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Basic Oxygen Steel Process Monitoring Using the Thermo Scientific Prima δB

Key Words

- Prima δB
- Basic Oxygen Steelmaking
- Decarburization Control
- Gas Recovery
- Impurity Prediction
- Iron & Steel
- Mass Spectrometry
- Off Gas Analysis
- Process Control
- Slopping Prediction

Introduction

Process mass spectrometers are now widely used for many important gas analysis applications on iron and steel plants, including blast furnace top gas analysis, coke oven gas analysis, secondary steel process control, fuel gas analysis and direct reduction processes.

In recent years, a number of steel producers have incorporated mass spectrometers into their manufacturing processes to provide dynamic process control. A single analyzer can accurately measure CO, CO_2, O_2, H_2, N_2 and Ar, replacing a number of discrete analyzers with a single reliable system.

The ability to measure a wide range of components on a single analyzer coupled with automatic calibration, data transmission and self-diagnostic software makes the Thermo Scientific Prima δB process mass spectrometer ideal for integration into the modern steel plant. For example, the gas from the basic oxygen furnace can be analyzed for decarburization rate and the onset of slopping. Accurate gas composition data can also be used in models to calculate residual carbon, phosphorus and manganese. In addition to improving control of the steel production process, the gas analysis data from the Prima δB is used to control the waste gas recovery system.

Decarburization Rate Control

As the waste gas composition changes rapidly during the steel making process (in a process which is complete in approximately 20 minutes), gas analysis data must be acquired quickly. Using mass spectrometry, this data can be updated in three seconds or less, compared with up to 20 seconds for conventional techniques such as infrared.

This decarburization can be expressed by the formula:

$$dC/dt = constant * (CO + CO_2) * waste\ gas\ flow/60$$

The ratio of CO/CO_2 in the waste gas gives an indication of carbon removal during the blowing phase. The study of these distinctive curves as well as that of the retained O_2 shows a pattern that correlates well with the beginning and end of decarburization. This lessens the need for "re-blows" and extra additions to the converted vessel, reducing costs and improving productivity.

One of our customers reports achieving a success rate of greater than 95% for blowing after converting to mass spectrometer control. This compares with a re-blow rate of up to 10% with the previously installed infrared systems.

The CO/CO_2 and O_2 retained curves which also gave an indication of the state of the slag development and, therefore, can assist with lance positioning at the beginning of the blow and O_2 rate and lance height control towards the end.

Thermo Scientific Prima δB scanning magnetic sector process mass spectrometer

Improved Prediction of Impurities

The ability to accurately measure the N_2 concentration in waste gas with the mass spectrometer yields significant benefits in the prediction of the residual carbon, phosphorous and manganese content in the steel. It is also possible to predict the temperature of the steel.

These components which can only be predicted with minimal accuracy using conventional techniques can, with the mass spectrometer, be predicted with the accuracy depicted in *table 1*.

The predicted carbon content with discrete analyzers would typically be accurate to only 0.02%.

Content	Standard Deviation (predicted/actual)
C	0.0100%
P	0.0014%
Mn	0.0400%
Temperature	8°C

table 1 – Accuracy comparison for Prima δB analysis

Slopping Prediction

The ability to successfully predict the onset of slopping is one of the most significant advantages that the mass spectrometer has over conventional techniques. The steel producer needs to know precisely how much oxygen remains in the converter in order to predict when slopping will occur. The mass spectrometer's ability to measure nitrogen directly enables the operator to accurately determine the quantity of air leaking into the converter hood. This, in turn, will yield a much more precise measurement of the oxygen leaving the converter.

Remaining O_2 = O_2 blown in – O_2% x gas flow

This precise oxygen measurement now allows the leading steel producers to use mathematical modeling techniques to predict when slopping will occur. At sites where several mass spectrometers have been installed, this modeling has successfully predicted slopping at a rate of 81%.

Hydrogen Analysis

The Prima δB also provides a stable analysis of hydrogen content of the waste gas, which can be used for the early detection of cooling leaks as well as the water content in flux additions.

Cost Savings through Efficient Gas Recovery

The normal sampling point is directly on top of the waste gas duct before the gas cooling and dust extraction systems. This, locally coupled with the exceptionally fast gas analysis, enables the steel producer to begin recovery of the valuable waste gas up to 20 seconds sooner and prolong the recovery for 20 seconds longer at the end of each charge. A typical gas flow rate of 150,000 Nm^3/hr can save the steel producer 1640 Nm^3 on each charge, resulting in significant cost savings.

Typical Precision

The analysis of the six components normally monitored with the Prima δB would typically yield the precision depicted in *table 2*. The table shows the results of a one hour analysis on a gas mixture. The measurement interval is less than three seconds.

	Cone (vol %)	Standard Deviation
N_2	15	0.040
O_2	3	0.003
Ar	1	0.001
CO_2	25	0.021
CO	52	0.040
H	4	0.004

table 2 – Typical precision on a one-hour analysis of gas sample mixture

Description of Analyzer

The Prima δB magnetic sector mass spectrometer utilizes technology which has been proven over many years in a wide range of iron and steel applications, including blast furnace, gas mixing stations, VOD, AOD, coke oven gas analysis and direct reduction processes. The method of analysis is achieved using the components depicted in *figure 1*.

Sample Inlet System

The inlet system consists of a rapid multi-stream (RMS) rotating sampler that ensures continuous sample flow and zero dead volume, eliminating the need for long sample flushing times. Constant inlet position feedback and gas flow rate monitoring provide ultimate sample integrity. The only consumable component is a sample seal which typically completes over five million operations between servicing, enabling a single Prima δB system to sample from more than one vessel.

Analyzer

There are essentially two types of mass spectrometers available for continuous gas analysis. The Thermo Scientific product line is unique and offers both types of MS systems. Magnetic sector has proven to be the most successful due to the inherently superior stability and lower maintenance requirements.

Gas components are separated according to their individual molecular weights. The gas molecules are ionized by electron bombardment. The positive ions are then accelerated through a magnetic field. The strength of the magnetic field is varied and this allows the instrument to select different gas species. The resulting highly stable mass

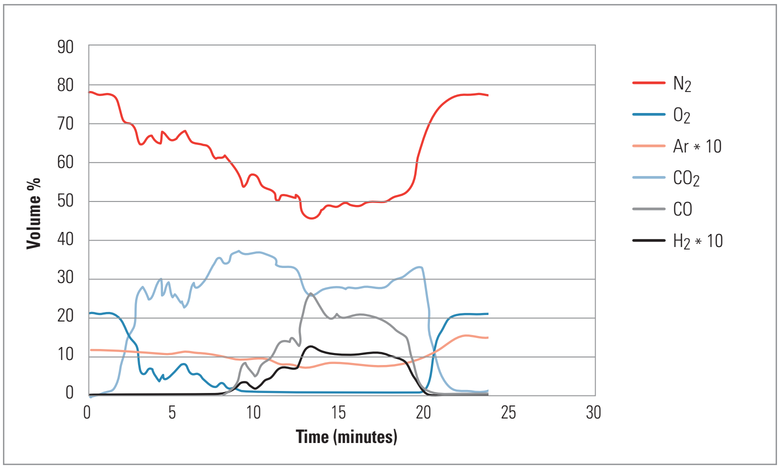

figure 1 – Typical Prima δB analysis

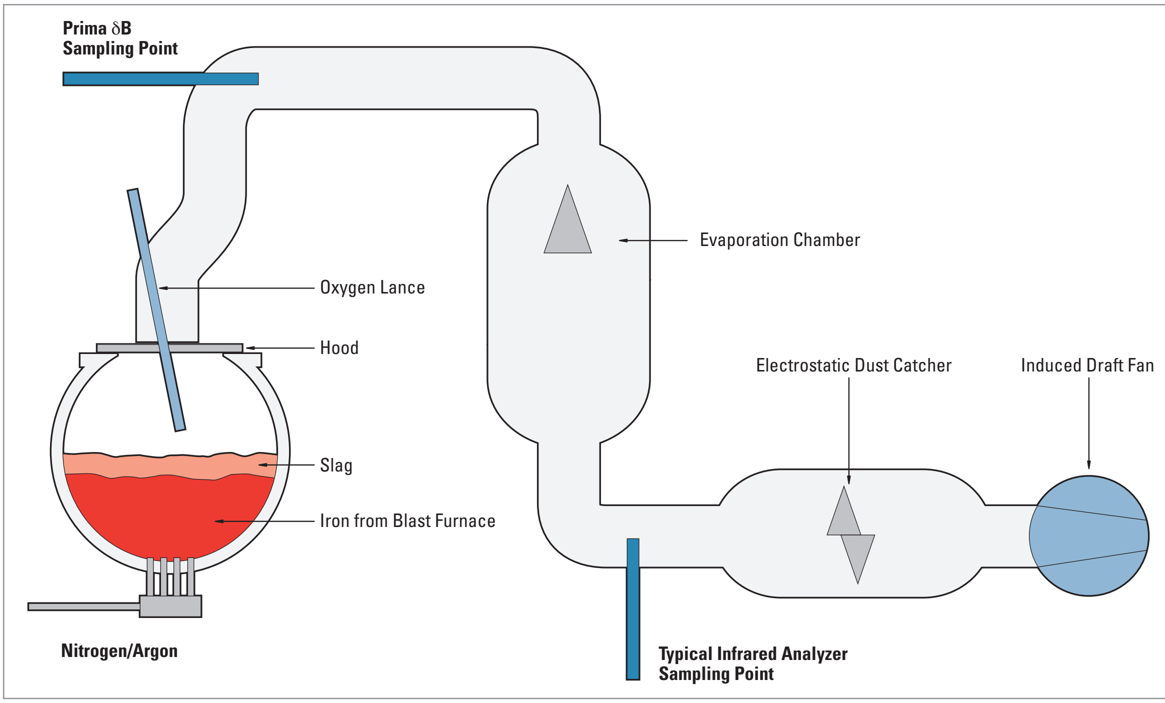

figure 2 – Typical Prima δB installation scheme

spectra can then be measured to determine the composition of the gas mixture. The measurement device is a Faraday collector coupled with a fixed gain amplifier. Frequent electronic zeroing eliminates baseline drift and reduces the calibration frequency.

The alternative technique is quadrupole mass spectrometry, which separates masses according to their mass to charge ratios by accelerating the positive ions between four rods with an RF/DC potential of varying power. However, this method has some significant disadvantages compared with the magnetic sector analyzer.

Quadrupole analyzers operate at ion energies of typically five volts, giving rise to ion interactions within the source that cause poor short-term precision.

The signal intensity at any specific mass position on a magnetic sector analyzer appears as a "flat top peak." This means that any small drift in the mass scale will not result in a change in signal intensity. This is not the case with quadrupole mass spectrometers that provide rounded shaped peaks.

Plant Integration

The Prima δB is normally located at the top of the converter in an analyzer shelter and takes samples from the waste gas duct. Sample conditioning is typically the same as for conventional techniques and would consist of dust filtering and removal. The mass spectrometer's PC can be located within the analyzer shelter or at a remote location such as the control room if preferred.

The traditional method of communication to the process plants distributed control system (DCS) is by analog and digital hardware input/output (I/O) communications. This method of communication is still very popular and is available as an option on all Prima δB units today. An increasingly popular method of communication is via RS232, RS485, Ethernet, and many proprietary networks and data highways like Modbus, PROFIBUS, Allen-Bradley® data highway, etc. The Prima δB can be connected via a multi-protocol interface to over 30 common communication protocols.

The communications link can be configured as a "Slave" or "Master," the former being that the Prima δB instrument is purely instructed to send information when requested by the DCS system. The more popular is a "Slave" mode where the following information is communicated:

- *Instrument Hardware Status.* Information for each stream monitored, indicating the current status (OK, Warning, Error, Fatal Error).
- *Gas Analysis Data.* Information for each stream analyzed; gas concentration data, analog inputs, derived values and time of analysis.

Often the plant's DCS receiving the gas data is configured by the instrument engineers to integrate with other process information and is specifically programmed for the process to give integrated gas measurement with closed loop process control.

If the Prima δB is configured as "Master," the DCS system has the ability to perform the following functions: *Stop/Start Analysis, Stop/Start Calibration, Enable/Disable Sample Points, Instrument In/Out Remote Control.*

The advantage of using a communication protocol is that it is often much easier to integrate the gas measurement data into the process control activity, particularly if modeling is being used. It is also easier to implement (less cabling connections) and lowers the cost if many gases are to be monitored.

Summary

Magnetic sector process mass spectrometry has been successfully monitoring converter waste gas at many of the world's iron and steel companies for years. By combining high speed with excellent stability, the ultra stable magnetic sector analyzer lends itself ideally to this demanding application.

The Prima δB also benefits from being housed in a rugged, industry standard enclosure and has the advantage of the unique rapid multi-stream inlet system, Thermo Scientific GasWorks Windows®-based software for flexibility and ease-of-use, and a host of plant interfacing technologies.

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