the slag volume in the BF via the sinter burden. Due to the higher slag volume, the coke breeze consumption in the sinter and the coke consumption in the blast furnace increase. The total cost change is US$1.44/tHM. In the case of the hot metal De-S operation, more agents must be injected into the melt. This results in the operation cost changes discussed in Figure 5. It is assumed that the skimming losses remain constant. In this case, the cost change is US$0.82/tHM. In the case of steel De-S, it is assumed that the additional work can be carried out without the addition of more flux, only by longer lance bubbling and higher aluminum consumption. A minute of lance bubbling costs approximately US$0.21/minute for lance refractory and argon gas. In the De-S cost estimate, this results in a change of US$0.60/tHM.

It can be stated that steel De-S — if generally applied — is the most cost-effective way to bring sulfur down. But in steelmaking, after the tap of the vessel, time is valuable. The complex logistics of sequence casting, especially in shops with more than one caster, require that a tight process schedule be followed. Therefore, hot metal De-S in front of the BOF is the best compromise in operations, as long as no additional skimming losses are generated. Control of the skimming loss is one of the most critical issues of the process.

Company Profile — Iskenderun Demir ve Celik A.S.

The process flow and the metallurgical facilities of Isdemir are illustrated in Figure 6. Four blast furnaces supply approximately 16 kt of hot metal per day. The hot metal is transported via rail-bound submarine cars to the BOF shop, which comprises a 3-stand/2-line hot metal desulfurization plant (HMDS) for the multi-injection of lime, calcium carbide and magnesium. The treated hot metal is then charged into three BOF converters with bottom stirring and a nominal steel weight of 200 t. The secondary refining has

Table 5

Number and Capacities of Isdemir's Major Steelmaking Units

Unit	Quantity	Capacity (tpd)	Specifications
BF	4	16,000	—
HMDS	3	16,500	Multi-injection, lime-preparation plant
BOF	3	14,400	200 t each
TWLF	2	14,400	—
LF	1	6,000	—
Billet caster	2	5,500	6 strands each
Slab caster	2	14,400	2 strands each

Table 6

Desulfurization Degrees of the Different Facilities at Isdemir

Unit	Typical De-S degree, %	De-S degree at Isdemir, %
BF	80–90	65
HM De-S	70–95	85
BOF without prior HM De-S	20–30	60
BOF with prior HM De-S	–	–9 (approx. 20 ppm S pickup)
LF	30–90	42

installed two twin-ladle furnaces (2x 30 MVA/2x 2.65 m tpy), one single-ladle furnace (20 MVA/1.0 m tpy) and a chemical heating station (1.0 m tpy). These furnaces are used for temperature control, alloying and refining operations of the liquid steel. The secondary metallurgy operates as the clearance buffer between the BOF and the continuous casting machines. Full automatic production control is provided via levels 1, 2 and 3 automation systems.

The production is split into a long product line and a flat product line. The flat product line has a capacity of 5.0 million tpy, and the long product line has a capacity of 2.0 million tpy. The quality program includes slabs for various kinds of hot and cold rolled applications. The quality program for long products is basically focused on the production of billets for export applications and wire rod for local market supply. A summary is given in Table 5.

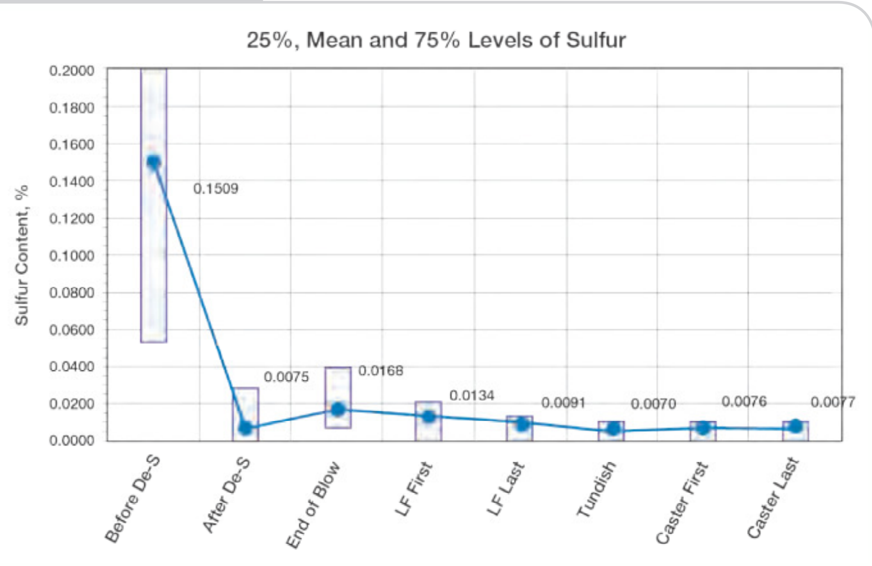
Isdemir's Sulfur Control Strategy

The company's iron source is a local supply located in Ermaden, approximately 500 km from the iron and steel works. The advantage of this supply, on the one hand, is the low cost compared to world market levels. On the other hand, the ore contains a rather high alkali content, which increases the alkali input into the BF up to 4 kg/t (normal levels are in the range of 2.0 kg/t and below).

To control this high alkali input, the BF slag basicity is adjusted in the range between 0.75 and 0.85. The low slag basicity results in very poor desulfurization efficiency of the BF slag. Furthermore, the sulfur input coming from the coke is in the high range of 4.5 kg/thm (normal levels are 2.5 kg/t and lower). Both factors together increase the hot metal sulfur content to a level of 1,500 ppm and higher. It is obvious that this high sulfur level in the hot metal requires special strategies for adjustment to common steel specification.

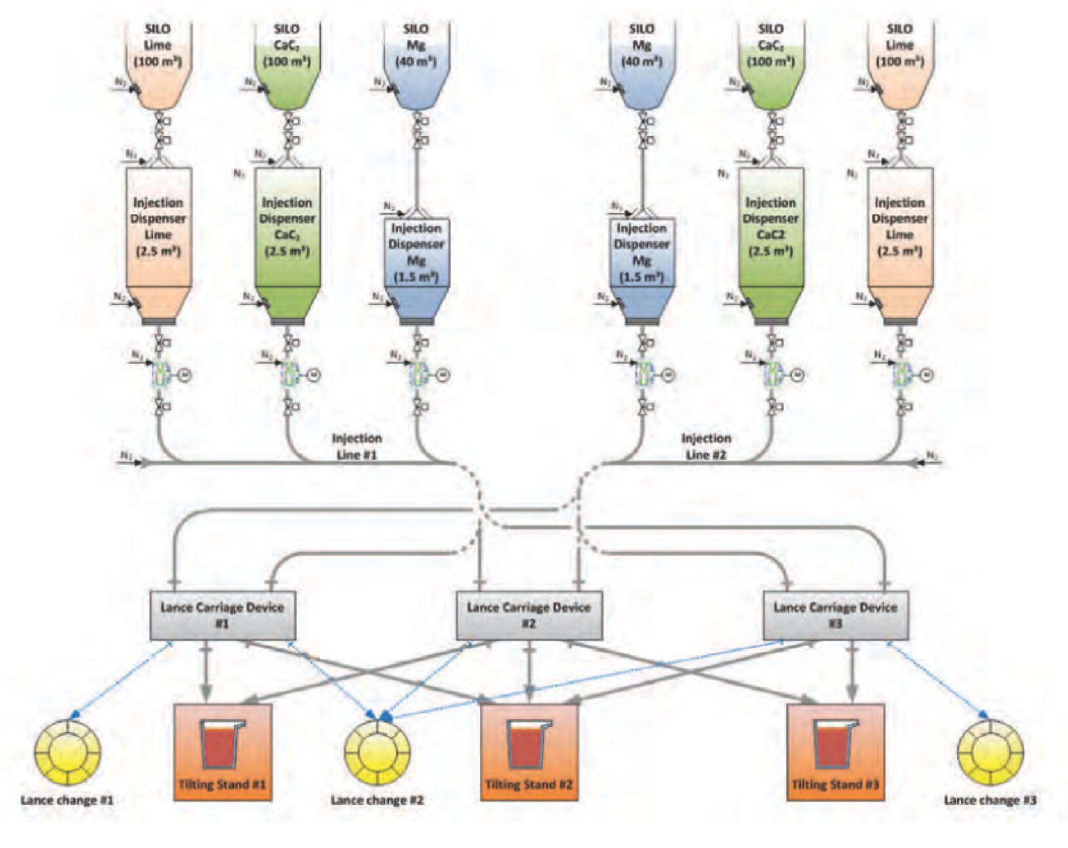
Isdemir steelmaking deals with the high hot metal sulfur by carrying out a strong hot metal desulfurization cut of 1,270 ppm (Figure 7). In the BOF, the pickup is controlled to a minimum of 20

Figure 7



Sulfur path at Isdemir steelmaking operations.

Figure 8



Basic process flow of Isdemir's HM desulfurization system.

ppm. In secondary refining, while tapping the heat from the BOF and ladle furnace operation, the sulfur is reduced to the final liquid steel release specification. Typical desulfurization results of other operators have been taken from literature investigations and are compared to the figures of Isdemir in Table 6.

Isdemir's Hot Metal De-S Technology

It is obvious that, due to the high demand for hot metal De-S, system capability and availability are the critical issues in the De-S strategy. Isdemir decided on a high-efficiency, multi-injection system to satisfy its demands. In 2006, this system was engineered, supplied and commissioned by Küttner GmbH, Germany. A preparation plant for fluidized quicklime was also a part of the supply. The desulfurization system is based on immersed lance technology and designed for multi-injection of magnesium, calcium carbide and lime. Figure 8 shows the basic process flow. The detailed plant installation layout is given in Table 7.

The following injection modes can be used:

- Co-injection of calcium carbide or lime with magnesium using different co-injection rates.
- Mono-injection of calcium carbide or lime.
- Multi-injection, including a pre-injection phase with lime only, followed by a co-injection phase with calcium carbide and magnesium simultaneously, followed by a phase with calcium carbide only, and finally a post-injection phase with lime only.

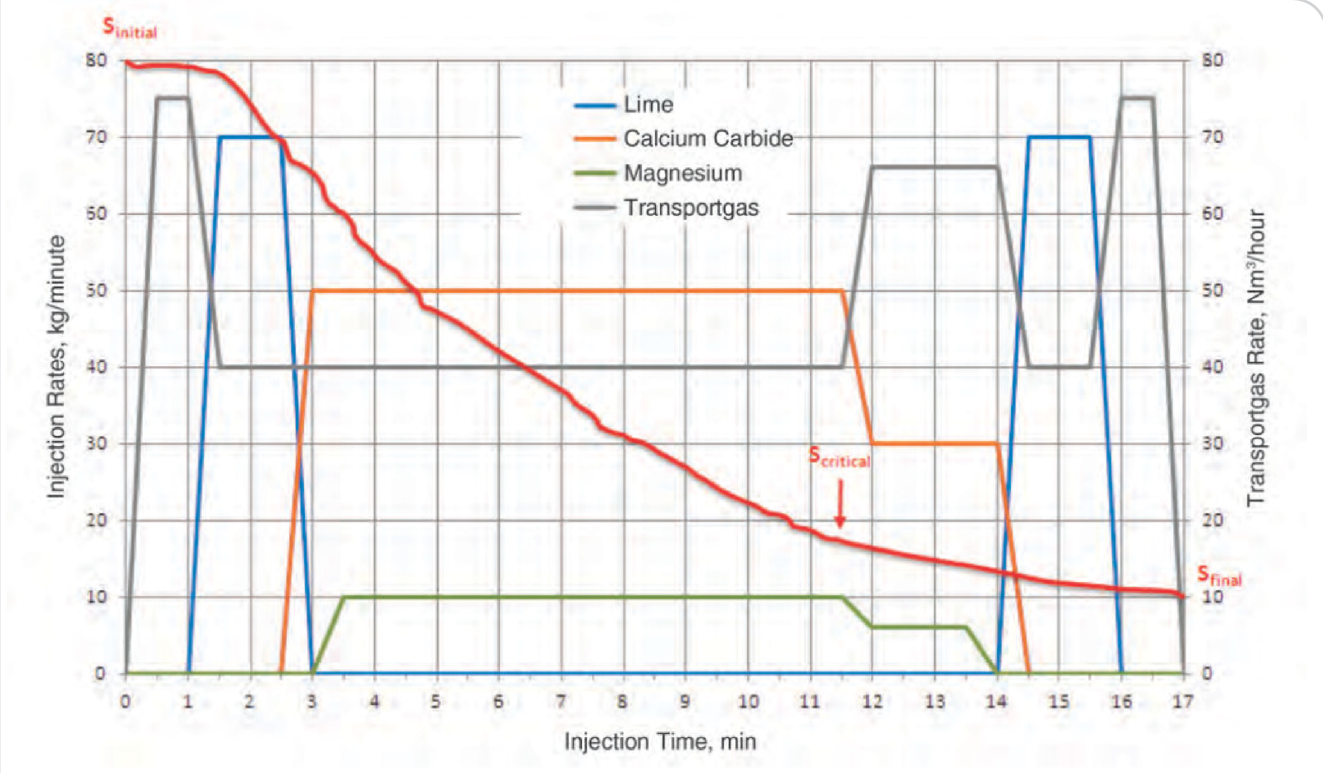
A schematic flow pattern used for a multi-injection treatment is given in Figure 9.

Isdemir's HM De-S Performance Results

The performance figures of the operations are given in Figure 10, comparing the different operation modes:

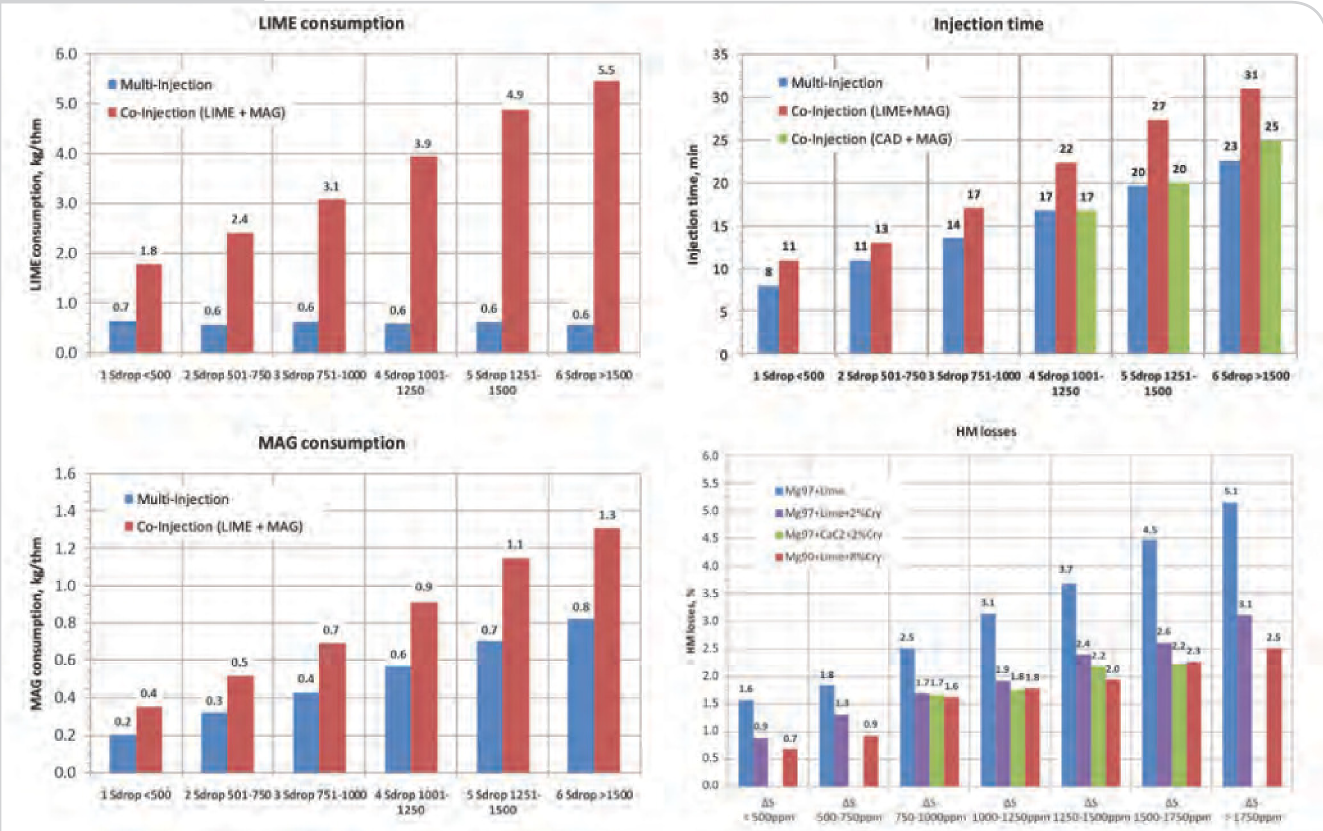
- Co-injection (lime + MAG).
- Co-injection (CAD + MAG).
- Multi-injection (lime + CAD + MAG).

Figure 9



Schematic sketch of the multi-injection process.

Figure 10



Isdemir's HM De-S performance results.

Table 7

Configuration of the HM Desulfurization Plant at Isdemir

Basic design data	
Number of treatment stands	3
Metallurgical reactor	Open HM (charging) ladle
HM amount	180 t
Ladle freeboard	400 mm
HM temperature	1,350°C
Initial sulfur	1,500 ppm
Final sulfur	70%: ≤ 100 ppm; 30 %: ≈ 500 ppm
Desulfurization reagents for multi-injection	
Magnesium	Mg97
Calcium carbide	KA70C
Lime	Homemade, fluidized
Transport gas	Nitrogen
Desulfurization reagents for co-injection	
Magnesium	Mg97
Lime	Homemade, fluidized
Transport gas	Nitrogen
Capacity	
Daily capacity	11 tpd
Annual capacity	4.0 mtpy

It can be confirmed that multi-injection, representing the blue bars in all diagrams, is the best technology available for desulfurization applications. De-S agent consumption figures are low and injection time is also lower, compared to other variants.

The skimming loss diagram in the lower right quadrant of Figure 10 shows another significant effect in modern hot metal De-S technology. It is shown that the use of small amounts of Kryolith in the De-S agent mix cuts the iron yield losses almost by half. The effect is well understood and is related to the fluidizing effect of Kryolith on De-S slags. Most of the skimming iron losses are not generated from metal removed with the skimmer, but from metal captured as droplets in the high-viscose De-S slag. Kryolith and other fluxes reduce the slag viscosity significantly and, by that effect, allow the metal drops to sink back into the melt. This effect is the main reason for lower yield loss results given in the figure for other process variants.

On the other hand, the change in slag viscosity causes other problems. In fact, the deslagging of the hot metal ladle will become much more difficult. To solve this problem, a slag viscosity increase flux is required to enhance the deslagging performance. To counteract the described effect, increasing flux is required before a slag viscosity. Agents of this type are normally used during deslagging. The powder is pneumatically blown on top of the slag. By chemical reaction, the slag is solidified and can be removed easily from the surface of the melt. Proper ladle mouth design and sensitivity of the deslagging arm, as well as the operator's skill, is required.

Summary and Conclusions

The increasing requirements for the production of low- and ultralow-sulfur steel grades have been highlighted. The reasons for increased sulfur input to the BF have also been given. Extension of the desulfurization work in the BF does not seem to be an acceptable method, with regard to performance and productivity losses of the BF. The concept of "alkali-oriented BF slag operation" has been introduced and discussed. As a consequence of this BF operation, elevated HM sulfur contents are unavoidable and the efforts for sulfur removal in the steelmaking shop have to be enhanced. But the softening of the sulfur limitations of the blast furnace is opening a huge potential for cost savings. Brief descriptions and discussions of the different metallurgical facilities in the BOF shop have been given with respect to their capability to remove sulfur. The combined utilization of BF, HMDS, BOF and LF as desulfurization facilities, with suitable and coordinated desulfurization degrees of all units, is the key to managing high sulfur contents of the HM successfully.

Isdemir, the largest Turkish steelmaker, has chosen this method for their steel works in Iskenderun. With Isdemir's production figures and HM desulfurization facility, it has been shown that this strategy pays off and that this concept is a viable option.

Besides the economical balance between savings at the BF and rising expenses in the BOF shop, the "alkali-oriented BF slag operation" seems to be especially interesting for all plants suffering from HM shortage or that want to increase their HM output without adding new melting facilities.

References

1. "Treatment of Hot Metal, Steel and Slag," Küttner company brochure.
2. Masteel UK Ltd. homepage, www.masteel.co.uk.
3. *The Making Shaping and Treating of Steel, 11th edition,* AIST, Warrendale, Pa., 1998.
4. Iwamasa, P.K., and Fruehan, R.J., "Effect of FeO in the Slag and Silicon in Metal on the Desulfurization of Hot Metal," *Metallurgical and Materials Transactions,* Vol. 28B, February 1997.
5. Kurunov, I.; Titov, V.; Arsamascev, A.; Basov, V.; and Tikhonov, D., "Analysis of Alkali Removal Influenced by Blast Furnace Operating Conditions," *METEC InSteelCon,* Düsseldorf, Germany, 2011.
6. Altland, R.; Beckmann, B.; and Stricker, K-P., "Verfahrensoptimierung am Hochofen durch kontrollierte Alkali- und Schlackenbedingungen" ("Process optimization of the blast furnace by controlled alkali and slag conditions"), *Stahl und Eisen,* Vol. 119, No. 11, 1999.
7. Ivanov, O., "Metallurgische Grundlagen zur Optimierung von Hochofenschlacken mit Bezug auf die Alkalikapazität" ("Metallurgical basis for the optimization of blast furnace slag, with reference to the alkali capacity"), dissertation, TU Bergakademie Freiberg, November 2002.
8. Bannenberg, N., "Recent Developments in Steelmaking and Casting," *Stahl,* 2000.
9. Kalla, U.; Kreutzer, H.W.; and Reichenstein, E., "Verfahrenstechnische Möglichkeiten zur Einstellung definierter Schwefelgehalte im Stahl" ("Procedural options for setting defined sulfur contents in steel"), *Stahl und Eisen,* No. 97, No. 8, 1977.
10. Ghosh, A., *Secondary Steelmaking — Principles and Applications,* CRC Press, 2001.
11. Yamagata, C; Kajiwara, Y.; and Suyama, S., "Mass Transfer Model for Desulfurization in the Lower Part of the Blast Furnace," *Transactions ISIJ,* Vol. 28, 1988. ✦

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