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Theme: Eletric Steelworks

EFSOP® SYSTEM TECHNOLOGY FOR REAL-TIME WATER DETECTION IN EAF STEELMAKING*

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Abstract

When water enters the EAF, some chemically dissociates to H_2 while some remains as H_2O vapor. Depending on operating conditions the levels of combustible gases (CO and H_2) and H_2O are continually changing throughout the course of any individual heat and on a heat-to-heat basis. The EFSOP® system has been implemented in more than 80 installations as a powerful tool to reduce furnace operation costs but with water detection technology the off gas technology is a valuable solution to improve safety. This paper describes the latest results when using Tenova Goodfellow's new standalone water detection technology that for the first time provides real-time analysis of both H_2O vapor and H_2 from start-to-end of a heat. It involves a newly designed water cooled probe and heated line that eliminates condensation during off-gas sampling and an analyzer equipped with a proprietary system for analyzing both H_2O vapor and H_2.

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

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1 INTRODUCTION

The first electric arc furnaces were developed in France with a commercial plant in the US in 1907. The Sanderson brothers formed The Sanderson Brothers steel Co. in Syracuse, New York, installing the first electric arc furnace in the U.S. Since earlier days the main issue to melt steel has been the cool down the shell and to protect the equipment used in the process of steel making.
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 furnaces usually exhibit a pattern of hot and cold-spots around the perimeter, with the cold-spots located between the electrodes. Modern furnaces mount oxygen-fuel burners in the sidewall and use them to provide chemical energy to the cold-spots, making the heating of the steel more uniform. Additional chemical energy is provided by injecting oxygen and carbon into the furnace.
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 [1].

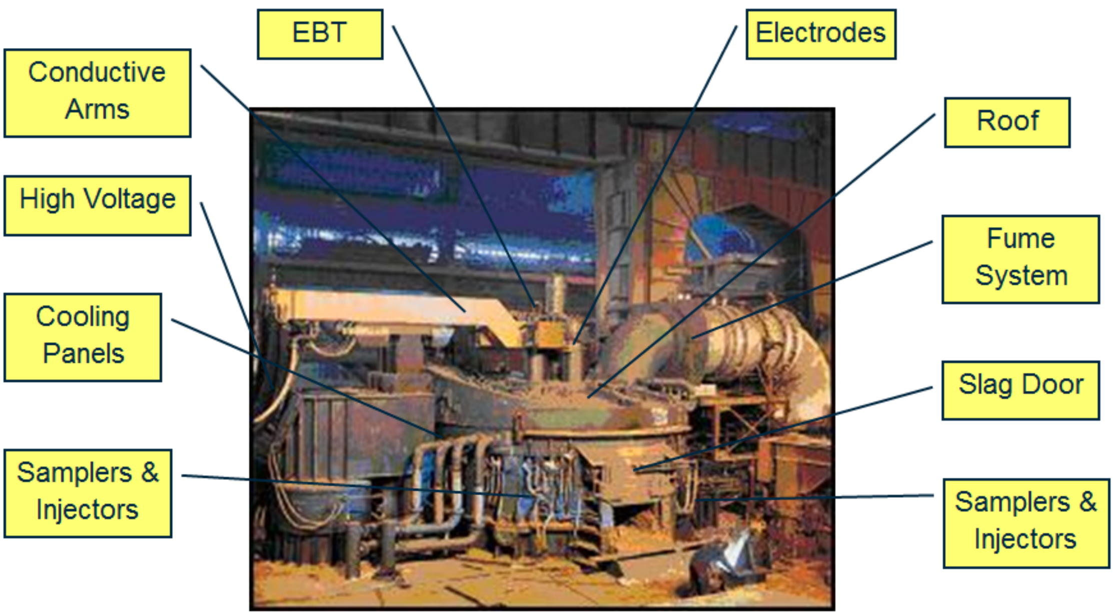

Figure 1. Overall Schematic of Water Cooling needs on an EAF.

The cooling water systems rely on continuous, high velocity water flow and it is an inherent part of every electric arc furnace (EAF); a system leak can quickly result in copious quantities of uncontrolled water pouring out in the vicinity of the furnace. If this water leaks into the EAF and hence comes in contact with molten slag and steel, there is the potential for a severe explosion that can not only damage equipment but also seriously threaten operator safety.
Direct measurement of inlet / outlet water flows has been proposed for detecting water leaks; however, experience has shown that a simple global in / out flow measurement is prone 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.
Tenova Goodfellow's EFSOP® system was commissioned in a North America Steel Making Plant to improve the performance and to increase safety via the EFSOP®

** Technical contribution to the 45th Steelmaking Seminar, May 25th-28th, 2014, Porto Alegre, RS, Brazil.*

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water detection algorithm by detecting the presence of water in the EAF that is not considered a normal part of the furnace operation (i.e. abnormal water events).[2]
The EFSOP Water Detection Technology[TM] is been tested via controlled water injection trials increasing the electrode spray water. The Technology was able to distinguish charges with water injection from those without. As a result of the position results from the trials, the system is currently being tuned by Tenova Goodfellow Inc. and by the plant for on- line, real-time abnormal water event detection [2,3].

2 DYNAMICS OF WATER IN THE EAF

As shown in Figure 2, the relative quantities of water vapor (H_2O_{gas}) and H_2 in the EAF freeboard are chemically linked to each other. Under normal practice, both H_2O_{gas} and H_2 are naturally present in the EAF as products of combustion from the burners and the injectors plus also from combustion of residual oils on the scrap charge. Since liquid water sprays are also used to cool the electrodes there is a continuous regulated flow of water into the EAF. All of these sources can be considered as contributing to “normal” levels of H2Ogas and H2 in the EAF freeboard.
Adding to this complex situation, when liquid water unexpectedly leaks into the EAF it will immediately form H_2O_{gas}. Depending on the location of the liquid water leak and whether the EAF is operating in an overly oxidizing or reducing condition, a proportion of the resulting H_2O_{gas} will further react and dissociate to H_2 thereby leading to an “abnormal” amount of H_2O_{gas} and H_2 in the EAF freeboard [1].
Figure 2 illustrates that since H_2O_{gas} and H_2 are continuously reacting with Fe, FeO, CO_2, CO and C, the dynamics of the H_2O_{gas}/ H_2 interactions can be quite complex and dynamic. Because of the complex interdependence of the chemical reactions, it is simply not possible to predict the relative proportion of H_2 and H_2O vapor in advance of a leak.

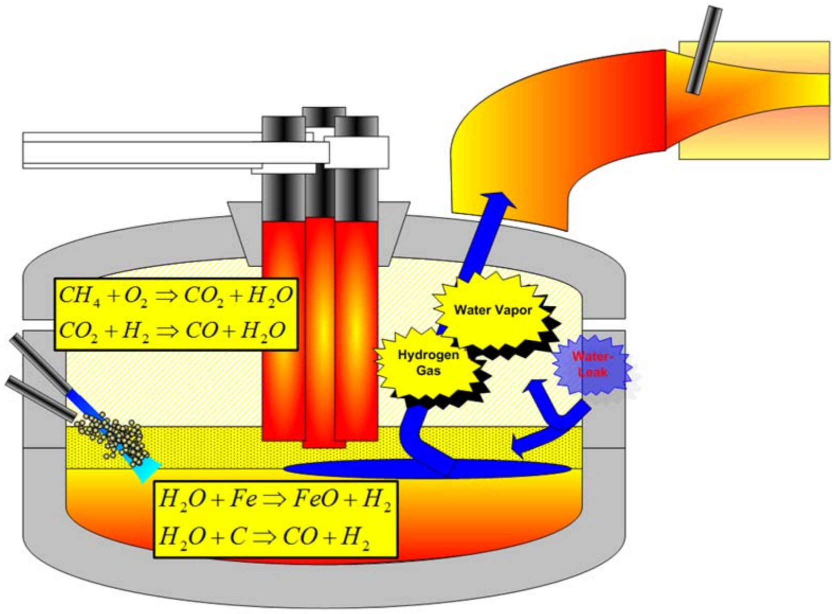

Figure 2. Dynamics of Water and Hydrogen in the EAF.

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ISSN 1982-9345

To be effective for water detection, off-gas analysis technology must be capable of;

- analyzing BOTH forms of water; H_2O_{gas} and H_2;
- minimizing false alarms by distinguishing between "normal" and "abnormal" levels of H_2O_{gas} and H_2;
- providing reliable and uninterrupted off-gas analysis from the start to the end of the heat;
- being effective in both oxidizing and reducing operating conditions;
- having a rapid response time.

The EFSOP Water Detection Technology™ uses the EAF off-gas measurements from the EFSOP® analyzer to determine abnormal water events in the furnace. The methodology first characterizes the normal level of water in the EAF operation such as electrode water spray, moisture contained in the scrap and the by-product from combustion reactions. The characterized normal level of water is compared to the level of water encountered during the active heat to trigger an alert condition. Abnormal water events in the EAF can be created by water panel leaks, seasonal changes resulting in heavy rain or snow contained in charge and changes in scrap that contain higher than normal levels of oils or organic material (turnings, tire wire, etc). The benefits for detecting abnormal water can minimize the risk of furnace and fume system explosions that can lead to equipment damage, injury and loss of life.
The importance of having a complete off-gas analysis, in this case H_2 analysis is clearly demonstrated in Figure 3. In this EAF plant, EFSOP® off-gas analysis (not equipped with water detection software) showed an abnormal increase in H_2 in the off-gas analysis after tapping during power-off period. Once the furnace was rocked at the start of the heat, there was a sudden explosion. Post mortem analysis of the incident confirmed that in this case the water leak manifested itself by a sharp and abnormal increase in off-gas H_2 concentration. Without H_2 analysis it would simply not be possible to identify the abnormal off-gas chemistry resulting from a water leak.

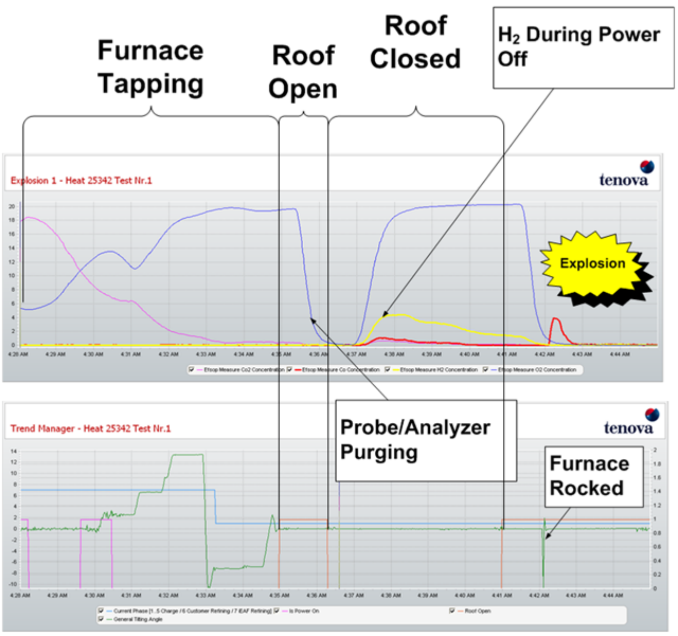

Figure 3. Water Leak manifested by an increase in off-gas H_2.

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ISSN 1982-9345

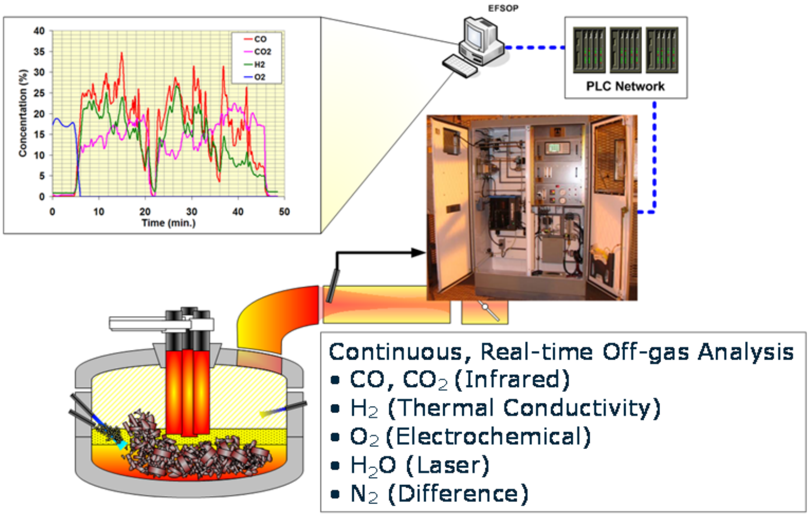

Figure 4. Schematic of EFSOP Water Detection Technology™.

2.1 Features of EFSOP Water Detection Technology™

The key distinguishing features of this second generation EFSOP Water Detection Technology™ include [1]:

- Reliable Analysis from Start-to-End of the Heat; A reliable water detection system requires reliable start-to-end of heat off-gas analysis. The EFSOP® extractive technology is renowned for providing reliable, continuous and uninterrupted off-gas analysis from the start to the end of every heat. Start-to-end of heat reliability is well in excess of 95%.
- Patented Off-Gas Sampling Probe; EFSOP Water Detection Technology™ continuously samples EAF off-gas with a patented water cooled probe. As shown in Figure 5, the off-gas sampling probe is positioned 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 5. 4th Hole Positioning of the Patented EFSOP® Probe Directly Inside Cone of EAF Off-Gas .

** Technical contribution to the 45th Steelmaking Seminar, May 25th-28th, 2014, Porto Alegre, RS, Brazil.*

- Capable of precisely analyzing all critical gaseous species; The second generation EFSOP® water detection analyzer is equipped with proprietary laser, thermal conductivity, infrared and electrochemical analytical technology that provides a continuous analysis for H_2O_{gas} plus H_2, CO, CO_2 and O_2. These 5 gases together with N_2 represent virtually 100% of the off-gas composition.
- Rapid Response Time; Effective water leak detection technology necessitates rapid response times. The EFSOP Water Detection Technology™ displays a continuous and complete off-gas analysis for H_2O_{gas} plus H_2, CO, CO_2 and O_2 within about 15 seconds of event occurrence within the EAF.
- Effective in all EAF operating situations (both oxidizing and reducing conditions); H_2O_{gas} will be more chemically stable when liquid water leaks into an EAF that is operating in an oxidizing condition which is typical whenever the EAF is over-drafted. Conversely, H_2 is more stable if the EAF is operating in a reducing condition which is preferable for reducing yield loss, refractory wear and electrode consumption. As such, the second generation EFSOP Water Detection Technology™ which analyzes both H_2O_{gas} and H_2 is effective under all operating conditions i.e. both oxidizing and reducing operation.
- Capable of distinguishing between "Normal" and "Abnormal" Water Levels; Depending on operating conditions the levels of combustible gases (CO and H_2) and H_2O_{gas} are continually changing throughout the course of any individual heat and on a heat-to-heat basis. To account for this variability, identification of abnormal off-gas chemistry is best done statistically, EFSOP Water Detection Technology™ uses proprietary statistical fingerprint software to differentiate between statistically "Normal" & "Abnormal" water levels in the EAF. The EFSOP Water Detection Technology™ defines two Off-Gas Indicator variables which identify both Dissociated Water Vapour (H_2) and Undissociated Water Vapour (H_2O_{gas}). A statistical fingerprint method (Figure 6) is used to describe "normal" off-gas chemistry.

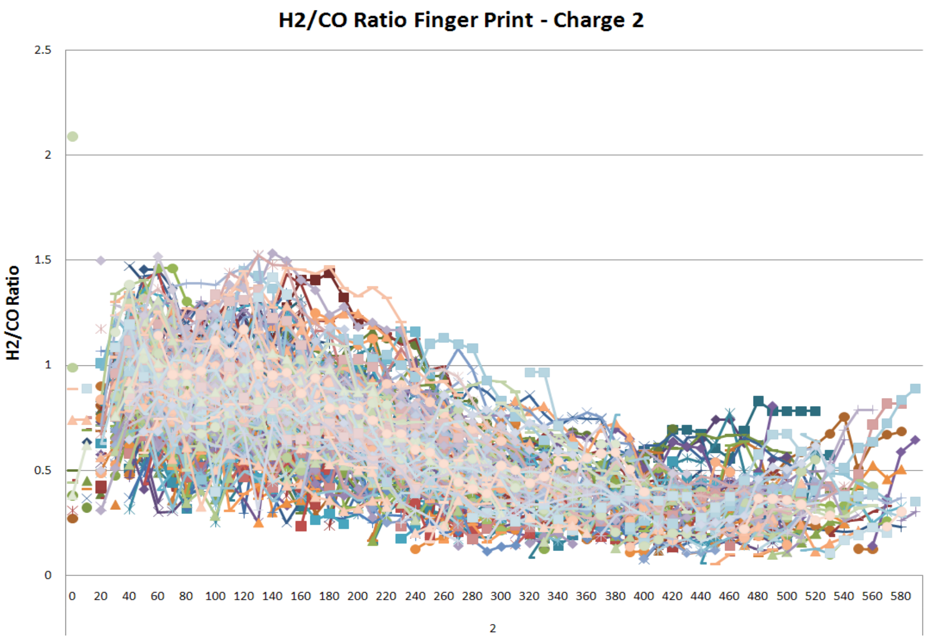

Figure 6. Statistical Fingerprint established from normal off-gas situations.

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- Minimized False Alarms; Dynamic Model automatically adjusts the Statistical Fingerprint for Normal Variations; EFSOP Water Detection Technology™ provides effective water detection with a minimum number of false alarms by employing a proprietary control algorithm that automatically and dynamically adjusts the "Normal Fingerprint" upwards or downwards in response to changing conditions. The software tunes itself dynamically to establish the Finger Print then dynamically adjusts for changing scrap conditions (wet/dry/oily) to minimize the number of false alarms.
- Provides 3 levels of alerts to reflect the severity of the probability of a water leak- Figure 7 schematically illustrates the methodology for triggering an EFSOP® water detection alert. While the system is not a failsafe method, it provides operators with valuable real-time alerts indicating the statistical probability of abnormally high amounts of water in the EAF. When the off-gas water detection indicator is:
  - equal to or less than the Normal Fingerprint Threshold, the system will display a "Green Alert"
  - When the indicator exceeds the Normal Fingerprint Threshold for a prescribed period of time but is below the defined Upper Threshold Limit, the system will issue an "Amber Alert"
  - When the indicator exceeds the Upper Threshold Limit for as prescribed period of time, a "Red Alert" is issued indicative that the off-gas chemistry is significantly out of the statistically normal range.

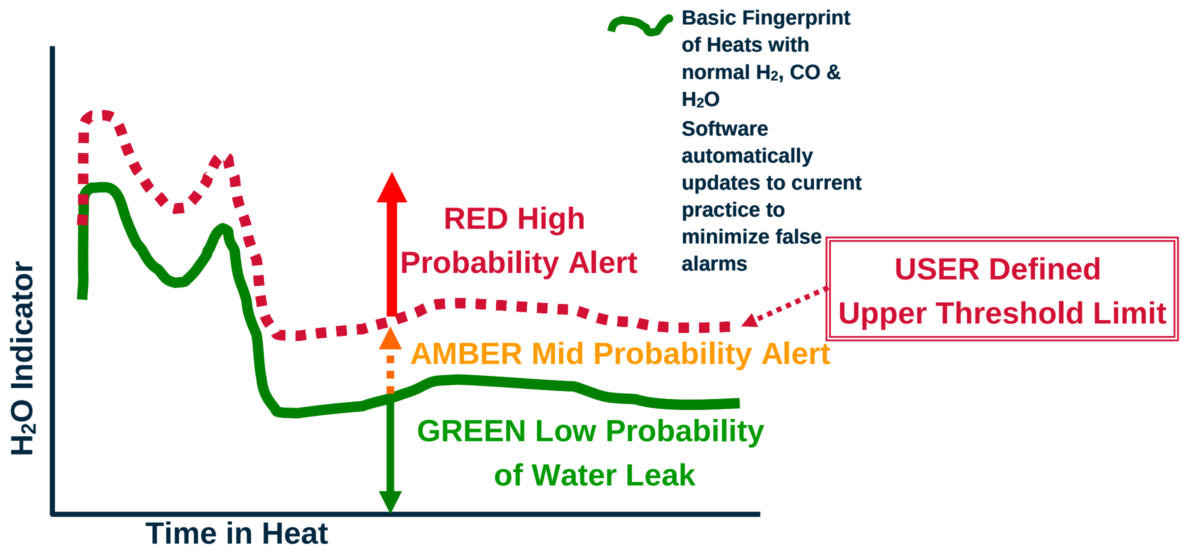


Figure 7. Methodology for Triggering an EFSOP® Water Detection Alert.

2.2 EFSOP Water Detection Technology™ Results

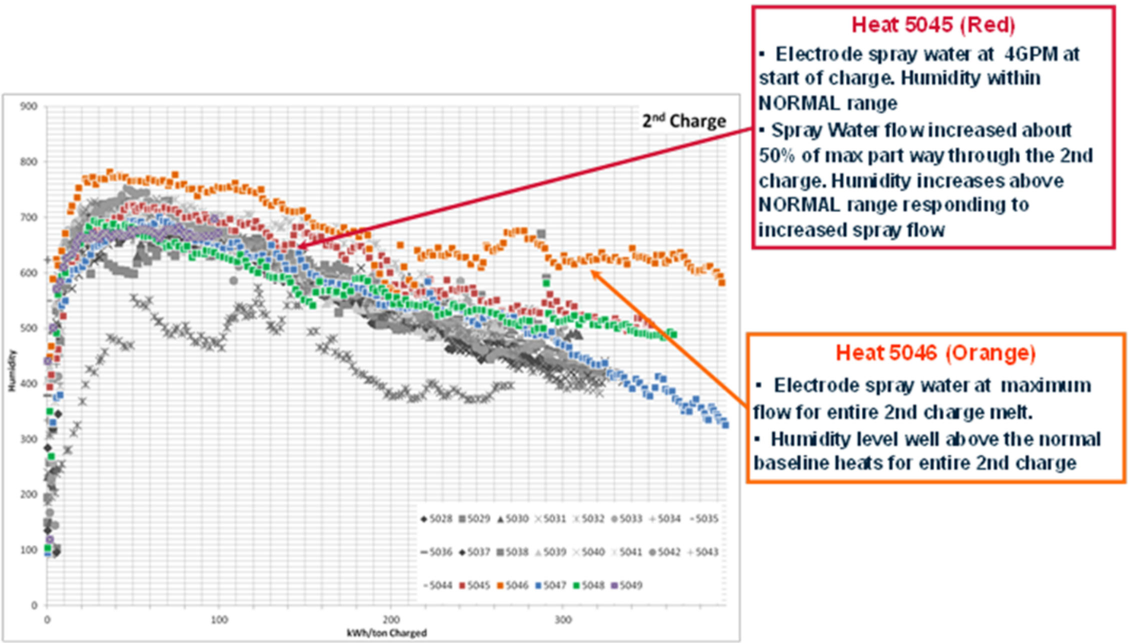
Figure 8 shows the results of these controlled electrode water spray tests - the horizontal axis is kWh per ton and represents a measure of time during the heat and the vertical axis is a measure of humidity as detected and reported by the EFSOP Water Detection Technology™.
In Figure 8 the background results with normal electrode water flow are shown in gray. The colored data points represent the EFSOP Water Detection Technology™ response to controlled changes in the electrode water spray flow rate.

** Technical contribution to the 45th Steelmaking Seminar, May 25th-28th, 2014, Porto Alegre, RS, Brazil.*

ISSN 1982-9345

The results in Figures 8 indicate this second generation EFSOP Water Detection Technology™ correctly and rapidly responds to the indicated changes in the electrode spray flow rate even when water flows were increased or decreased partway through the charge;

- Heat 5045: red data points indicate that the System rapidly responds when the electrode water spray is increased by about 50% part way through the charge
- Heat 5046: orange data points show the System correctly responds to situations where the water spray volume is turned to maximum from start to end of the 2nd and 3rd charge.
- Heat 5047: blue data points are within the mid to lower range of "normal" showing the System responds to situations where the electrode water sprays have been turned-off through-out the2nd and 3rd charge
- Heat 5048: green data points show the System responds immediately when the water sprays are turned to maximum near the end of the 2nd charge and throughout the 3rd charge.



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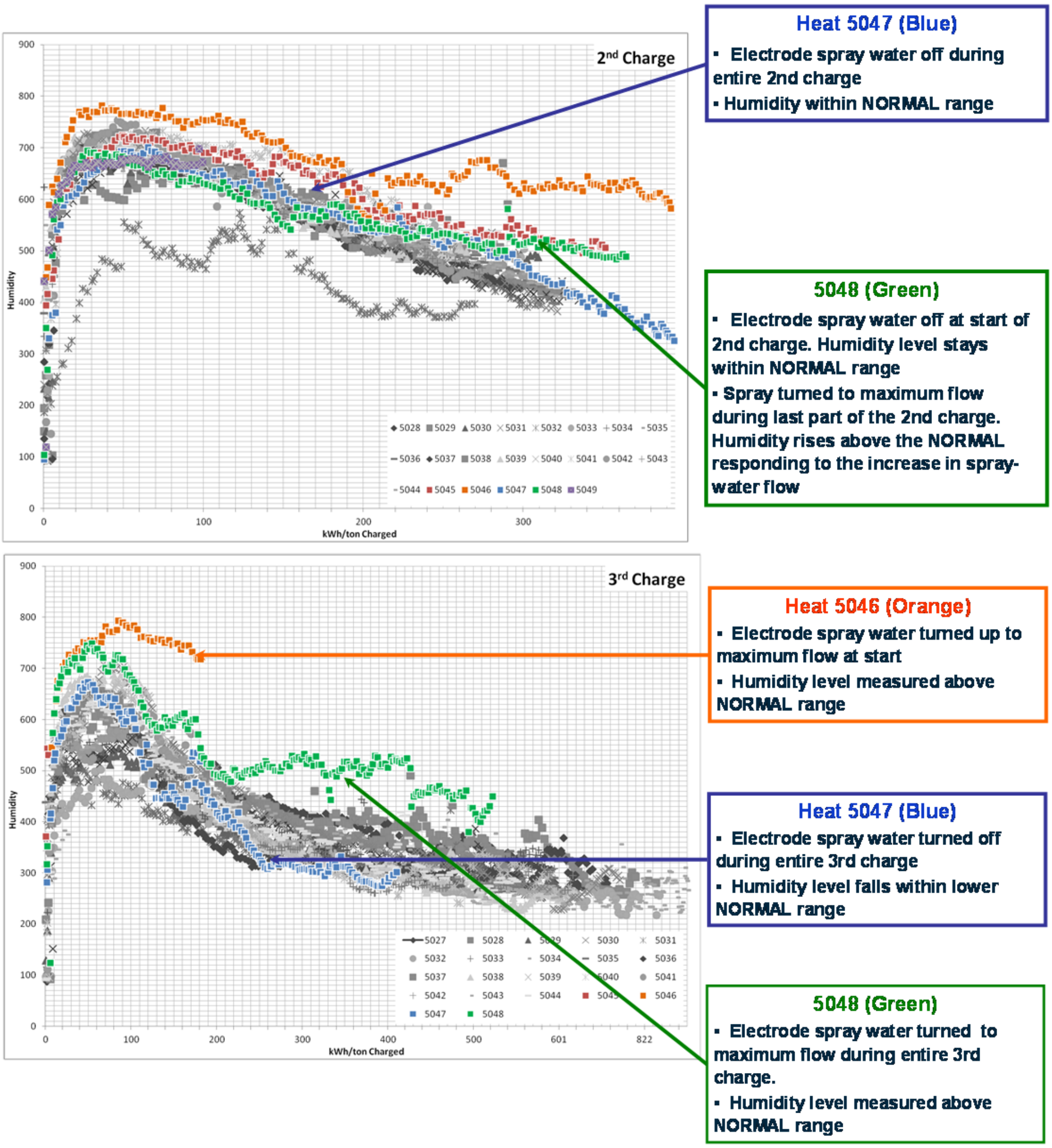

Figure 8. EFSOP water detection technology™ response to controlled changes in electrode spray flow rates.

3 CONCLUSIONS

When liquid water enters the EAF it will immediately vaporize to water vapor which in turn reacts with Fe, FeO, CO_2, CO and C to form H_2O_{gas} and H_2. Since the dynamics of the H_2O_{gas}/ H_2 interactions are quite complex and dynamic, it is simply not possible to predict the relative proportion of H_2 and H_2O_{gas} in advance of a leak. Hence, effective off-gas based water detection requires real-time, continuous and reliable analysis of BOTH forms of water; H_2O_{gas} and H_2 [4].
Tenova Goodfellow has developed an effective second generation water detection technology capable of analyzing both H_2O_{gas} and H_2. 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"

** Technical contribution to the 45th Steelmaking Seminar, May 25th-28th, 2014, Porto Alegre, RS, Brazil.*

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levels of H_2O_{gas} and H_2 in the EAF freeboard. The system software automatically tunes itself to provide a “normal finger print” which is representative of normal water levels in the EAF. A proprietary control algorithm automatically and dynamically adjusts the “Normal Fingerprint” upwards or downwards in response to changing scrap conditions (wet/dry/oily) to minimize the number of false alarms.

Controlled electrode water spray trials were 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 [4].

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