

Blast Furnace Process Monitoring Using the Thermo Scientific Prima δ B

Key Words

- Mass Spectrometry
- Blast Furnace
- Off Gas Analysis
- Gas Efficiency
- Mass Balance
- Heat Balance
- Probe Analysis
- Iron & Steel

Introduction

In an effort to reduce energy costs and improve efficiency, many of the world's iron and steel companies have achieved outstanding success by adopting mass spectrometry (MS) as the preferred off gas analysis technique.

The rapid and accurate analysis of all the important constituents of the off gas, including CO, CO₂, H₂, N₂, CH₄, and O₂ by one analyzer, provides information essential to the calculations of gas efficiency and mass balance as well as the early detection of leaks.

This has resulted in huge savings in fuel costs, and payback times measured in months.

The advantages of process MS over conventional analysis techniques in the iron and steel industry have been proven over many years. The ability to measure a wide range of components on a single analyzer coupled with advanced calibration, data transmission, and self-diagnostic software makes MS ideal for integration into the modern plant. Accurate gas composition analysis is being used on blast furnaces to calculate reduction efficiency, mass balance, and heat balance using mathematical models. The analysis of gas collected by moving sample probes is used to monitor the distribution of the burden materials.

Description of Analyzer

The Thermo Scientific Prima δ B is a magnetic sector MS and utilizes technology that has been proven over many years in a wide range of applications including iron and steel, petrochemical,

and pharmaceutical manufacturing. The method of analysis is achieved using the following components.

Sample Inlet System

The inlet system consists of a rapid multi-stream (RMS) rotating sample valve. Continuous sample flow and zero dead volume eliminate 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 5 million operations between servicing.

Analyzer

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 thus allows the instrument to select different gas species. The resulting highly stable mass 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 interval.

Gas Efficiency

It has long been established that the efficient control of the blast furnace process relies on accurate and fast analysis of CO and CO₂ concentration in the top gas.



The Thermo Scientific Prima δ B Scanning Magnetic Sector Process Mass Spectrometer II

MS has a distinct advantage over the more traditional technique of infrared analyzers due to the reduced sample time, increased accuracy through automatic and extensive calibration techniques, and long-term stability.

Too high a CO₂ level results in heat leaving the furnace by the exothermic reaction:



If CO is too high this results in chemical heat leaving the furnace in the form of coke consumption as fuel. Gas efficiency can be explained by:

$$h = \frac{100 \times CO_2}{CO + CO_2}$$

A 1% increase in gas efficiency at constant direct reduction can result in a decreased coke consumption of 8 Kg/tonne hot metal and an increased yield of 3.5% of hot metal.

To realize these cost benefits,

the analysis time (from Tuyere to data point) must be kept to an absolute minimum. One major steel company has seen this dead time reduced from 10 minutes to 2 minutes since installing our process mass spectrometer on the blast furnace. It is also essential that the analysis is accurate. The traditional method of infrared analysis relies on the manual calibration of two discrete analyzers.

The Prima δB will provide analysis of all components on a single analyzer. This, coupled with automatic self-checking against a certified calibration standard and superior long-term stability, provides the best available gas analysis in this process area.

Mass Balance

Essential to the measurement of the melting capacity, fuel rate, and hot metal production is the top gas flow. When using discrete analyzers, the nitrogen analysis (which is fundamental to this calculation) has to be inferred by the calculation:

$$N_2 = 100 - (CO + CO_2 + H_2)$$

This relies on the accuracy of three discrete analyzers. The mass spectrometer is able to measure all of the critical components, and the accuracy of this instrument is constantly maintained by comparison with a certified gas standard. The material and heat balances are an essential input to

the mathematical models being developed by many steel-making companies, to calculate excess heat in lower regions of the furnace. Consistent iron quality can only be maintained through close control of the furnace temperature. A 1% error in the nitrogen analysis can result in a 3% error in the mass balance prediction. Similarly, a 1% nitrogen error can cause the following discrepancies:

- Coke rate ~ 5 kg/thm
- Blast Volume ~ 10000 m3/hr

These errors arise because the mass balances are closed on the assumption that the measured nitrogen in the top gas is representative of the total nitrogen input to the furnace (nitrogen not having any part in the furnace reactions). The final accuracy of the mass balances is dependent on which of the other gas species is interchanged with nitrogen in the form of errors. The improved nitrogen analysis afforded by the Prima δB (for reasons stated earlier) significantly reduces mass balance errors.

Heat Balance

Gas analysis forms a central part of the thermal control of the blast furnace via the generation of a furnace heat balance from which it is possible to predict hot metal silicon for the cast ahead. The basis of this heat balance requires accurate and repeatable top gas analysis. The heat balance yields

a value known as the WU factor, which expresses the amount of heat available to serve the hot metal quality parameters (including silicon). The value of WU (and therefore the ability to predict silicon) is sensitive to the gas analysis such that an error in the region of 1% precludes its use in any sensible control scheme.

Hydrogen Analysis

Increases in the hydrogen level within the furnace can indicate a leak from the furnace cooling system. This has implications both for safety and furnace temperature. The cooling of the furnace due to water leaks can result in a heat loss and a subsequent increase in the consumption of fuel.

In addition, the analysis of hydrogen during maintenance can help prevent the hazardous mixture of explosive gases. The analysis of hydrogen is also made with the Prima δB, removing the need for an additional discrete analyzer.

Probe Analysis

Another advantage of the Prima δB over discrete analyzers is that the rapid analysis allows for a number of other streams to be analyzed using a single instrument. This is achieved with the use of a fully automated multi-inlet system designed to switch between sample streams at high speeds with a minimum of sample flushing times. One example of this is the Burden probe analysis which can be made at frequencies determined by the operator. It is also possible to use the single Prima δB to analyze top gas from more than one furnace, and as analysis interval is still less than 20 seconds per sample point, the furnace control is not compromised.

Argon Analysis

While the analysis of argon may be of little interest to the blast furnace optimization, in circumstances where nitrogen is being used as a purge gas, the nitrogen/argon ratio in the top gas analysis is an ideal

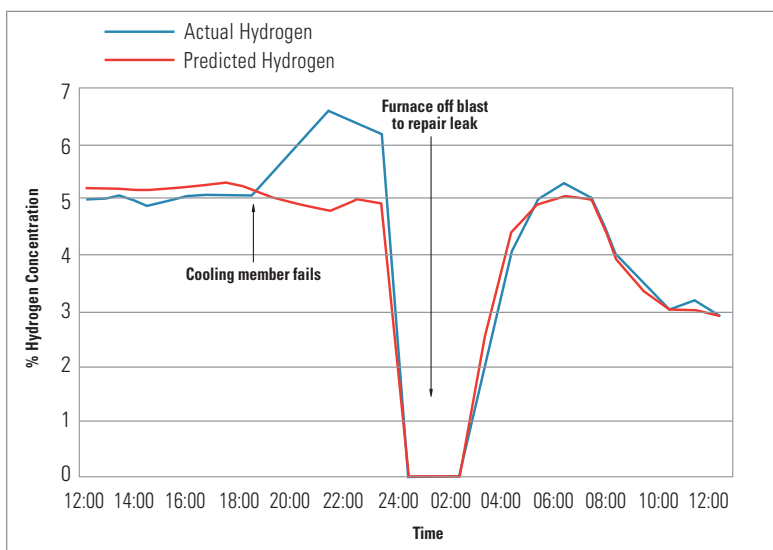


figure 1 – Predicted versus actual top gas hydrogen concentration

marker for detecting failures within the sampling system. Alarm levels may be attributed to this ratio to alert the operator to the probability of an error. This enables the early detection of failures and minimizes costly down time.

Typical Prima δ B Installation

A Prima δ B process mass spectrometer is typically installed on a blast furnace for measuring the following components in the top gas: CO, CO₂, N₂, H₂, O₂ and Ar.

Analysis of the furnace top gas is continuous and analysis speed is 6 seconds.

In addition to analysis of the furnace top gas, validation of the MS would be made by analysis of a certified gas mixture as described in *table 1*.

Component	Concentration %
CO ₂	26.00
CO	24.00
H ₂	4.01
N ₂	45.99

table 1 – Typical certified gas mixtures

Further Results

Analysis of the blast furnace has proven to be extremely reliable with availability greater than 99%. Calibration of the analyzer is fully automatic and is completed in approximately 10 minutes. The analyzer regularly checks its accuracy against the calibration gas standard. When the analysis falls out of accepted tolerance levels (0.3% abs for CO), a calibration is prompted. The calibration interval is typically one to two months.

Plant Integration

The Prima δ B would normally be located at the base of the furnace in an analyzer shelter, taking samples from the top gas as well as the above burden and below burden probes as required. Sample conditioning is typically the same as for conventional techniques, and would consist of dust filtering and moisture removal. The mass spectrometer control 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 plant's distributed control system (DCS) is by analog and digital hard-wired input/output (I/O) communications. This method of communication is still very popular and is available on all units today. In a modern facility, analog signals

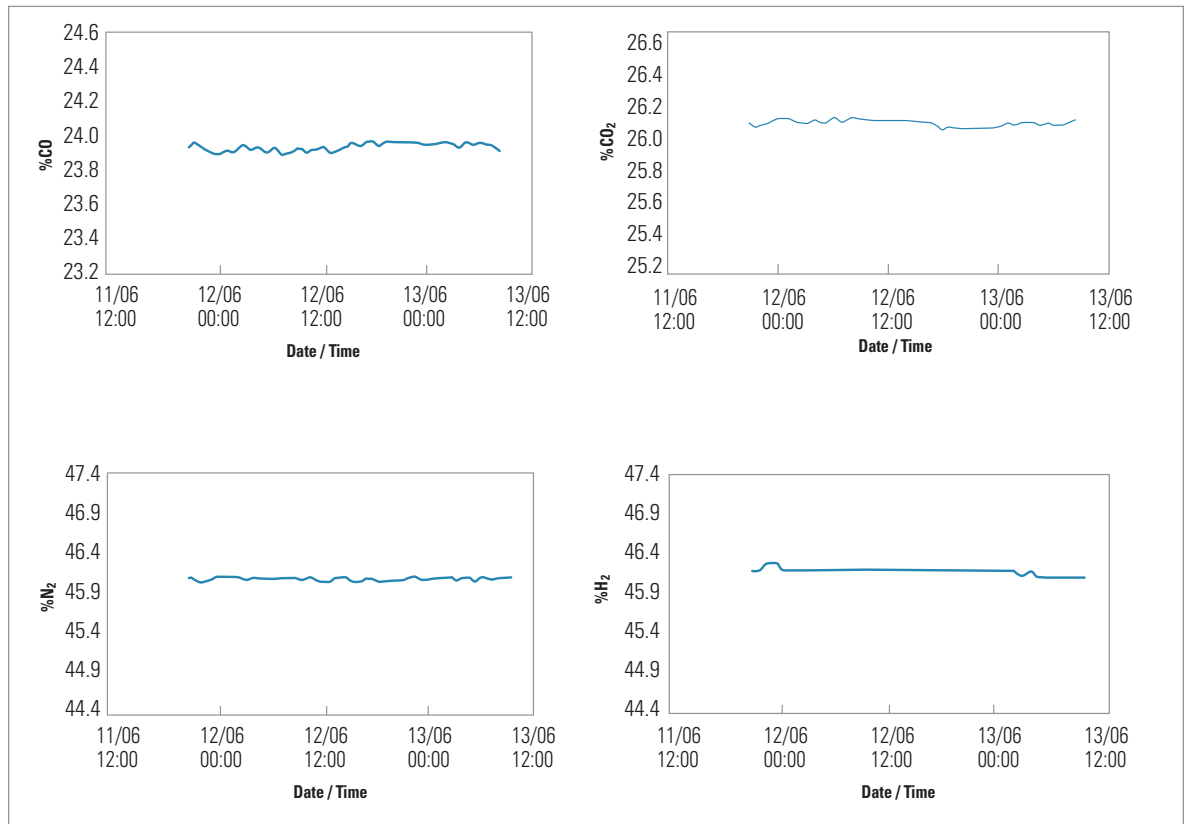


figure 2 – The results shown are representative of a typical blast furnace installation; they show the stability of analysis of a certified gas standard over a period of 36 hours. During the test, the analysis of the gas standard was made at intervals of approximately 55 minutes.

Component	Units	Mean	Standard Deviation	Minimum	Maximum
CO ₂	%	26.028	0.0150	25.995	26.073
CO	%	23.946	0.0209	23.891	23.995
H ₂	%	3.986	0.0040	3.979	3.995
N ₂	%	45.999	0.0174	45.959	46.048

table 2 – Typical precision for Prima δ B for blast furnace gas analysis



Blast furnaces and cooling towers at the Usinor steel plant

are replaced by serial data communication via RS232, RS422, RS485, or ethernet. Communication protocols include Modbus, Profibus and Alan Bradley Data Highway.

The Prima δ B can be connected via a multi-protocol interface to over 30 common communication protocols found on modern industrial process plants.

The communications link can be configured as “slave” or “master,” the former being that the instrument is purely instructed to send information when requested by the DCS system. Alternatively, as a “master,” it can send and receive messages to and from the DCS. The more popular is a “slave” mode where the following information is communicated:

- Instrument Hardware Status
- Gas Analysis Data.

Often the plant’s DCS receiving 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. Data can be mapped to a single or any number of location registers, dependent upon the DCS and the application.

If our system is configured as a “master,” then the DCS has the ability to perform the following functions:

- Stop/Start Analysis
- Stop/Start Calibration
- Enable/Disable Sample Points
- Instrument In/Out of Remote Control.

The advantage of using a communication protocol is that it’s often much easier to integrate the gas measurement data into the process control activity, particularly if modeling is being used. This allows for easy implementation (less cabling connections) and lower cost, if many gases are to be monitored.

Summary

Thermo Scientific Process MS systems have been successfully monitoring blast furnace off gas for several years at many of the world’s leading iron and steel companies. Corus UK reported that advanced gas analysis techniques (for gas efficiency, heat & mass balances, and hydrogen analysis) have been contributing to the control of the blast furnace for 10 years now via superior mathematical modeling, resulting in savings of up to 100 kg of coke per ton of iron. The flexibility of the MS lends itself ideally to a wide range of gas analysis within the integrated steel works including DRI, VOD, AOD, Steel Converter, and Coke Ovens.

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