DETECTION OF WATER LEAKS USING EFSOP WATER DETECTION TECHONOLOGY®*

Armando Vazquez Arredondo[1]

Abstract

Tenova Goodfellow Inc. has successfully installed the proprietary EFSOP® (Expert Furnace System Optimization Process) system in over 80 installations worldwide. For over 15 years, the EFSOP® System has successfully achieved its main objective of improving performance and operating costs through the reduction of electricity, oxygen, methane, injected and charge carbon use. Using the off-gas information provided by the EFSOP® System, Tenova Goodfellow Inc. has now developed a solution for detecting abnormal water events within the EAF steelmaking process. When water form enters the EAF, it immediately forms into water vapor (H_2O_{gas}) and a proportion of the resulting water vapour will further react and dissociate to H_2. Effective water detection technology must be capable of detecting BOTH forms of water; H_2O_{gas} & H_2. Tenova Goodfellow has the technology to measure in real time and simultaneously H_2O_{gas} & H_2. This paper will provide a summary on how the EFSOP Water Detection Technology® is used during the EAF operation. Details regarding the technology, software, alarm rate and information on sensibility water trial tests will be provided within this paper.

Keywords: Water detection; Water vapor; Condensation; Off-gas; Alarm.

[1] *BA, Electronics & Communications Engineering, Manager, Sales & Marketing, Tenova Goodfellow Inc., Mississauga, ON, Canada.*

ISSN 1982-9345

1 INTRODUCTION

An electric arc furnace used for steelmaking consists of a refractory-lined vessel, covered with a retractable roof, and through which one or more electrodes enter the furnace. The traditional electric arc furnace operates as a batch melting process, producing batches of molten steel. The operating cycle is called the tap-to-tap cycle and is made up of the following operations: Furnace charging, Melting phase, Refining, De-slagging, Tapping and Furnace turn-around [5].

During the EAF operation, from Melting to before tapping, the off-gas analysis provides valuable information to improve process operation that minimizes transformation. Based on off-gas information, optimization objectives can be achieved by making adjustments to the various aspects of the EAF process: including fume system control to maximize combustion and minimize energy losses to false air entering the EAF freeboard; adjustment to the charged carbon practice to minimize the heat load to the primary fume system; scrap distribution in the charge buckets to mitigate inconsistencies in operation due to scrap diversity; burner intensity and timing to optimize energy evolution in the freeboard; refining practice through the intensity and timing of injected carbon and lanced oxygen; and overall furnace pacing to ensure consistency of the operation.

The cooling water system is an inherent part of EAF steelmaking. Continuous water flow is used to cool not only the sidewall and roof panels but also the fume system ducts, transformer, delta closure, bus tube and electrode holder [3]. The off-gas analysis has an inherent response time advantage over other water leak detection systems since the products of a water leak are gaseous H_2O vapor and H_2 and because of the fume system's high suction rate which extract the freeboard gases including H_2 and H_2O vapor from the EAF through the 4th hole in a matter of a few seconds.

As indicated on Figure 1, there are several water cooled systems. Most of the systems are designed on an open loop circuit; some water is consumed in the furnace (electrode spray water) and some other systems use a cooling tower for energy dissipation. The water cooled elements such as water cooled panels, water cooled roof panels, water cooled off-gas system ducting, water cooled furnace cage etc. will receive cooling water from a cooling tower.

ISSN 1982-9345

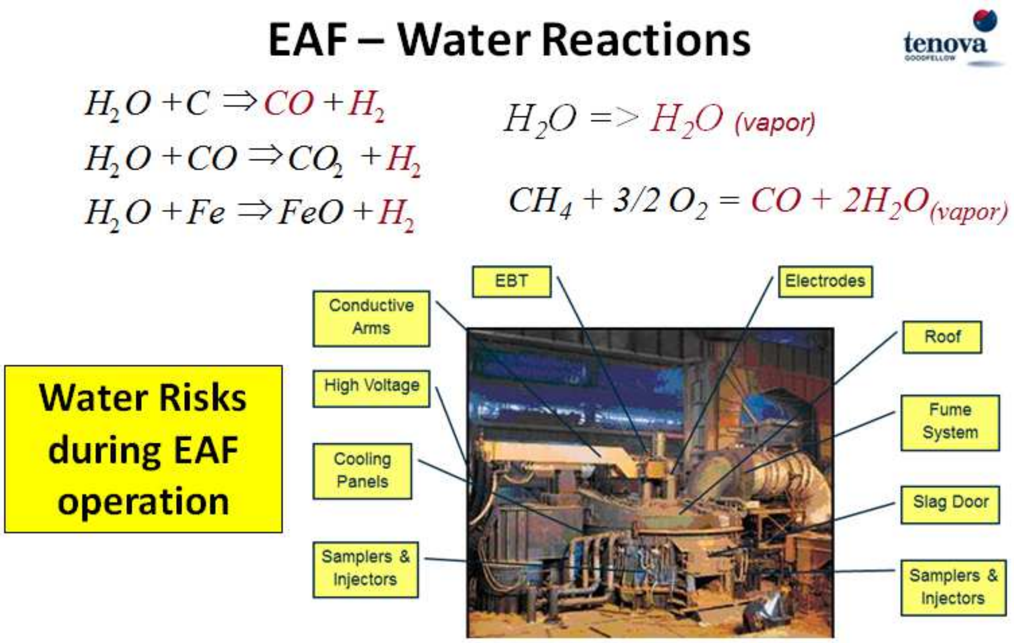

Figure 1: EAF Water Reactions including of the water cooling needs on an EAF

Direct measurement of inlet / outlet water flows has been used for detecting water leaks; however, experience has shown that a simple global in/out flow measurement is not effective due to high signal noise and poor response times. Therefore to increase the reliability of such systems a multiple instrumentation and sub-cooling systems need to be implemented increasing the cost, maintenance and hardware sustainability. [5]
The EFSOP Water Detection Technology® is able to distinguish change in humidity levels as well as Hydrogen concentration in the off-gas, therefore the system can be set up for detection of an on-line, real-time abnormal water event.

2 WATER REACTIONS WITHIN THE EAF PROCESS

Tenova Goodfellow's detailed analysis and experience on EAF process, shows that an effective EAF off-gas water detection system needs to analyze both H_2 and H_2O vapor. This is because when liquid water enters the EAF it immediately begins to boil to form steam (i.e. H_2O vapor). However, depending on chemical conditions inside the EAF, a varying proportion of the H_2O vapor will further chemically react to produce H_2. The actual H_2O vapor to H_2 ratio in the off-gas will depend on many factors. For example, where the leak takes place and also the oxidization potential of the freeboard gases inside the EAF. Further, if the EAF freeboard is overly oxidizing such as when draft suction is high then the chemical dynamics favor H_2O vapor. Alternatively, H_2 is favored if the freeboard is more reducing. While the most efficient and lowest cost operation usually occurs when the freeboard gas is mildly reducing, in actual practice it is difficult to avoid swings between overly oxidizing and overly reducing freeboard chemistry. Because of the complex interdependence of these chemical reactions and their dependence on the level of combustion within the EAF and the amount of fume system suction, it is simply not possible to predict the relative proportion of H_2 and H_2O vapor in the freeboard off-gas in advance of a water leak. [1-3]
The EFSOP Water Detection Technology® incorporates the analysis of both H_2 and H_2O vapor in real-time together with an advanced software package that provides

ISSN 1982-9345

operators with clear alerts on the water leak status of the EAF with minimal false alarms.

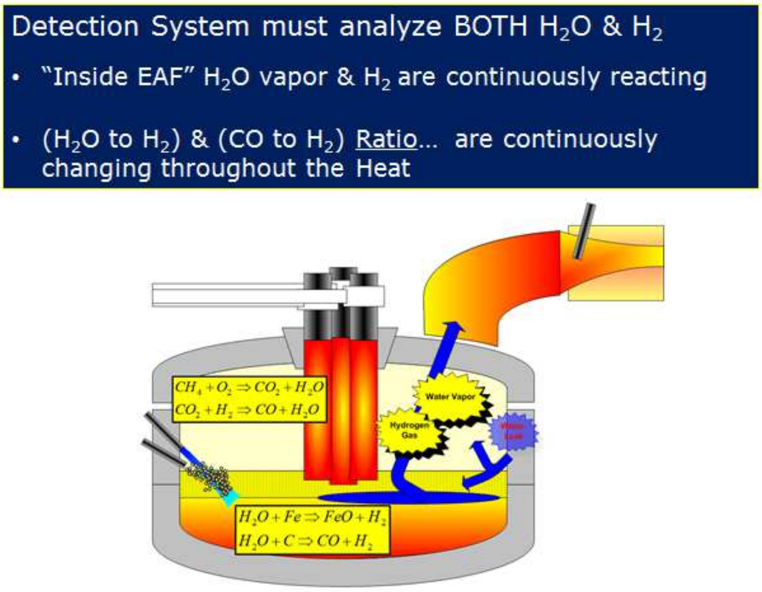

Figure 2: Dynamics of Water and Hydrogen in the EAF

Two basic off-gas analysis technologies are available for use on an EAF: [4]

- **Insitu laser systems** use a tunable diode laser to transmit a beam in the near IR range through the off-gas for subsequent pick-up by an optical detector. The transmitted laser's wavelength is modulated around the particular spectroscopic line of the gaseous species of interest. The amount of absorption in the detected beam is subsequently used to calculate the concentration of that particular species in the off-gas. EAF insitu laser systems use up to 3 separate lasers, one laser for CO_2 and H_2O vapor, one for CO and one for O_2. While insitu laser systems can analyze several gases, lasers cannot analyze many mononuclear diatomic gases including H_2. [1]
- **Extractive systems** use a water cooled probe, heated line and analyzer to continuously extract and analyze a sample of EAF off-gas from the fume duct. Various analytical methods are employed to continuously analyze a complete spectrum of off-gas chemistry in real-time including CO, CO_2, O_2, H_2 and H_2O. The EFSOP® extractive technology is the established industry standard for off-gas analysis and EAF process optimization. [3]

Effective water detection under all EAF operating conditions requires that the "system used" must demonstrate:

a. Exceptional reliability;
b. Fast response times;
c. The capability to analyze both H_2 and H_2O vapor;
d. The capability to provide "Operator Alerts" with minimal false alarms;

2.1 System Reliability

It is critical that a water detection system be available and working reliably from "start to end" of the heat and especially whenever the power is on. Gaps in water detection measurements during the course of the heat can represent a potentially serious situation especially if a water leak were to occur when the detection system is

inoperative for whatever reason. Also to be effective for process control and water detection, the off-gas analysis technology must analyze “true furnace gas” before dilution with combustion air introduced at the 4th hole.
Insitu laser systems can be categorized as “passive” technology – they rely on passive transmission of a laser beam through the off-gas fume from the emitter to the detector. Any attenuation or interference of the laser signal that prevents its sufficient detection will result in interrupted off-gas analysis. Early insitu laser systems suffered from serious laser beam attenuation difficulties and lost signals because of significant amounts of dust prevalent in EAF off-gas. To help mitigate laser beam attenuation problems, today’s insitu optical off-gas systems use semi-continuous N_2 purged, water cooled horizontal steel pipes to shorten the laser transmission path length.
On the other hand, extractive off-gas systems are “active” technology - whenever power is switched on, extractive systems automatically switch to an active, positive high suction to rapidly extract a sample of off-gas from the fume duct at high flow rate for chemical analysis. Extractive systems are designed to automatically switch to an active N_2 purge during “power-off” periods to clean the probe and filters before the start of every heat and whenever power is off during the heat. Historically, such extractive technology has demonstrated exceptional reliability – when properly maintained, EFSOP® extractive technology has consistently demonstrated better than 99% reliability to provide continuous off-gas chemistry from start-to-end of the heat. As shown in Figure 3, the probe is designed to operate directly inside the cone of off-gas exiting the EAF at the 4th hole thereby ensuring the system is sampling true process gas before dilution with combustion air.

Figure 3: Off-gas system 4th Hole configurations; EFSOP® extractive probe

2.2 Fast Response Times

When liquid H_2O enters the EAF it quickly produces H_2O vapor a portion of which will further react to produce H_2. These gaseous products of a water leak are immediately present in the freeboard off-gas inside the furnace. Because of the fume system’s high suction rate, the freeboard gases including H_2 and H_2O vapor will be extracted from the EAF through the 4th hole in a matter of a few seconds. As a result, properly designed off-gas based water detection systems have an inherent quick response time advantage over other potential detection technologies such as water flow measurements. Insitu optical systems have been reported to provide analytical results at about two second intervals.
Tenova Goodfellow’s second generation EFSOP Water Detection Technology® has proved response time as short as 9 seconds. The results of Controlled Water Trials

ISSN 1982-9345

confirm the immediate and clear response of this second generation water detection technology to changes in off-gas composition and EAF humidity.
In summary, it can be concluded that when combined with the high fume system suction rate, the insitu optical system and the redesigned second generation EFSOP® extractive system both have exceptionally fast response times as is required for effective water detection.

2.3 Capable of Analyzing Both H_2 and H_2O Vapor

The relative quantities of H_2O vapor and H_2 in the EAF freeboard are chemically linked to each other. Under normal practice, both H_2O vapor and H_2 gas are naturally present in the EAF from electrodes water sprays, from moisture in the scrap charge and as products of combustion from the burners, post combustors, injectors and residual oils on the scrap. All of these sources can be considered as contributing to "normal" levels of H_2O vapor and H_2 in the EAF freeboard. Once present in the EAF, H_2O vapor and H_2 are continuously reacting with Fe, FeO, CO_2, CO and C, the dynamics affecting the actual "H_2O vapor to H_2 ratio" in the freeboard off-gas are quite complex and variable.
Adding to this complex situation, at any time during the course of the heat, the EAF can effectively switch between an oxidizing and a reducing freeboard off-gas chemistry depending on the level of burner firing, oxygen lancing, post combustion and fume system suction. When liquid water unexpectedly leaks into the EAF it will immediately begin to boil to form H_2O vapor. Depending on the location of the liquid water leak and whether the EAF is operating in an overly oxidizing or reducing condition (see figure 4), a proportion of the resulting H_2O vapor will further react and dissociate to H_2 gas thereby leading to an "abnormal" amount of H_2O vapor and H_2 in the EAF freeboard. The equilibrium off-gas chemistry will shift towards more H_2 if the furnace is operating in a more reducing condition. However, the thermodynamics will favor a shift towards more H_2O vapor if the furnace is more oxidizing which for example, can happen if fume system suction is too high.
Because of the complex interdependence of these chemical reactions and their dependence on the level of combustion within the EAF and the amount of fume system suction, it is simply not possible to predict the relative proportion of H_2 and H_2O vapor in the freeboard off-gas in advance of a water leak. Hence, for water detection to remain effective under all operating situations, it is absolutely necessary that the off-gas analysis technology be capable of analyzing both H_2O vapor and H_2 gas.

ISSN 1982-9345

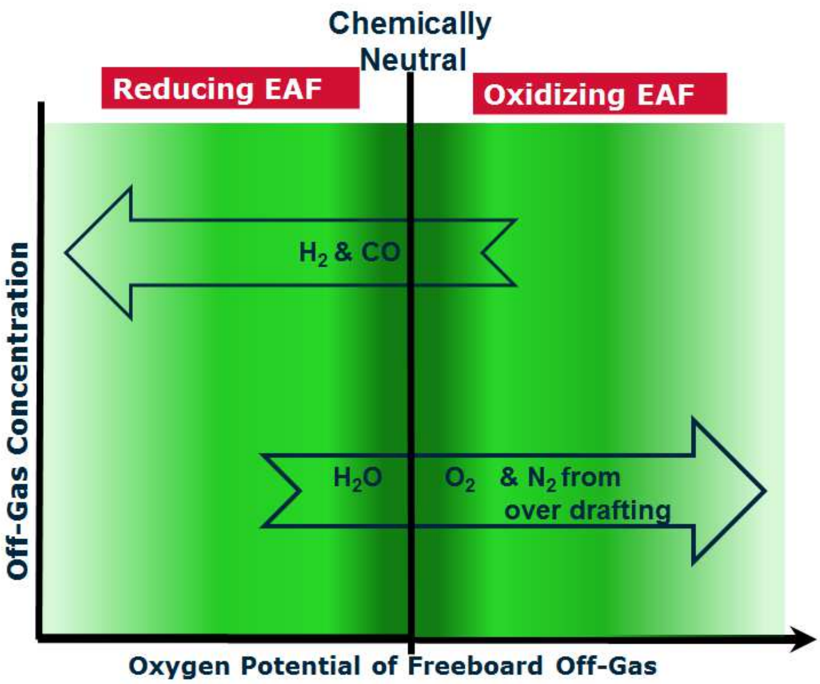

Figure 4: EAF Process environment

The following can be concluded when assessing the analytical capabilities of the respective off-gas analysis technologies:

- **Insitu laser technology** is capable of analyzing polyatomic molecules in the off-gas such as H_2O vapor, CO & CO_2 but since most homonuclear diatomic gases do not absorb infrared radiation, lasers cannot under any circumstances analyze many single element diatomic gases including H_2 [3]. Hence, insitu laser technology is capable of providing the H_2O vapor part but not the H_2 part of the off-gas analysis spectrum required for a complete water detection system. From a water detection perspective, insitu lasers will be more effective if the EAF is operating with an oxidizing freeboard off-gas chemistry and less effective if the EAF is operating under reducing conditions when H_2 is favored.
- **EFSOP Water Detection Technology®** the EFSOP® system involves two significant industry breakthroughs which are critical for effective and reliable water detection; first; a newly designed water cooled probe and heated line assembly that eliminates any possibility of water vapor condensation during off-gas sampling and transmission of the off-gas from the probe to the analyzer. Second; a fully integrated analyzer equipped with a built-in proprietary sensor and analyzer bench to provide continuous analysis for H_2O vapor together with hardware to analyze H_2, CO, CO_2 and O_2 (see Figure 5). The key to this innovative analytical system is that the hot, wet process gas coming from the probe & heated line into the analyzer is fully cleaned of particulate matter prior to analysis thereby ensuring that the off- gas analyses are reliable and uninterrupted even when the 4th hole off-gas is extremely dirty (e.g. during melting). By analyzing both H_2O vapor and H_2, the second generation water detection technology is the only commercial system designed to be effective under all EAF operating conditions i.e. during both oxidizing and reducing operation.

ISSN 1982-9345

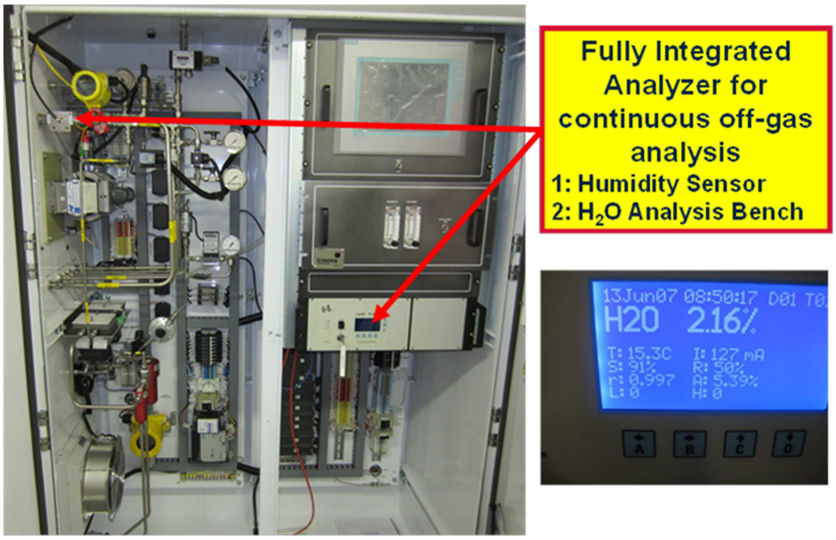

Figure 5: Fully integrated second generation water detection analyzer for continuous CO, CO_2 & O_2 plus H_2 & H_2O vapor analysis

2.4 Capable of Providing Effective "Operator Alerts" with Minimal False Alarms

As discussed above, there is always a "normal" background level of H_2 and H_2O vapor in the freeboard off-gas inside the EAF. However, it is important to note that the absolute level of "normal" H_2 and H_2O vapor in the off-gas and the ratio of H_2O vapor to H_2 in the off-gas will be varying from start to end of the heat and from heat-to-heat depending on how wet and/or oily the scrap charge is, on the amount of burner firing and post combustion at any point during the heat, on the level of the electrode sprays and on the level of fume system suction. [4]

To be effective, a water detection system must be able to quickly and correctly distinguish between "abnormal" H_2 and H_2O vapor levels due to a water leak into the EAF and "normal" background levels of H_2 and H_2O vapor due to operating practice.

Tenova Goodfellow has developed a software package that can dynamically and quickly analyze the actual H_2 and H_2O vapor off-gas chemistry in real-time, use defined algorithms to dynamically calculates and predicts the expected levels of humidity ("normal" water in the EAF) and H_2 during the EAF operation, this prediction is compared with actual real time measurements to determine variability and risk levels (Figure 6). The models are tune to response to changing scrap and furnace conditions and then they correctly distinguish between "normal" and "abnormal" conditions providing to the EAF operators a well-defined "alerts" indicating when H_2 and H_2O vapor levels exceed normal levels.

The EFSOP Water Detection Technology® uses proprietary software to differentiate between "Normal" & "Abnormal" H_2 and H_2O vapor levels in the EAF. Because the system can analyze both H_2 and H_2O vapor, it has the unique capability to provide more complete coverage by defining two "Off-Gas Indicator" variables which identify when either the H_2 and/or the H_2O vapor are outside of the normal expected range.

ISSN 1982-9345

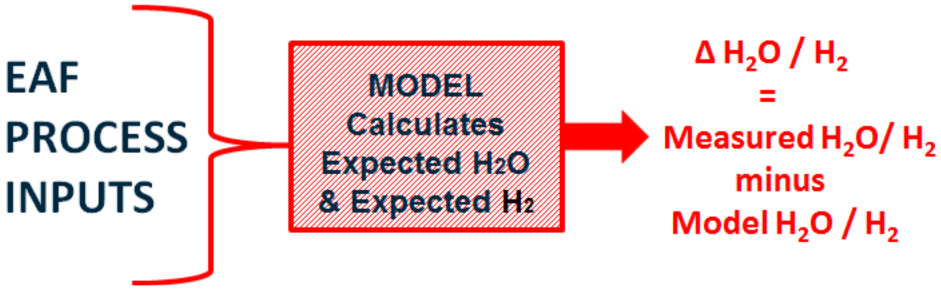

Figure 6: H_2O and H_2 Model for Expected level during EAF Operation

Figure 7 illustrates the methodology for triggering “Operator Alerts”. While the system is not a failsafe method, it does provide operators with valuable real-time alerts indicating a probability of abnormally high amounts of both H_2 and H_2O vapor in the EAF. Specific threshold limits are set together with the EAF plant to maximize system effectiveness and to minimize the possibility of false alarms. When the off-gas water detection indicators are equal or high than the Threshold, the water detection software will display an indication that the off-gas chemistry is significantly out of the normal range and there is a high probability of excess water in the EAF. These Alerts require immediate protective action by EAF operating staff.

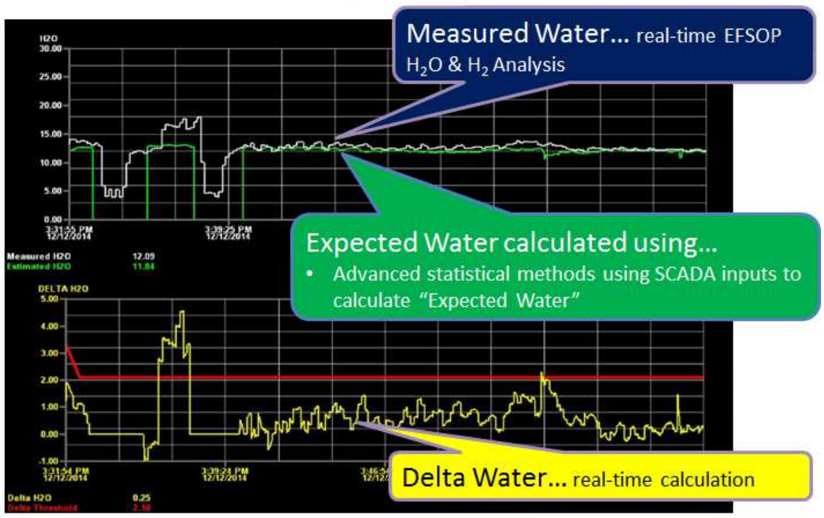

Figure 7: Methodology for triggering a water detection alert

When properly tuned, the EFSOP Water Detection Technology® is designed to incur less than about a 3% false alarm rate.

Figure 8: HMI provides "Operator Alerts" for both H_2O vapor and H_2

3 CONCLUSION

Tenova Goodfellow has developed an effective water detection technology capable of analyzing both H_2O_{gas} and H_2. The EFSOP Water Detection Technology® provides reliable and uninterrupted off-gas analysis from start-to-end of the heat. It rapidly and accurately distinguishes between "normal" and "abnormal" levels of H_2O_{gas} and H_2 in the EAF freeboard. The software provides information of "normal humidity levels: during the heat or high levels of humidity triggering an alarm.

Controlled electrode water spray trials have been conducted to simulate a water leak. The results confirm the system rapidly and correctly responds to both increasing and decreasing electrode water flow. EFSOP Water Detection Technology® can be provided as an add-on module to an existing EFSOP® analyzer or as a complete standalone water detection system which in future can be upgraded to a full EFSOP Holistic Optimization® system for EAF process control and optimization. [5]

REFERENCES

1 K.Nikkanen, M.I.Khan, J. Gavina, "Furnace Water Leak Detection and Reduced Conversion Costs Efforts at Aceria Compacta de Bizkaia, Spain using the Goodfellow EFSOP® System", *AISTech 2007 Conference*, May 2007

2 N. Boin, M.I.Khan, M. Missio, "Optimization results at Ferriere Nord using EFSOP® Technology", *AISTech 2010 Conference,* May 2010

3 D Zuliani, V. Scipolo, O. Negru, M. Khan, " Breakthrough Technology for Real-Time Water Detection in EAF Steelmaking" AIST 2013 Conference May 2013

4 D.J. Zuliani, H. Alshawarghi, V. Scipolo, M. Khan "Real-Time Water Detection Technology at ArcelorMittal Coatesville", AISTech 2014 Conference, USA, May 2014

5 A. Vazquez, "Latest development of Real Time Water Detection Technology in EAF", ISA 2013 Rosario Argentina, November 2013.