Sublance: Ultimate Tool for Steelmaking

Subrat Mishra** Manish Wadhwa** Guido Van Hattum*
*Daniei Corus BV, Rooswijkweg 291, 1951ME Velsen-Noord, The Netherlands
**Danieli Corus India, New Delhi, India
Email: subrat.mishra@danieli-corus.com, Edo.Engel@danieli-corus.com, Peter.Gootjes@danieli-corus.com, Guido.van-Hattum@danieli-corus.com

Abstract

Due to its complex nature, the BOF process control is the determining factor in the steelmaking process and the shop performance. In the past, the steelmaking process depended on operator experience and empirical production rules using preset loading schedules and manual measurements and sampling. The introduction of computer based process models brought better control of the steelmaking. While the static part of the model does its job based on readily available data, the dynamic part of the process model requires input from the actual steelmaking process. For tight end point control with high hit rates and avoidance of secondary blow cycles, it is absolutely necessary to operate a sublance system with the static and dynamic model. Over the last decades, many improvements have been made in this area, such as the use of a sublance, waste gas analysis, bottom agitation system and ASCON slag control. All of these tools depend on a solid, well-tuned process model to be successful.

The automatic steelmaking system, developed by Danieli Corus, integrates all available tools and combines them within the Static - Dynamic process model for BOF steelmaking. This model was first developed at the IJmuiden steel plant and further improved during implementation in other plants world-wide. It has been consistently successful with high hitting rates and substantially reduced tap–to–tap times. Recently, the sublance and static - dynamic model is successfully installed in all seven (7) converters at JSW, Tornagallu. This article also reviews the successful installations of sublance with static - dynamic model at JSW.

Key words: BOF, sublance, process control, JSW, return on investment, phosphorous
Introduction

Due to its complex nature, the BOF process control is the determining factor in the steel shop performance. A proven method for obtaining these objectives is the introduction of the latest process control model which can dynamically adjust the steelmaking process by the use of sublance measurement data such as steel bath temperature, carbon content, oxygen activity, phosphorous prediction and actual bath level.

The combination of the latest developments in sensors, valve control, computer modeling and the proven technology of the sublance system brings a process control into the converter area that will pay back its investment in a very short period. Through logging of all relevant process data, valve positions and production conditions, the static - dynamic model can trim and improve production efficiency.

Taking current base material pricing and actual production performance into account, a three 200 t converter steel shop could increase its capacity by ~ 10 % and earn back the investment in less than a year.

Advantages of making steel using sublance and SDM (Static Dynamic Model) was first witnessed in India with the successful installation of the first sublance system in February, 2013 at SMS - 1 in JSW at Vijayanagar works. Subsequently, JSW, Vijayanagar works became the first Indian steel maker to install sublance and SDM at all 7 converters of JSW, Vijayanagar works alongwith Danieli Corus as the technology supplier. The successful installation of all seven (7) sublance system was considering a customized design to suit the existing steel shop facilities and a steelmaking practice different from normal like intermediary de-slagging facility, etc.

Sublance equipment and DIRC

Sublance is a tool to measure bath temperature, solidus temperatures during the blow and oxygen activity at the end of blow or during the blow. This tool allows online measurement without interrupting the blowing pattern while the convertor is still in vertical position. The measured data from sublance is processed in a digital computer (proprietary to Danieli Corus), whereby, it displays the bath temperature and the carbon content (from the solidus temperatures) during an in-blow measurement and bath temperature and oxygen activity in the bath during the end of blow measurement. It also calculates the bath level during the end of blow measurement.
Substance equipment installations can be customized depending on the space availability at the steel shop. In the case of our recent installations at JSW, it was tailor made design to suit the site conditions and the space available, which is unique out of our more than 120 installations worldwide. This combines with the latest state-of-the-art DIRC-VI

**Essential parameters for steelmaking process control**

The control of the steelmaking process inside the converter is a very complex matter, because a manifold of parameters have an effect of the actual process. Therefore, a comprehensive process model is required at the core of the system. The system integrates operation and exchange of information with plant systems varying from raw material ordering all the way up to e.g., the plant's ERP and MES systems. With the Danieli Corus Process Control System, basic oxygen converters can be operated in full computer mode based on calculations and recipes, but the system also accepts overruling by the operator.

Over the decades, the system has been implemented at numerous steel plants. The hardware and the process model have proven their flexibility throughout all of these implementations. The system can be fine-tuned to any plant and optimized to follow existing operational procedures.
Fig. 3 shows precise scales, valve control and good process measurement are necessary for optimized process control.

In preparation of each heat, the static part of the process control model should calculate the amount of hot metal and scrap, the oxygen quantity to be blown, the required amount of material additions and the carbon and oxygen flow out of the converter.

A reliable process control model output requires sufficient quality of input data. For instance, in day to day operation, this means that reported weights of scrap and hot metal are equal to actual weights. Scrap itself should be well defined in size and composition. The scrap yard should not be used as a factory waste bin, where all the excess materials are dumped. Also temperature and analysis of hot metal should be reported on time. If a desulphurization station is in operation, its process result should be taken into account of the model calculation. Composition and quality of material additions, such as lime or manganese, should be updated in the system as soon as a new batch is used for steelmaking.

At the moment the oxygen blowing starts, the dynamic part of the process control model takes over. The dynamic process control model requires a different set of input data to control the oxygen blowing process and to have exact end point control. Material additions must be reported correctly, feeding the dynamic model with charging start / end time, valve positions and charging weights.
For a continuous monitoring of the blowing process, many steel shop have installed a waste gas analysis system (WGA). The WGA system can provide important process data, such as dC/dT and off-gas composition. However, for a reliable end point control with high hit rates, the waste gas analysis system alone is too limited. Especially, if the produced steel grade has an aim > 0.1 % C, where the dC/dT does not show a clear offset at end of heat. If the carbon content > 0.1 %, the static model alone will be more accurate and give better hit rates than the WGA.

Apart from the limitations of the waste gas analyzer itself, it also lacks the capability of measuring critical process parameters (solidification / bath temperature, bath level) and no steel samples can be obtained without interruption of the blowing process.

Without these critical and other important parameters, it becomes impossible to operate the steel shop cost efficient and to produce at maximum capacity.

![Diagram showing target window and sublance measurements as function of decarburizing process](image)

**Figure 4 : Schematic overview showing target window and sublance measurements as function of decarburizing process**

The sublance equipment is proven to be a robust and very reliable system for obtaining actual data from the converter during the steelmaking process. The sublance is designed to handle various probes, such as the TSC (Temperature, Sample, Carbon) for the "in blow" measurement and TSO (Temperature, Sample, Oxygen) for the "end of blow" measurement. Some steel shops make use of T (Temperature only) types. In figure 4a schematic overview of the target Window, defined by % C and Bath temperature, and
sublance measurement points is given. Parallel to sublance measurements, steel samples are taken from an upright converter without the need to interrupt the blow. Therefore the steelmaking process can be continued, which has great advantages in maintaining a stable process.

Modern steelmaking is dependent on the sublance measurements to adjust the oxygen blowing volume and the quantity of converter additions. The dynamic steelmaking models and the accurate sublance data enable "quick-tap" and "direct-tap" modes of operation.

**JSW experience**

With the successful commissioning of all seven (7) sublances and SDM at JSW, Vijayanagar, it was evident what this tool can bring to the primary steelmaking.

The field data and the prediction by model allowed better judgment on blow pattern and thereby proving a dynamic control of the steelmaking process and this dynamic control allowed the operator to control re-blows, oxygen percentage and parameters as shown in the following graphs.
Return on investment

The economics for implementing a process control model based on sublance measurements is quite straightforward. The sublance system will lower a set of fixed and variable costs and will cause additional costs, such as the initial investment, maintenance and consumables. Based on BOF production data, from the installation of more than 120 sublance system all around the world and recent 7 systems at JSW, Danieli Corus has developed several return on investment models. However, to summarize the return on investment of sublance and SDM for a 200 t converter is less than a year time. This claim is also proven in JSW.
Latest development in BOF process control

Online phosphorous measurement

Controlling phosphorous levels during the steelmaking process has always been difficult. With the increased use of iron ores containing high phosphorous, the measurement of phosphorous at end point in BOF steelmaking continues to be a subject of interest because of the impact of phosphorous on steel quality. BOF slag is complex in nature and contains several oxides like CaO, SiO2, P2O5, MgO, MnO, and FeO, etc. Towards the end of blow the kinetics of different reactions slows down such that slag composition approaches a kind of pseudo equilibrium with metal. Thus, application of (thermo-dynamic) models alone for direct estimation of phosphorous distribution does not yield sufficient reliable information for quick tapping.

Over a decade ago first attempts were made to use signals from the end of blow measurement for phosphorous determination. Three years ago, a new team of engineers took up the challenge to go beyond existing technologies and develop real time phosphorous measurement. Key aspects of the measurement such as the oxygen sensor, the measurement cycle, the data recording and data processing were subsequently optimised for phosphorous determination. This was done under two strict conditions that existing performance for carbon and end temperature control should remain equal and that during factory trials, the phosphorous measurement should not influence normal steelmaking operation in any way.

Because the normal measurement cycle only focuses on the measurement in the steel bath, a new cycle was needed that also takes the measurement from the slag data into account since for phosphorous determination, slag composition also needs to be known. Existing hardware was improved to allow for measurement not only in the steel bath, but also in the slag layer.

The standard oxygen sensor, as applied for carbon and temperature measurement, had to be improved to give a better and more stable signal oxygen activity signal in the slag. Through a series of hardware modifications to the sublance data processing computer (a DIRC - 6 from Danieli Corus), it was possible to measure simultaneously the oxygen level of two oxygen sensors. Because of this configuration, no disturbance of normal sublance measurements occurs and production is not affected by the development work.
The most complex step was to convert the process data into information and to find a suitable way of presenting the measured phosphorous. First step was to extract key components of a full size level 2 process control model. These components were combined into a miniature process model, focussed on calculating phosphorous. This P - model was ported to run on a process computer, allowing it to calculate the phosphorous from TSOP measurement data in real-time.

First results of the development work were an optimised sublance measurement cycle and an improved oxygen sensor. Adding oxygen activity from sublance and real time level two (2) process data (such as hot metal composition and material additions), phosphorous can be determined in real-time using the oxygen activity data from the end of blow measurement.

In Figure 5, the experimental results from field trials in two Chinese steel plants are shown. It should be mentioned that both steel plants made no alterations to their normal converter operation to come to more favourable conditions for phosphorous measurements.

No precautions were taken, with respect to converter addition material quality, quantities or other process control parameters. In both plants it was possible to limit the error to 20 ppm up to a phosphorous content in the steel bath of 300 ppm.

![Figure 5 : Phosphorous content determined by sublance TSO versus laboratory analysis of steel sample](image)
Similar Model is also under installation at JSW, Vijayanagar works.

Conclusions

Sublance and SDM is the ultimate tool for BOF steelmaking. It returns direct benefits like reduced tap-to-tap time and reduced re-blows. It also provides intangible benefits like optimization of oxygen consumption, aluminum consumption and increased lining life.

JSW, by installing seven (7) systems at their Vijayanagar works, have realized the benefits of sublance and SDM.

The phosphorous model, which is under final stage of development will add to the strength of the process model and enable operator to reach the automatic steelmaking practice.

Danieli Corus has installed and commissioned more than 120 systems worldwide in varying converter size of 120 t up to 300 t. All these plants benefit from the possibilities to maximize steel output capacity, minimizing consumption of fluxes and refractory and limiting waste gas production.

The capital investment of a sublance system has a realistic pay-back time of less than one year. With an expected life time in excess of 20 years for a steel shop, this tool will have very significant effect on plant performance for each BOF that decides to install and operate a sublance system alongwith SDM.

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