Maximising BOF production and lowering costs by using sublance-based process control

A proven method to increase BOF output and/or lower costs is the use of the latest process control model which can dynamically adjust the steelmaking process using sublance measurement data such as steel temperature, carbon, phosphorous and bath level. In China, more than 30 steel shops have chosen to install over 90 sublance systems producing in excess of 200Mt/yr.

Due to its complex nature BOF process control is the determining factor in steel shop performance. In the past, steelmaking depended on operator experience and empirical production rules using preset loading schedules and manual measurements and sampling. The introduction of computer process models brought better control of steelmaking, and 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 actual steelmaking. A sublance system is essential for tight end-point control with high hit rates and to avoid secondary blow cycles.

The BOF shop can be divided roughly into three process areas: the hot metal pit combined with desulphurisation station, the converter area and secondary metallurgy treatment stations. Process models that control equipment in these areas will optimise either individual performance or, at most, the process area. Introduction of an overall process control system, optimising from hot metal pit to caster, can reduce energy consumption and waiting times.

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

**ESSENTIAL PARAMETERS FOR STEELMAKING PROCESS CONTROL**

The control of the steelmaking process inside the converter is complex, because many parameters have an effect on the actual process. Therefore a static process control model must contain an extensive set of metallurgical relations which are used for the prediction of manganese, phosphorus, sulphur, Fe-total in the slag and basicity of the slag, along with temperature losses during waiting, lance height calculations and the prediction of the average percentage of CO₂ in waste gases.

In the preparation of each heat, the static part of the process control model should calculate the amount of hot metal and scrap, the oxygen 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 (See Figure 1).

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 and the scrap yard should not be used as a factory waste bin, where all excess materials are dumped. Also, temperature and analysis of hot metal...
equipment has proven to be a robust and very reliable system for obtaining actual data from the converter during steelmaking. It 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 2 a schematic overview of the target window, defined by %C and bath temperature, and sublance measurement points is given.

In parallel to sublance measurements, steel samples are taken from an upright converter without the need to interrupt the blow, which has great advantages in maintaining a stable process.

Modern steelmaking is dependent on the sublance measurements to adjust oxygen blowing volume and quantity of converter additions. The dynamic steelmaking models and the accurate sublance data enable ‘quick-tap’ and ‘direct-tap’ modes of operation. Next generation (dynamic) process control models will further increase the efficiency by increasing the active measured and controlled parameters. As an example, Danieli Corus is finalising the development of a new sublance probe, which will allow for the measurement of phosphorous content and which gives information on slag level and composition.

In Figure 3 results of sublance measurements are shown coming from regular production in one of China’s most modern BOF shops. The relationship between phosphorous content and the analysed steel sample content is such that active control of phosphorous during the blowing process is possible. If the process control model receives this %P at the time of in-blow measurement, it can adjust the blowing process if it is outside the target range. Costly downgrading due to phosphorous can then be avoided.

**REDUCING COSTS AND EMISSIONS**

In today’s market steel producers must broaden their interests from production-related issues to economic and environmental topics. Increasing prices and limited availability of base materials and scrap put pressure on the cost of steel production. Energy consumption and re-use of waste gas and process heat have become important. They will have an impact on cost, but efficient energy consumption has a positive impact on the environment.

**Active addition control** The amount of material additions during the blowing process is metallurgically determined and varies for each heat. Depending on what grade is produced and on the mix of scrap and hot metal, the programmed blowing/addition scheme determines the actual addition. Often, materials will be added in two or three batches at given points in the blowing process.

After material addition, many models receive data from
the bin system confirming that bin valves were opened and material added. Specific weights of added material, however, are not available, thus in these cases the process model has to assume that the required weight was added and calculate with that.

For efficient use of the dynamic part of the process control model, there must be an active feedback loop that receives input from the bin system on actual weights of added material. If actual weights differ too much from required weights the dynamic model will update the weights of materials that still need to be added during the current blow.

This dynamic adjustment will not only decrease the number of downgraded off-specification heats but will also improve the quality of statistical analysis of production data. With reliable statistical data, blowing schemes and amount of material additions can be further optimised, leading to better cost control. Avoiding excess material will also reduce the environmental impact of the steelmaking process. Less dust and cleaner slag mean less pollution.

**Optimising grade production by reducing downgrading of heats** Without actual process data, it is difficult to end the blowing process at exactly the right time. As stated earlier and under limited conditions, a WGA system can provide carbon content data and the static model can calculate the actual bath temperature. For high-quality steel grades, however, such as automotive or packaging, this is an insufficient level of process control, leading to notable and expensive downgrading of heats.

Near the end of the oxygen blow, the sublance will perform an in-blow measurement. The results are collected and sent to the process control model which will determine and update the required amounts of oxygen to be blown and coolant to be added, to meet the steel carbon content and temperature end-point requirements of the steel.

At end-point, a second (end-blow) sublance measurement can be done to obtain a steel sample and measure bath temperature and free oxygen content to determine the final carbon content. The Danieli Corus process computer (DIRC) uses the sublance signals from this measurement to calculate the bath level. Thus a separate probe and measuring cycles for sampling and bath level are no longer required, avoiding loss of valuable production time.

At the end of the heat the sublance measurements will be used by both the static and dynamic parts of the process control model to fine-tune the model. This continuous fine-tuning will further increase the hit rate, meaning less downgrading of heats.

**MAXIMISING STEEL SHOP OUTPUT**

There are many reasons to maximise the output of a new or existing steel shop. No other combination than a process control model using process input data coming from a sublance system, can bring the steel shop capacity to its maximum output.

Because of better end-point control with a sublance, the main oxygen blow time can be reduced (by 8 mins) and the number of re-blows will be reduced because of the increased hit rate. In terms of the environment, reduced oxygen consumption means reduced energy use, while decreased tap-to-tap time means less waste gas production per tonne of steel.

In a steel shop with three 300t converters with an annual capacity of 6Mt/yr, a process control model based on a sublance system can increase capacity to 6.4Mt. This is reached by minimising the amount of re-blowing, avoiding intermediate process interruption and converter tilting for manual sampling and more heats per campaign.

For an existing steel shop, maximising output means that the fixed production cost can be divided over the maximum possible tonnage of produced steel. The average fixed cost price per tonne will be lowered by 7% and the variable cost by 0.3%.

For a greenfield BOF the benefit of maximising output can be used in two ways. Either the converter size can be tailored towards the required capacity by downsizing, or the converter size is kept constant giving the steel shop the possibility to handle more hot metal when it becomes available for steelmaking. If the downsizing option is chosen, a tremendous decrease in capital expenditure can be realised.

**RETURN ON INVESTMENT (ROI)**

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 bring additional costs, such as initial investment, maintenance and consumables. Based on BOF
Steelmaking and Casting

**Cost in...**

<table>
<thead>
<tr>
<th>Cost difference between scrap and HM/t</th>
<th>INR</th>
<th>Euro</th>
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</thead>
<tbody>
<tr>
<td>Oxygen cost/Nm³</td>
<td>1,500</td>
<td>20</td>
</tr>
<tr>
<td>Al cost /t</td>
<td>150,000</td>
<td>6,000</td>
</tr>
<tr>
<td>FeMn cost/ts</td>
<td>35,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Refractory cost/ts</td>
<td>35</td>
<td>1</td>
</tr>
<tr>
<td>Fixed costs for existing BOF equipment/ts</td>
<td>1,625</td>
<td>25</td>
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</tbody>
</table>

Table 1 Production cost indication used for ROI

**Fluxes to the converter per heat**

<table>
<thead>
<tr>
<th>Fluxes</th>
<th>Consumption per heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen, Nm³/t</td>
<td>49.8</td>
</tr>
<tr>
<td>Al, kg/t</td>
<td>2.24</td>
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<tr>
<td>Iron ore, kg/t</td>
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</tr>
<tr>
<td>FeMn, kg/t</td>
<td>14.5</td>
</tr>
<tr>
<td>Lime, kg/t</td>
<td>55</td>
</tr>
</tbody>
</table>

Table 2 Oxygen and addition consumption for BOF plant

Production data from the 80+ sublance systems around the world, Danieli Corus has developed a ROI model. For this, some assumptions have to be made with respect to fixed costs/ts. It is obvious that this must be adjusted for each individual steel plant, however the model has proven to be a good reflection of feasible ROI. The ROI calculation is based on certain assumptions, in order to make it compatible with the Indian market (see Tables 1 & 2).

Without operating a process control model based on a sublance system, an existing plant with three 300t converters and an average tap-to-tap time of 50mins should be able to produce around 6Mt/yr. With a sublance system the annual capacity will increase to 6.4Mt, which is the major contributor to ROI. This means that an additional 400,000t of steel can be produced at no additional fixed cost, saving almost 11million Euro, when a fixed cost of 25Euro/ t is taken for production without sublance.

On top of the saving, the 400,000t will bring additional profits via sales of finished product. If a very modest margin of 8Euro/ t is taken, sales show an additional profit of 3.3million Euro. Finally, reduced consumption of fluxes and refractory will save another 3.5million Euro.

Of course, the sublance system comes at a cost. Money must be invested and interest, depreciation, system maintenance and sublance probes must be paid for. As can be seen from Figure 4, the total cost during the first year of operation is just over 6million Euro, of which 4.2million is from the initial investment of the sublance system (without model).

With a depreciation time of five years, ROI adds up to a massive 89.5million Euro. From Figure 5 it can be seen that costs related to sublance investment and operation remain at a modest 14million Euro. This brings the ROI of the initial investment of 4.2million Euro for a sublance system (without process control model) to 542%.

**CONCLUSIONS**

A continuous increase in market demand for steel means more production capacity is necessary. At the same time environmental demands get stricter every day, putting pressure on current production methods.

In China more than 200Mt of steel is produced by 30 steel plants which operate a process control model based on sublance measurements. Their converter sizes vary from 120 to 300t. All benefit from the possibility of maximising steel output capacity, minimising consumption of fluxes and refractory and limiting waste gas production.

Capital investment of a sublance system has a realistic payback of only three months, and with an expected lifespan of 20-plus years will have a significant effect on performance for each BOF that operates such a system.

Walter Vortrefflich is with Danieli Corus BV, The Netherlands.

CONTACT: walter.vortrefflich@danieli-corus.com