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Reduce Slag Carryover Reliably in Steel Production

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Steel slag, a molten liquid melt of silicates and oxides, is a normal occurrence during the steel-making process, but it is also an expensive and detrimental consequence. Slag is created by the separation of the molten steel from impurities inherent in iron ore and scrap metal.

Slag impurities degrade steel. For example, slag will pull phosphorous from iron and, if not removed, the phosphorus reverts back into the steel, lowering its quality. It also causes substantial wear and tear on the vessels involved.

When slag is carried over, it results in:

- Longer processing time
- High inclusion formation and steel cleanliness challenges
- Difficulty in ladle desulphurization
- Caster nozzle clogging
- Ladle refractory wear

While slag has use in the aftermarket in a variety of applications, its presence as a result of the steel-making process causes substantial time, expense and equipment damage. Until now, it has taken herculean efforts to remove slag. Now, based on recent advances in detection, slag is more reliably and effectively managed.

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How Steel is Made

Steelmaking starts with iron in a furnace, the two most common furnace types being a basic oxygen furnace (BOF) and an electric arc furnace (EAF). The two vary as follows:

Basic Oxygen Furnace

A basic oxygen furnace is a refractory-lined and tiltable converter. When steel is made within a basic oxygen furnace, molten iron and scrap are heated and oxygen is then blown through nozzles into the charge via a water-cooled oxygen lance. The BOF is able to rotate, enabling it to charge raw materials and fluxes that are used to remove impurities. It also allows it to sample the melt and pour the steel and slag out of the furnace. The oxygen converts the pig iron, which accounts for approximately 94 percent of the volume; the remaining six percent is composed of impurities including manganese, carbon and silicon. By the end of the steel-making process, steel made via BOF will have impurity levels of approximately one percent.

In the basic oxygen process, hot liquid blast furnace metal, scrap and fluxes, consisting of lime and dolomitic lime, are charged to a furnace. A lance is lowered into the converter and high-pressure oxygen is injected. The oxygen combines with and removes the impurities in the charge. These impurities include gaseous carbon monoxide, silicon, manganese, phosphorus and liquid oxides that combine with lime and dolomitic lime, forming steel slag. At the end of the refining operation,

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the liquid steel is tapped (poured) into a ladle and the steel slag remains in the vessel and is subsequently tapped into a separate slag pot.

The steel-making steps in a BOF include:

- Charging the scrap
- Adding pig iron to the furnace
- Charging the fluxes
- Oxygen blowing
- Sampling
- Tapping
- Ladle refining
- De-slagging

The molten steel is removed from the furnace when the steel is at its optimal consistency, and it is removed through the tapping hole. During the process of manufacturing the steel, the tapping hole remains plugged to keep heat from escaping the furnace.

Electric Arc Furnace

In comparison, an electric arc furnace (EAF) creates steel from scrap and direct reduced iron (DRI) and uses three vertical graphite electrodes to charge the iron and scrap via electric current. This furnace is analogous to a wok with a lid. Metal is added, the lid is closed, and an arc is created between the electrodes. The power, strong enough to power a small city, melts 100 percent of the steel scrap.

At this point, limestone flux is added. A hole in the base of the "wok" opens and a ladle is positioned underneath. The molten steel comes out into the ladle, and the hole closes when slag is detected.

The steel making steps for an EAF are:

- Charging scrap metal, iron and limestone
- Lowering the electrodes, melting the metal with electric current
- Oxidation
- De-slagging
- Adding new fluxes for reducing stage to eliminate sulfur and oxide absorption
- Tapping
- Lining maintenance to eliminate molten steel breakouts from excessive lining depletion

With both types of furnaces, molten iron is tapped at regular intervals. Accurate temperature monitoring ensures steel quality is consistent and improves process efficiency.

While it seems that the steps are straightforward, detecting slag and keeping it from degrading the steel is an art and a science, and the detection methodology has evolved substantially over time.

Slag Detection – Measurement Methods

When slag begins to exit along with the steel the pour is stopped. Initially, the process of detecting slag was visual. An operator wore a dark viewing shield, or visor, to observe the color of the pour. Since slag has higher emissivity, it looks brighter than the steel preceding it. Once the slag was spotted, the operator signaled for the molten steel vessel to tilt, preventing it from pouring out.

There are several downsides with this method. A major one is safety. The operator's eyes were often damaged. Repeatability is a major issue, as reliability varied from operator to operator. Fumes often cloud the environment so that complete accuracy is impossible. Its use also prevents improvements to the process. This visual method is still used in some areas of the globe.

Figure 1. Visual detection of slag is not only inconsistent but the operator's eyes are easily damaged with the practice. Source: AMETEK Land

Another method involves a ceramic ball or dart that is shot into the molten steel. The stem of the dart is visible as the dart floats on top of the steel. Once slag begins to flow through the tap hole, the flow density lowers and the dart sinks into the tap hole, reducing slag flow until the operator reverses the tilt. Inserting the dart is problematic in that in many cases it requires an expensive machine run by a highly trained operator. The darts are also consumable and add expense to the process.

A third method is to use a circular induction coil, which is wound around the tap hole in a refractory. Current passes through the coil and the induction field varies based on the material composition of the flow. When slag is present, a signal from the induction coil determines the time when reversal should occur. This method actually works well.

Figure 2. The induction coil, while initially accurate, has shelf-life and reliability over time challenges. Source: AMETEK Land

The coil, however, does not last as long as the vessel does. When the coil fails, it means casting a new coil into the hole or waiting for a reline and moving to manual slag detection in the interim. Accuracy over time is the major issue. Again, the coil is consumable, so using this method also adds ongoing expense.

Two decades ago, the thermal imaging camera arrived on the scene. Non-contact, it did not wear out or add any consumables to the bottom line. This detector was an optical or infrared detector array that featured an electronic processor and repeatability was greatly enhanced.

Were there drawbacks? Yes. Like the visual method, there would occasionally be fumes that obscured the view in the sight path.

Advances over time included long-wavelength thermal imagers with an 8-14 µm response. The results were good, as the emissivity between steel and slag was accentuated by the long wavelengths. There was still fume obscuration and the optical materials used in these thermal imagers were not sufficiently durable for the harsh environment, requiring frequent protective window or lens replacements.

An Atmospheric Window

Although long wavelengths were problematic, mid-wavelength thermal imagers offered several possibilities. A thermal imager working at a narrow waveband could see through hot CO2 and hot water vapor. This atmospheric window was first documented in NASA test data more than five decades ago. The shorter 3.9 µm waveband also enabled extremely durable optical systems, including sapphire protection windows with good transmission characteristics from ultraviolet to approximately 5.5 µm in the infrared. These capabilities are built into the AMETEK Land Slag Detection System (SDS).

AMETEK Land Slag Detection System

The AMETEK Land Slag Detection System (SDS) delivers improved yields, higher-quality steel and reduces costly downstream processing for BOF and EAF steel-making operations.

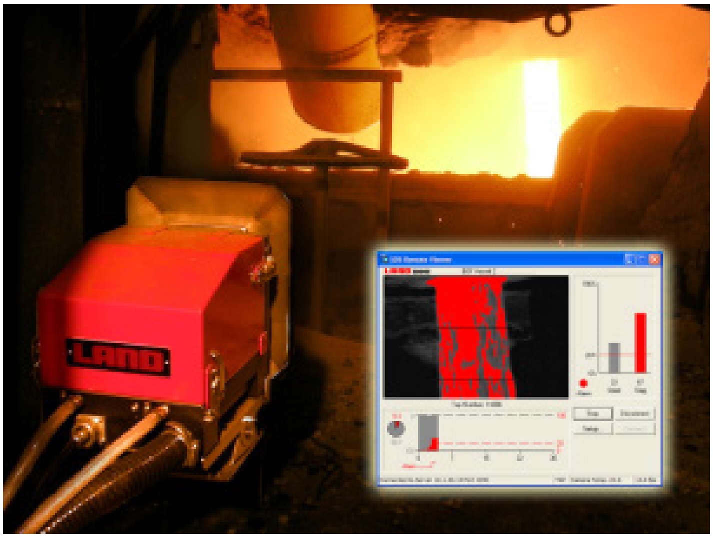

Figure 3. The AMETEK Land SDS. Source: AMETEK Land

The AMETEK Land SDS is based on more than 60 years of experience in the steel industry, monitoring and aiding in the control of slag carry-over from one process to another. It is specially designed to withstand the harsh conditions of continuous operation in the steel plant, with minimal maintenance requirements.

The industrial thermal imaging sensor is housed in a rugged, water-cooled and air purged enclosure and continuously views the tapping area. As the tap begins, dedicated software automatically records the tap, producing a log and graph of the relevant steel and slag data. When the level of slag reaches a pre-determined level, an alarm is generated to stop the tap. Full access to the tapping data is available to the operator for quality control purposes.

SDS uses a high-resolution thermal imaging camera to detect the transition between steel and slag with a particular wavelength to reduce "blackouts" caused by smoke and fume. By warning the operator in a dependable, repeatable and timely manner to stop the tap before slag is carried over, SDS improves production yield and ensures a lower slag content, improving quality. This also reduces energy costs further along the process and lowers the maintenance on the furnace vessel.

Using the SDS has been demonstrated to improve operator response time and consistency at the end of each tap. This results in a typical reduction in slag depths of up to 25 percent compared to traditional methods of monitoring.

Key features include:

- Four-parameter set up
- Full screen displays relevant tapping information (see Figure 4)
- Five user-defined variables display specific updatable information
- Alarm activation, independent of operator, when a preset percentage of slag or steel is detected within a defined window. The alarms directly stop the tap before the slag is carried over
- Fully automatic operation including auto tap detection, steel/slag ratio, video file, log file of all data, steel/slag percentage graph — all saved as tap number
- Product traceability includes the automatic storage of temperature data from each coil for subsequent analysis
- Water, air, power input, communications, video, located to the rear of the enclosure
- SDS based on AMETEK Land's advances in nano-waveband technology

These features are innovative in slag detection and thermal imaging, providing an excellent man-machine interface for the steel industry.

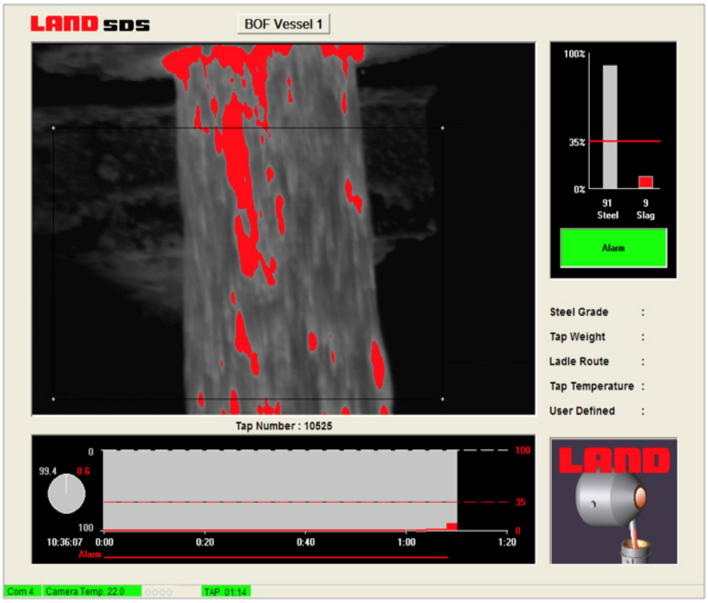

Figure 4. The full screen displays relevant tapping information and enables remote viewing of the live tap anywhere on the plant network.

There are many important benefits to using the SDS, including:

- Improves operator safety
- Because SDS is non-contact it lasts longer than the vessel
- Very fast response time with consistent "every time" results
- $20,332.65 saved in aluminum additions for every 50,000 tons of steel produced by reducing ladle slag height by 2.5 cm
- Phosphorous reversion reduced between 0.002 to 0.003 percent max
- Refractory and argon stirring lances increased lifespan by 10 and 20 percent respectively

Summary

Although measurement methods have evolved over the past few decades, the quality of metallic scrap and iron feed stocks have simultaneously deteriorated. This results in greater slag generation and slag-related challenges for the steel industry. The existence of slag causes substantial processing time, lower steel quality, difficulty adding alloys and conditioners, and substantially higher processing and treatment costs.

The AMETEK Land Slag Detection System withstands the harsh conditions of continuous operation inherent in steel production. The SDS solution reduces slag carryover in steel production facilities, saves money and dramatically improves operator safety.

For additional information on the AMETEK Land Slag Detection System, visit AMETEK Land. AMETEK Land works closely with its customers to implement solutions that solve existing production and process challenges, with an eye to the bottom line.

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ABOUT AMETEK LAND

Founded in the UK in 1947, AMETEK Land (Land Instruments International Limited) developed a reputation for producing innovative, resilient measurement technologies designed to operate in the most challenging conditions. Acquired by the Process & Analytical Instruments Division of AMETEK, Inc in 2006, today AMETEK Land is the premium supplier of product application solutions to world industries including steelmaking, glass making, minerals processing, hydrocarbon processing and thermal power generation.

Our success rests on award-winning technologies that push the limits demanded by the ever-increasing technical demands of global industry. Aligned with our expert knowledge, we meet the challenges of a wide range of applications, delivering process safety, process control and product quality our customers depend on.