Sublance-based On-line Slag Control in BOF Steelmaking

M. Spanjers
Heraeus Electro-Nite Intl NV
Centrum Zuid 1105
Houthalen
Belgium
Tel: +3211600362
Fax:+3211600400
Email: Mspanjers@electro-nite.be

W.Glitscher
Heraues Electro-Nite Intl NV
Centrum Zuid 1105
Houthalen
Belgium
Tel +3211600226
Fax:+3211600400
Email: Wglitscher@electro-nite.be

Key words: BOF steelmaking, Sublance probes, dynamic control, quik tap, slag measurements, improved functions.

Introduction

The paper reports the recent experience with a new generation of sublance sensors in Europe and South Africa, capable to read simultaneously, temperature and oxygen activity of steel and slag, bath level, and slag thickness. Associated calculations comprised in an expert model allow a very precise carbon tap prediction and “Go - No Go” decisions on direct tapping. For the first time a direct phosphorous prediction is one of the system’s new features. It can be estimated that the BOF capacity, on average, can be increased by at least one heat per day. On-line BOF slag control allows for improved blowing practice and a longer lining life.

Advantage of a Sublance system

.

The sublance system has provided valuable information for the process model to reach the final target without a reblow.
At this time about 175 sublance systems have been installed worldwide. Modern BOF vessels run their sublance combined to a Static Dynamic process control Model (SDM). Sublance and SDM united, provide a substantial reduction in Tap-to-Tap time resulting in a higher production rate and simultaneously reduced refractory cost. Danieli Corus, supplying sublance systems, recently even reported a 25% rise in production capacity coinciding with 17% reduced BOF cycle time at an integrated Brazilian shop with their newly installed sublance system. The vessel’s lining life was increased by remarkable 41% at the same time.

Different to an off-gas mass spectrometer controlled vessel, the sublance system offers the chance to correct temperature and chemistry uninterrupted about 2 minutes prior to oxygen stop. Together, sublance and SMD have been providing the best chances for a very high targeted hit rate for carbon and temperature without re-blows.

Classic way of operation a sublance

The most preferred way for a BOF plant to use a sublance measurement in the converter is to have two sublance measurements per heat. The first measurement is the so-called in-blow measurement. This measurement is generally taken 2 minutes before the end of the oxygen blow. A Temperature-Sample-Carbon style probe is most often used for the in-blow measurement. The in-blow measurement leads to a correction of the blow model in order to achieve simultaneously the aim temperature and the carbon content at the end of the blow.

The second sublance measurement is taken after the oxygen blow. This end point measurement is standard carried out with a TSO probe. This probe measures the steel temperature and the active oxygen of the steel, and also provides a lab sample for checking the final composition of the steel. The oxygen measurement provides within seconds, the actual carbon content of the steel, based on the C-a(O) relationship. Furthermore, a pre-calculation of the required amount of deoxidant (Aluminium) during tap, can be given. Combined with the analysis of the in-blow sample, the temperature measurement and the oxygen/carbon measurement may lead to a decision to quick tap the heat.

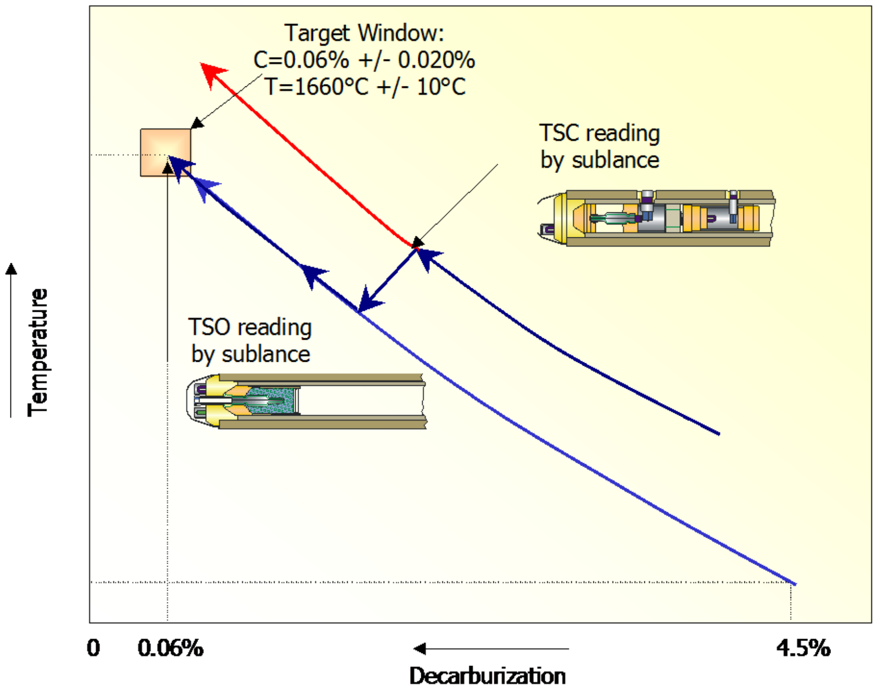


Figure 1: Decarburization process in converter

New developments

The new generation of sublance sensors, combined with new developed instrumentation, is able to read simultaneously the temperature and oxygen activity of steel and slag, bath level and slag thickness. Also with the new developed instrumentation, the carbon predictions of the in-blow measurement and the end-point measurement are improved.

Improved carbon prediction inblow.

The in-blow carbon prediction is based on the measurement of the liquidus temperature of the steel. This liquidus temperature is defined by the amount of carbon in the steel, however, the other elements present in the steel can depress the liquidus temperature. Therefore, depending on the steel grade, the liquidus formula should be adapted.

A new system of carbon determination was developed that allows a more precise determination of the carbon. In Figure 2 the difference between the normal in-blow carbon calculation and the improved carbon calculation is shown. The dark coloured points indicate inblow carbon (Ci%corr) calculated with the improved formula. As you can see, the scatter in the new results are less then the in the results with the normal carbon formula. The light coloured points (Ci%) indicate the carbon calculated with the standard formula

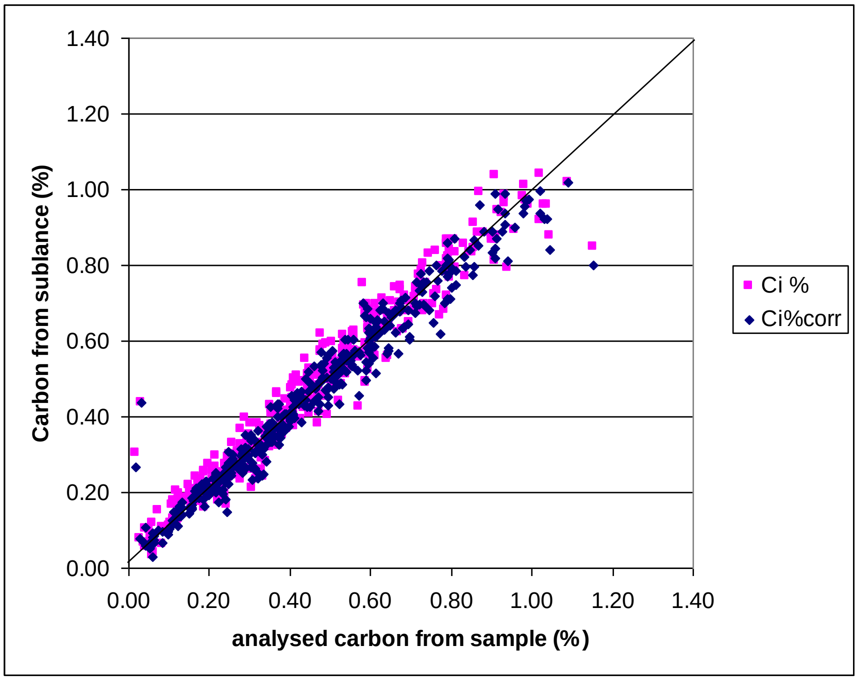


Figure 2 Comparison between improved carbon formula and standard formula

Carbon determination end point measurement.
Using the oxygen measurement in the steel, the carbon is being calculated via C-a(O) formula.

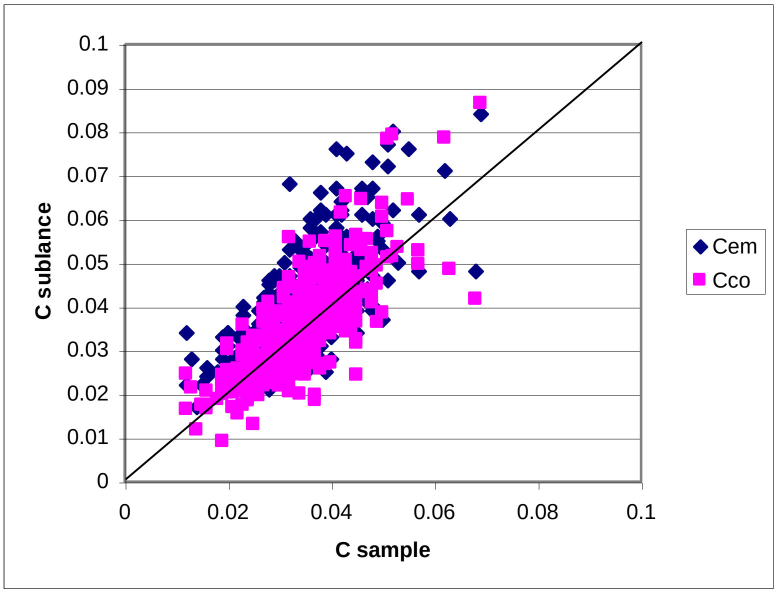
Log %C = 2.236 – 1303/T- log a(O)

T = temp (°C)
a(O)= oxygen activity (ppm)

This is a static formula while the converter process is dynamic.

The new system is able to follow the actual situation in the converter leading to higher accuracies and lower standard deviation in the carbon prediction. In figure 3 the light coloured points (Cco) are result of the carbon prediction with the new system. Those follow the 45-angle line, while the standard formula (Cem) generally predicts a higher value, especially at the higher carbon levels. With this system the confidence for a Quick Tap decision is increased.

Figure 3: Comparison of C prediction end point determined with fix or floating CO product.



Bath level prediction

During the TSO measurement there is a possibility to determine the bath level. When the probe is lifted out of the steel bath, the probe passes through the steel-slag interface. This interface is characterised by a jump in the oxygen signal and a change in the temperature signal. Both events can be used for the bath level determination. In the new system we added a third signal, which we use for the slag oxygen measurement. We now have multiple traces for the bath level evaluation. Each trace is evaluated with different algorithms and this leads to an array of bath level results.

From this array we calculate the bath level position, and we also give an accuracy level of the bath level determination in centimetres (cm). This system adds more value to the steel plant because operating decisions can now be made with better confidence, based on this accuracy factor.

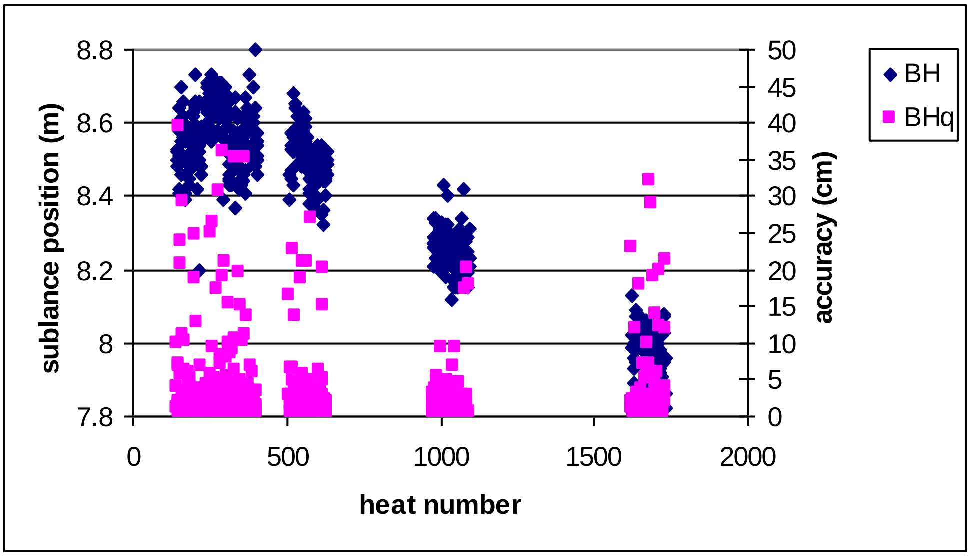


Figure 4: Results of improved Bath height determination including the accuracy of each bath height measurement.

In Figure 4 is a dataset shown from one converter in pilot phase of the project. The data collection is still underway, so the data set is somewhat limited. The dark coloured points represent the bath height (BH), expressed in the sublance position, in meters. It becomes clear that the bath height decreases over the lifetime of the converter, but this should not influence the quality of the bath height determination. The light coloured points (BHq) indicated the accuracy of the bath level detection.

Slag measurement

The new software, together with improved sublance probes, is now capable to measure oxygen level in the slag. With this additional measurement, this system can detect slag thickness. In Figure 5 there are three measurement traces depicted from the TSO measurement. The curve of the temperature has two plateaus. The first plateau is the steel temperature, and the second is the slag temperature. The blue curve (EMF steel) is the oxygen trace from which we determine the oxygen level in the steel. The third curve (pink) is the curve used for determination of oxygen activity of the slag and slag thickness. As can be seen, this EMF curve has a clear jump at the same position as the EMF steel curve. However, instead of creating noise like the steel EMF, after the jump, this curve again finds a plateau. This plateau is used for the determination of oxygen activity of the slag.

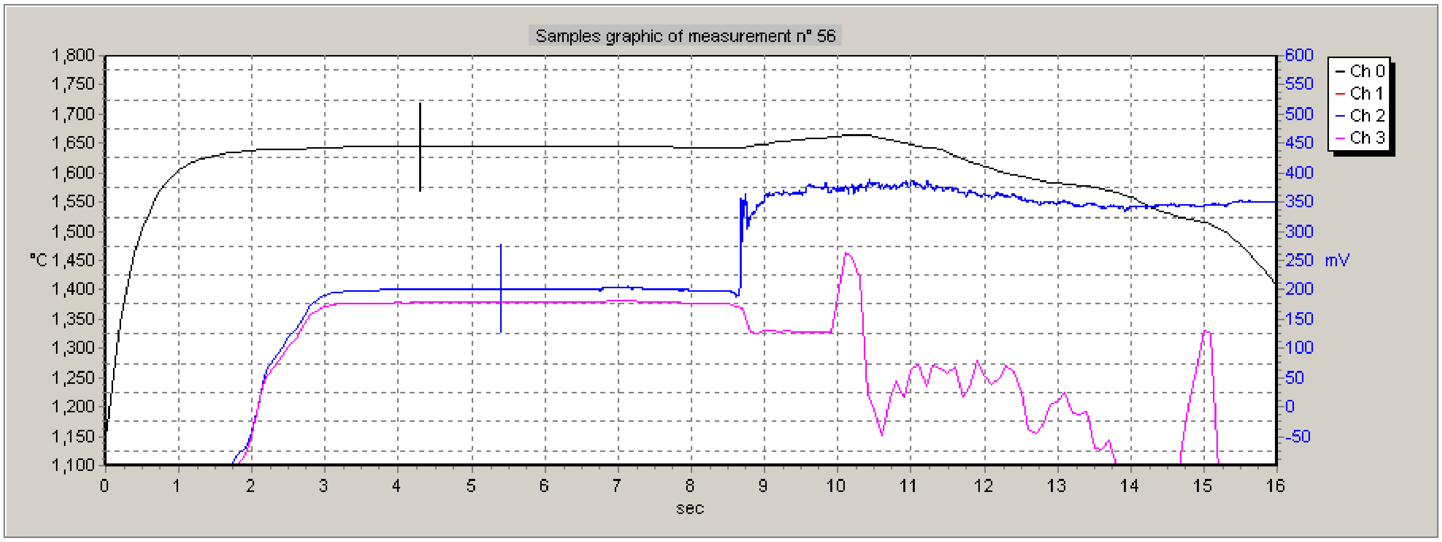


Figure 5 Example of a TSO measurement with temperature, oxygen steel and oxygen slag

When the sensor passes the slag-air interface, the slag EMF again shows a clear jump. Based on the timing of this jump, combined with the travel speed of the sublance, the slag layer thickness is calculated.

Figure 6 is based on measurements in a BOF plant in South Africa. During the life of the converter the bath level drops and is closely followed by the dwell position of the sublance, indicated in dark blue. The yellow points indicate the slag air interface. In order to calculate the slag thickness, the position of the steel slag interface (bath level indicated in pink) is subtracted with the position of the slag air interface. Sometimes the result of the slag thickness is in order of 2 meters. In that case, the measurement took place in a converter with foamy slag. So the slag thickness also can be used as an indicator for foamy slag.

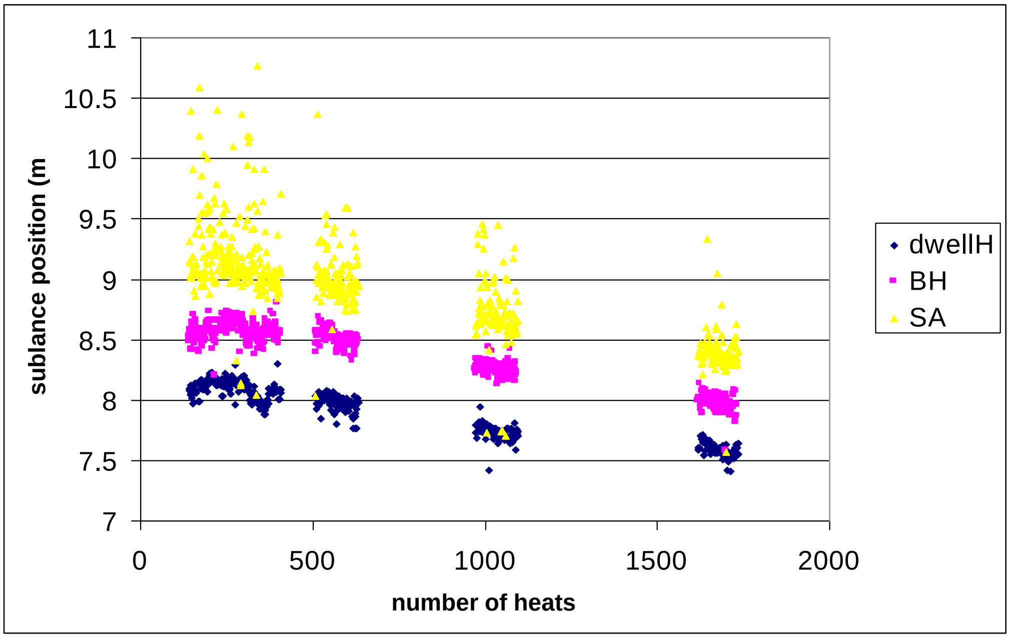


Figure 6:Determination of the Dwell position, steel-slag interface and slag-air interface

Knowledge about slag thickness combined with the knowledge of slag temperature and oxygen levels in the slag can be used to correct the oxygen lance height and to reduce refractory wear.

Instrumentation

All the new developed functions can be activated with a specific line of instruments: Multi-Lab III® Multi-Lance with the Multi-Lance@function or in combination with a DIRC V® system. Both are a 4-channels instrument equipped with the latest technology and communication protocols.

The set up of the instrumentation is as depicted in Figure 7.

In order to get the improved functions, the instrumentation needs a two-way communication with the level 2 system of the BOF plant. Necessary for the applications, is the input of the analysis of the sample into the Multi-Lab, and the lance position during the measurement. Only when those requirements are fulfilled, can improved function can be realized.

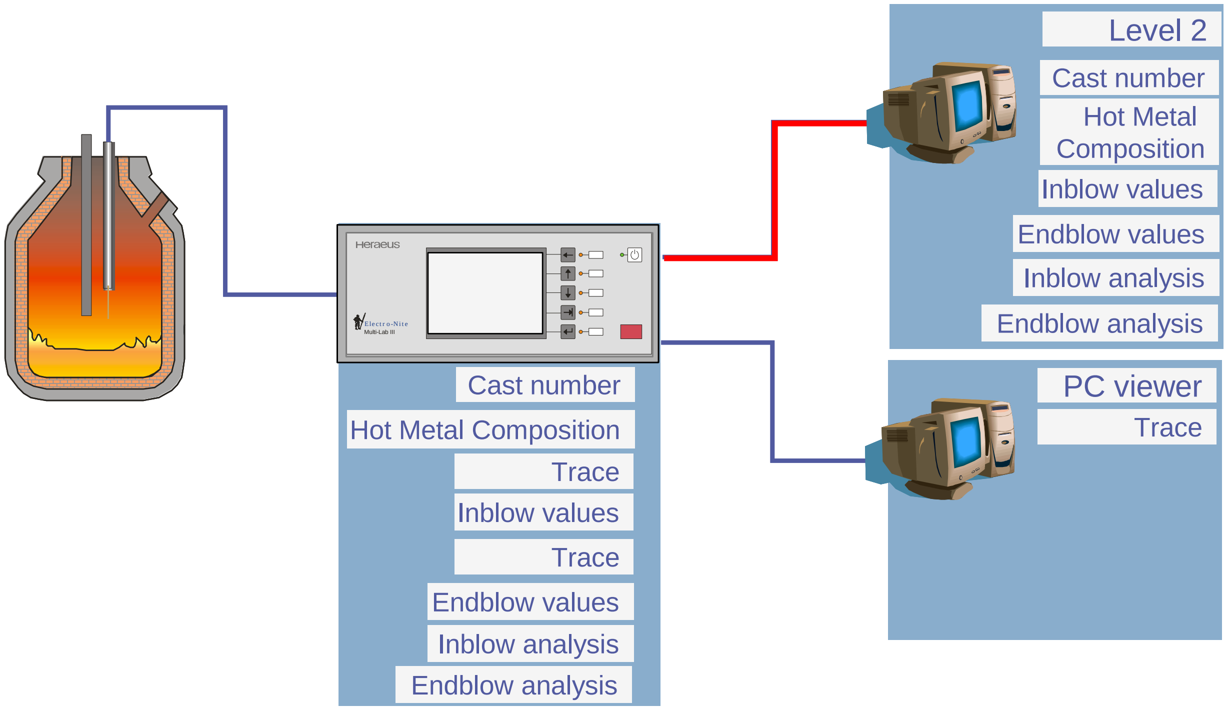


Figure 7: Instrumentation and communication layout for slag measurements

Outlook for the future

Based upon the slag oxygen measurements, Phosphorus levels can be calculated. Development work is underway that can generate a Phosphorus prediction from a sublance measurement. The system that is now under development will give a tapping advice. The goal is to create a system giving a green light when P content is below the set value, giving a red light when the P content is above the target value, and giving a yellow light when the algorithms behind the measurement have a conflict situation and the accuracy of the prediction is poor. In the last case the process model of the steel plant should take over.

Conclusion

A new generation of instrumentation and sensors for sublance measurements has been developed. This new system is able to read simultaneously temperature and oxygen activity of steel and slag, bath level and slag thickness. The new features of this system are an improved carbon in-blow, improved carbon end point, and improved bath height determination. New for the sublance is the measurement of slag oxygen activity and slag thickness. Development work still in-progress, is a Phosphorus prediction from a sublance reading.

References

1) P.D. Hubbeling, G.A. Oostermeijer, "Sublance Control. Sublance and Dynamic Control: The Ultimate Tool in Steelmaking"
2003 Iron and Steel Exposition.

2) W. van der Perre, "Various Designs, Aplications and Typical Results of Modern Sublance Probes"
1997 Oxygen Steelmaking Congress, Italy.