Development of prediction models and their on-line applications with through process approach as support to maintain proper slag conditions for steelmaking management and slag valorization

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In modern steel productions, the necessity of a better knowledge and control of the process became more important in order to improve production performances, to maintain repeatability on the product quality and to support the necessary process flexibility due to frequent changes in production programs.
For this reason the capability to better understand the phenomena in the different process phases of the steelmaking process including scrap melting, steel treatments in ladle and solidification process in continuous casting is important to optimize operating practices. A through process view is necessary to respect the process/quality constrains aiming at improvement of performances and productivity.
Based on the off line approach also the on-line installation of mathematical simulators has been realized in order to gain on-line process monitoring, and real time digital twins to be used to support online decision support systems with a through process approach for whole steelmaking area.
In particular these systems can be used in order to generate capabilities to define new operating practices, to assess on-line guidelines for process corrections and making available alerts in case of deviations respect aimed conditions on slag properties necessary to have correct steelmaking process and for subsequent valorization.
Acciaierie di Calvisano and Feralpi Siderurgica strongly address its productions developments to improvement of production plants with adoption of new technologies and solutions Industry 4.0 for data analysis and process control also supported by RFCS funding scheme in the funding R&D projects.
With the contribution of the R&D department, process technology, production areas and research partners, in Feralpi predictive mathematical models have been created for production phases and whole steelmaking process.
This has been done internally in order to be able to better setup the optimal operating practices for each process phases as EAF, Ladle Furnace, and Continuous Casting also as a way to capitalize the knowledge and competences of steelmaking and metallurgy gained in process management

KEYWORDS: STEELMAKING. PROCESS, SIMULATION, ON-LINE CONTROL, EAF, LF SOLIDIFICATION

INTRODUCTION

For a steel production company as Feralpi the necessity to continuously improve the capability to manage the production process run in parallel with necessity to continuously develop production plants, internal management practices and skills.
The activity described is included in the RFCS funded project iSlag to gain support both from knowledge from other research partners and with economical support to

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the research realized.

In particular the activity is devoted to develop control strategies to combine both necessities:

- To enable optimal liquid steel treatment to support metallurgical process for final product
- To enable to maintain optimal slag condition for subsequent reuse avoiding improper conditions

The main principle driving this developments are:

- Necessity to support the Steelmaking treatments with knowledge about real status of slag conditions as parameter to evaluate the real effectiveness of the process targets
- To combine the evaluations about slag conditions as waste for their reuse with the steelmaking treatment necessary for steel production in a single evaluation making evidence to their interdependency
- The necessity to support the knowledge of the status of the process with mathematical modelling as necessary to predict the parameters describing phenomena occurring on the process when not measured.
- The necessity to maintain internally the know-how about mathematical modelling in order to gain deeper process knowledge and maintain capability of continuous applications functions and their use on the production practices.

Taking into account these development needs long time having as preconditions the development of internal skills and structures and the application both on conventional steel for civil construction and special steel for automotive.

DESCRIPTION

General approach / Scheme

Following the general scheme of the systems developed are described (Figure 1), in particular the main scope is to describe in a same view the 2 route of steel treatment in different positions of the ladle and for subsequent yard disposal.

In particular the steel tratment in ladle is followed along the production route from the EAF process including following steps :

- EAF scrap Charge
- EAF melting and refining process
- Steel taping in ladle and ladle positions
- LF treatment and additions
- Steel in tundish till casting

The evolution of steel conditions in different ladle positions are followed in order to estimate and detect the slag conditions during interaction with steel and the conditions when taken for yard disposal.

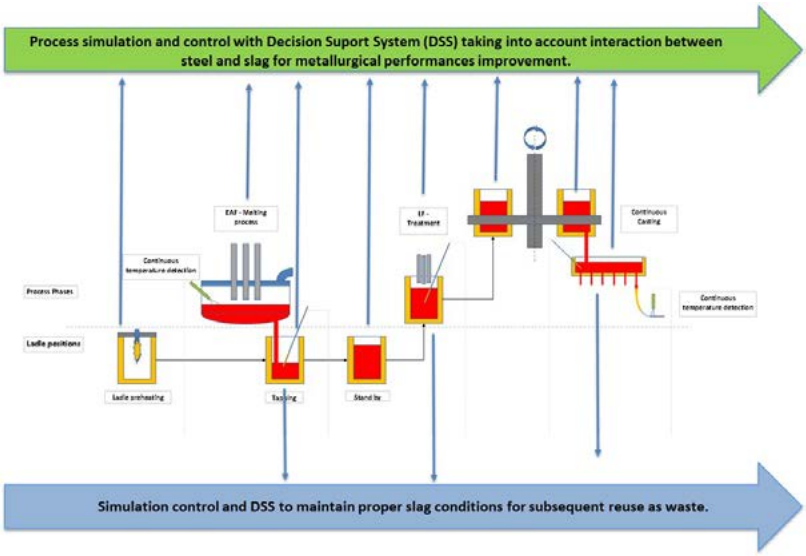

Fig.1 - General scheme of the parallel view of metallurgical treatment and slag conditions for reuse.

Off-Line modelling for prediction of EAF process

The application of mathematical simulation of the EAF and LF process have been started with Matlab/Simulink code as following described and the main input/output for EAF are described in table 1:

Tab.1 - Main input and output data for EAF Process simulator.

Input	Output
Scraps weight charged in basket	Steel/slags/Off Gas compositions
Dynamic electrical parameters adopted	Steel/Slag/Off Gas temperatures
Chemical injections O_2, Gas, C, CaO	Electrical/material consumptions, Power On, Losses

The input data about charge mix and operating practice adopted can be flexibly managed describing time evolution of practice in off-line mode as in figure 2 for Oxigen and gas Flow rates, Coal and Lime injected, electrical power input.

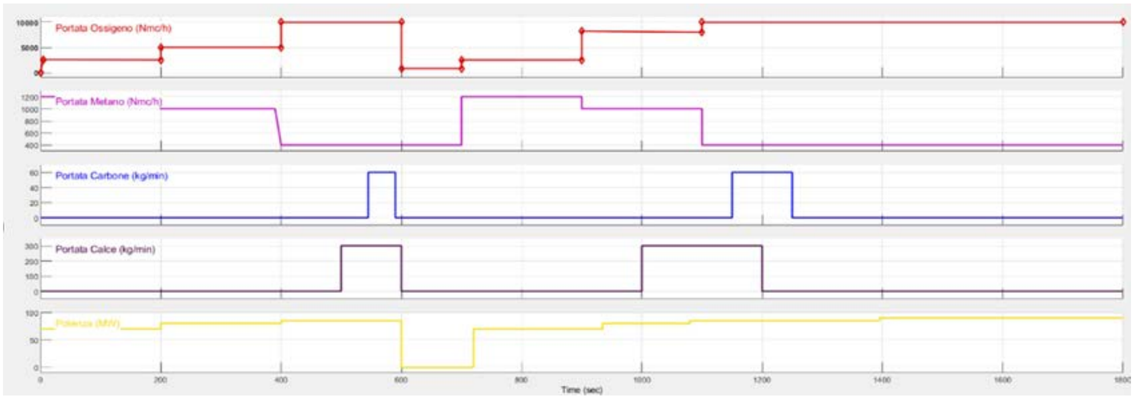

Fig.2 - Terms of the operating practice evolution described as input.

Looking at output data the evolution of the consumption of the different sources (electrical, Oxygen, Gas and solid materials) can be estimated dynamically and time dependent till to determine the EAF process performances obtained at the end of the process (Figure 3).

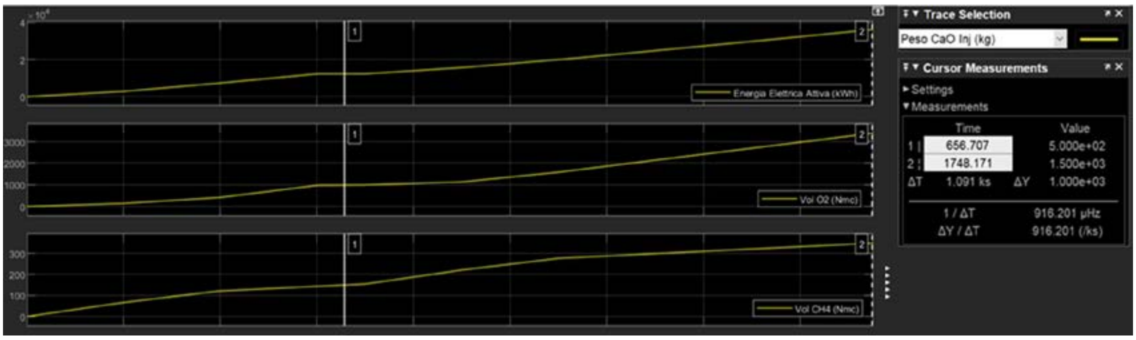

Fig.3 - Simulation results in terms of electrical and main chemical consumptions.

Final results in terms of Steel and slag masses formed, their compositions and temperature is also estimated dynamically showing their evolution during the process (Figure 4).

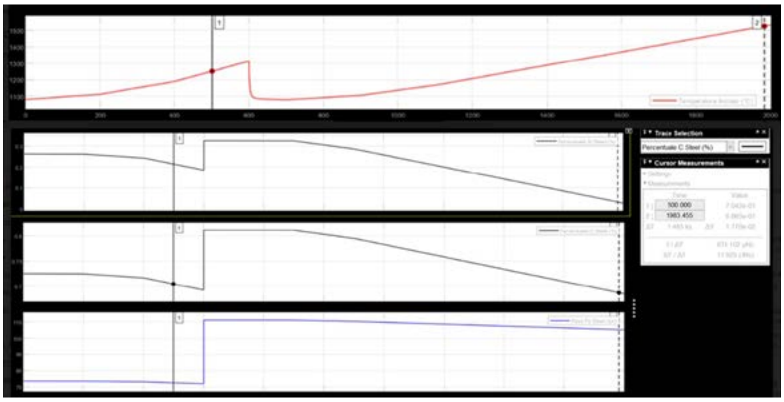

Fig.4 - Simulation heat results in terms of steel temperatures and compositions evolutions.

Thanks to this system the prediction of final results and performances of EAF process can be predicted taking into account the charge mix and operating practice adopted in order to evaluate efectivene of operating practice setting choices.

This approach is presently used to evaluate comparison between effectiveness of different practices and as base to optimization of the on-line EAFProcess control system that is based on EAF process simulation and for this reason external off-line calibration of calculation is needed.

Off-Line modelling for prediction of LF treatment

The simulator is focusing on the treatment of the secondary metallurgy of the steel, staring from tapping in EAF and finish in tundish of continuous casting.

The practical use of the simulator is to find out the best operative practice to treat the steel in terms of time of treatment and the optimal amount of ferro-alloys to add to steel.

In this way, thanks to the software is possible to have an improved view of the process and act on different input data, is possible to have different operative practice to treat the steel.

Model Architecture

The main input data for liquid steel treatment include (Figure 5) condition of steel coming from EAF Tapping, Tapping and ladle additions, dynamical input as ferroalloy additions, electrical power used and stirring gases adopted. The model is able to simulate the treatment of secondary metallurgy over time in particular to obtain:

1. Estimation of the temperature trend over time
2. Estimation of the trend over time of the level of Sulfur (Desulphurization Process)
3. Estimation of the trend over time of the oxygen level (Deoxidation Process)
4. Estimation of the trend over time of the main elements of steel
5. Estimation of the trend over time of the main elements of the slag

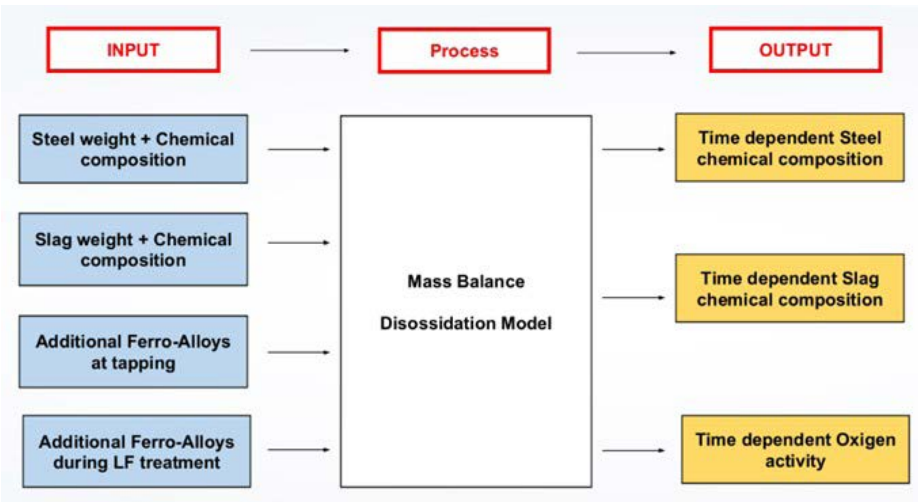

Fig.5 - General architecture of LF process simulatore and input / output data adopted.

As it is said above the model takes into account different input to obtain a real representation of the steel treatment. It's important to say that those data are time-dipendent data.
In fact, the only way to obtain a process based on kinetics of the reaction is to have a time – depenedent data input that reflect the steel plant treatment.
The input data are described dynamically in order to enable a time dependent prediction (Figure 6).

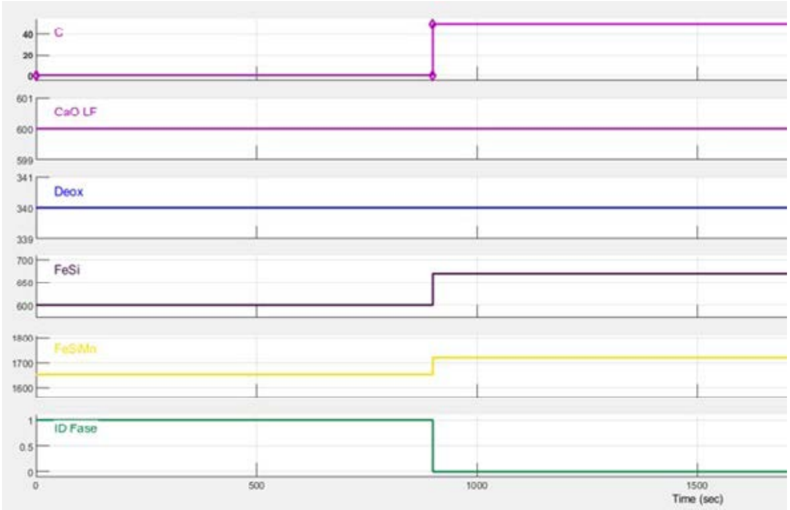

Fig.6 - View of dynamic input data adopted in LF simulator.

Oxygen balance
The simulation model also includes as example the calculation of the oxygen balance. This calculation requires that at each iterations the oxygen level is updated by subtracting the oxygen reacted with the deoxidizing elements. This calculation is carried out by considering: Si, Mn and Al.

$$O_i = O_{i-1} - \Delta O(Si)_i - \Delta O(Mn)_i - \Delta O(Al)_i$$
$$\Delta O(Si) = \frac{(\%Si)}{[\%SiO_2]} * (\%O) * K_{emp\_Si} \qquad \text{For Si, Mn, Al} \qquad [Eq.1]$$

The graph below shows oxygen activity in steel bath during ladle treatment, starting from tapping.

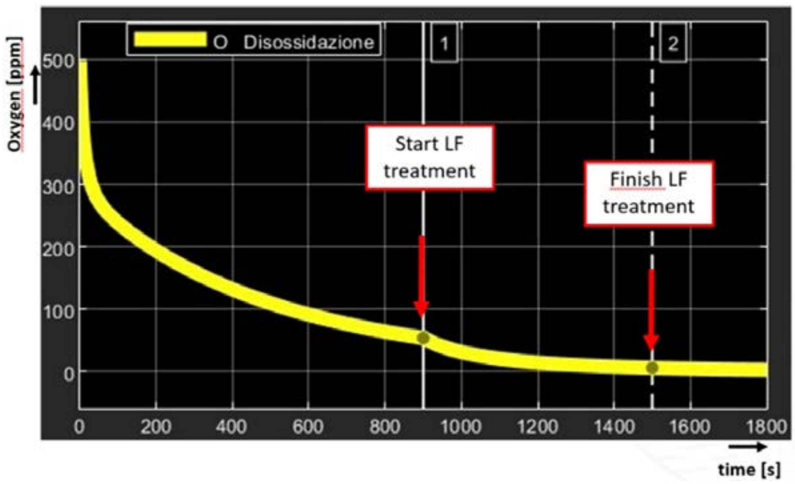

Fig.7 - Off –line oxygen activity estimation during ladle treatment since EAF tapping till tundish.

Following the curves of estimation of different steel temperature along the steel treatments in ladels are shown In particular also comparison with real steel temperature detection is reported in order to evaluate and improve estimation of steel temperature

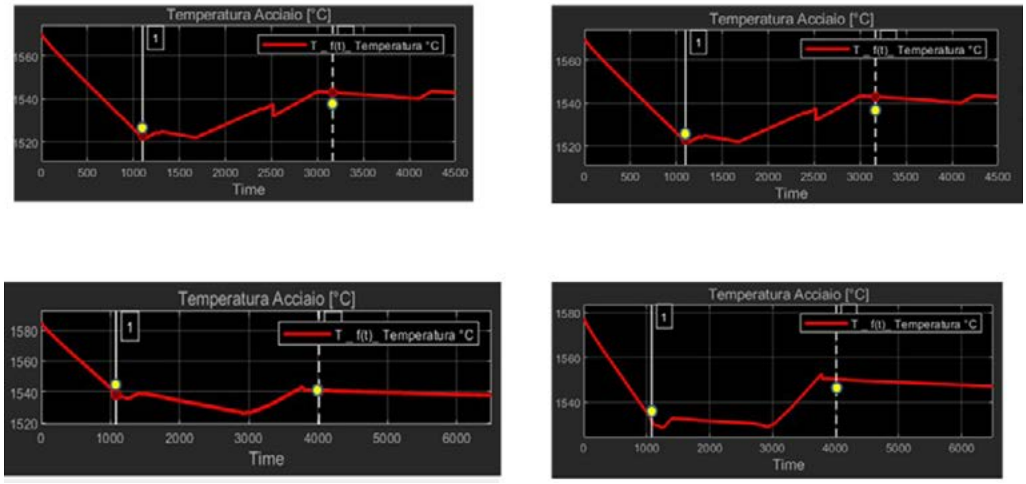

Fig.8 - Exemplary curves of prediction of EAF performances.

Tuning of the LF simulator and sesitivity analysis has been ealize in order to evaluate and improve continuously its accuracy in determination Steel and slag composition in LF exit (Figure 9, 10) and to evaluate the effectiveness on prediction of results for tratment management variations.

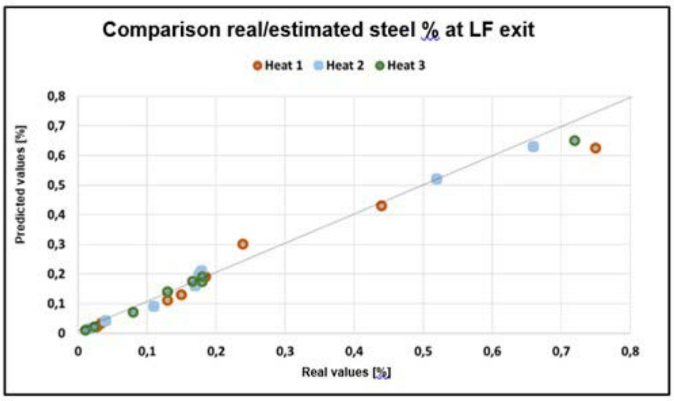

Fig.9 - Comparison of estimations and samplings for steel composition.

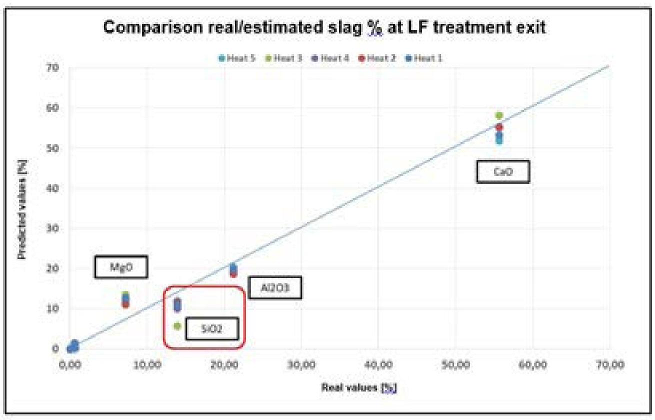

Fig.10 - Comparison of estimations and samplings for slag composition.

On-line simulation for process control

The on-line application of the system is aimed to reach the scheme described (Figure 11).

In particular following main items are aimed to be included:

- Process data acquired in real time from EAF and LF process
- Data from ladle position are acquired to couple steel slag conditions with their position
- Data acquisition from specific sensor for:
  - Slag foaming detection from acoustic signal
  - Detection of carryover of slag during EAF tapping
  - Real time steel temperature detection in tundish
- Module 1 of Mass and energy balance to predict steel and slag conditions
- Module 2 – For use of thermodynamic analysis of steel and slag interaction as support to adapt steel and slag conditions under thermodynamic laws.
- Module 3 – For online Decision Support System for both EAF and LF process adaptation s and additions.

Whole this system is applied ladle by ladle in order to combine a full monitoring of EAF and LF process and along the process route to estimate all condition of steel and slag in terms of masses, compositions, temperatures.

At the moment whole this scheme has to be completed while part of it is yet on-line available.

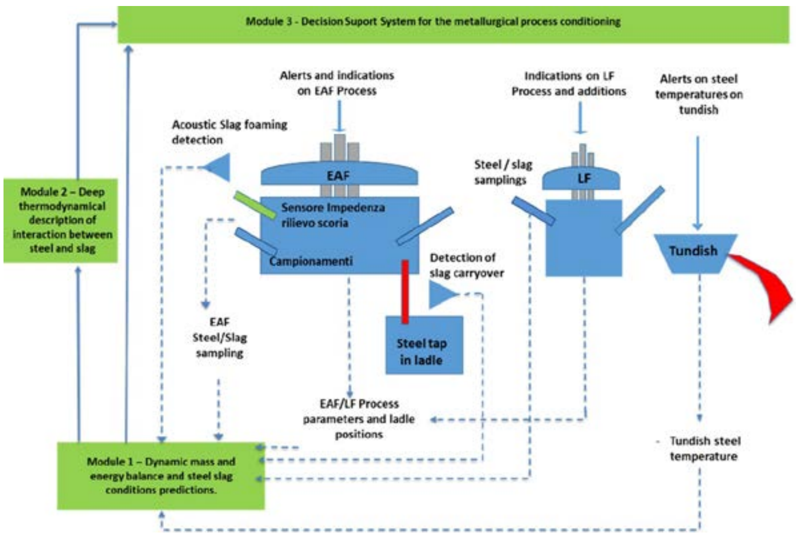

Fig.11 - Comparison of estimations and samplings for slag composition.

For EAF Process Feralpi the on-line system EAFPro developed with Rina CSM has been implemented in both steelmaking plants of Feralpi Siderurgica and Acciaierie di Calvisano.

The EAFPro system is able to follow on-line the EAF process in order to:

- Collect all data of the EAF
- simulate process conditions
- give indication as support to process control
- Summarize process relevant KPI's

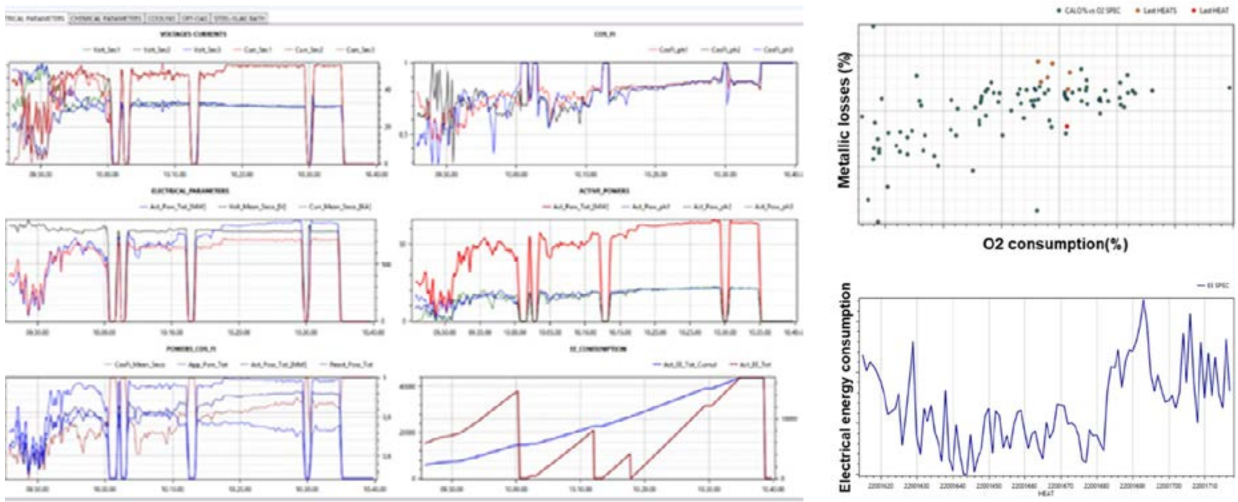

Fig.12 - Main view on-line available for monitoring of EAF process and heat summary results.

Result of dynamic mass and energy balance in EAF:

- Steel and slag masses
- Evolution of %C and steel composition during the process
- Steel temperature evolution

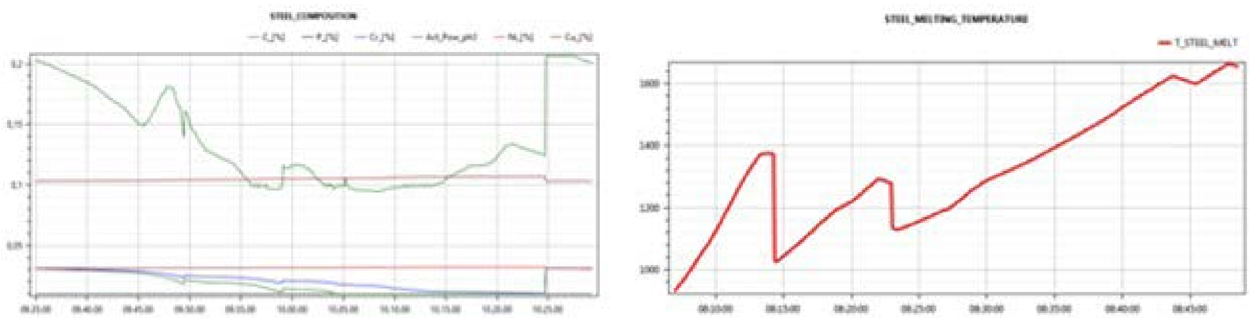

Fig.13 - Steel composition and temperature on-line by dynamic mass and energy balance.

<u>On-line simulation application for LF process</u>

The on-line ladle treatment is followed ladle by ladle and represented in site views.

In particular following steel temperature are estimated depending by steel treatment followed including: treatment time, ladle position, electrical energy provided, stirring gas activation, ladle additions real temperature detection.

In this way the main functions on-line available are:

- Temperature estimation on-line for each ladle
- Auto tuning depending by real temperature samplings
- Prediction of temperature estimated at ladle arrival to further process phases
- Alerts function in case of abnormal temperature predicted

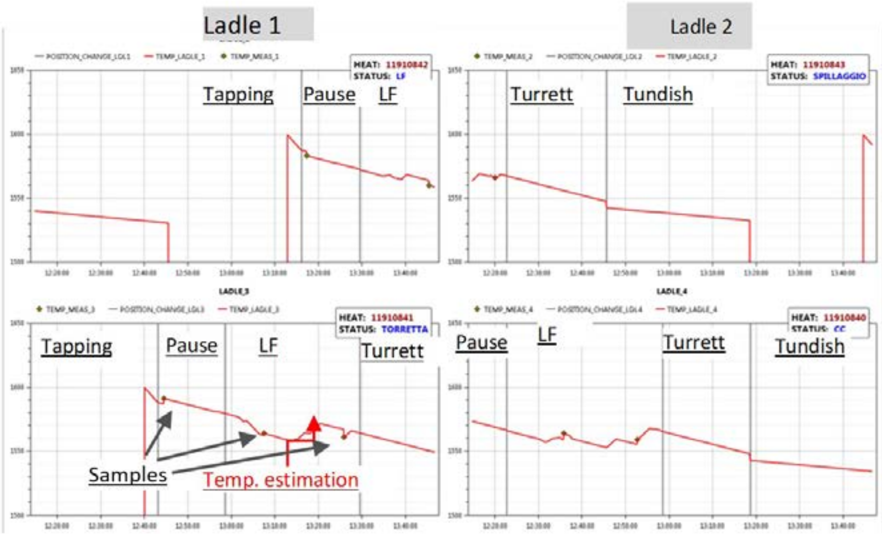

Fig.14 - Page views of temperature estimation on-line for different ladles.

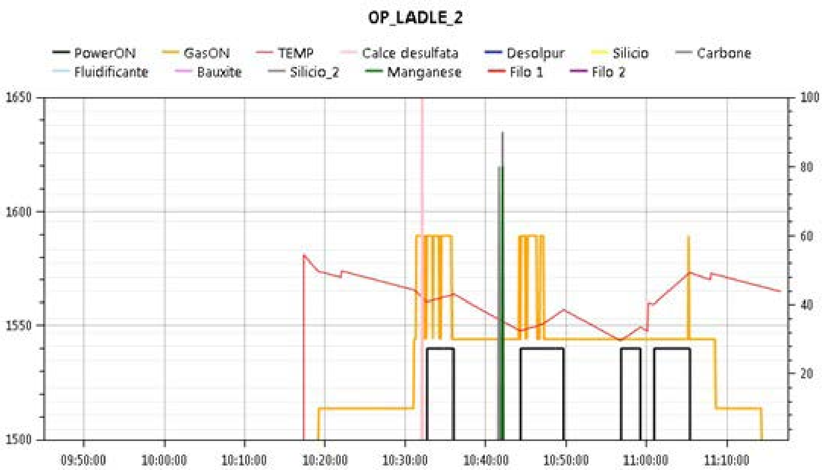

Fig.15 - Page views of On – line monitoring of LF practices adopted for each ladle.

Following some view of temperature accuracy estimation for each ladle in inlet to LF and in outlet to LF

Tab.2 - Summary view of EAFPRo accuracy in steel temperature in Ladle determination .

	AVG Err.	Dev STD Err.	% Err <10°C	% Case Out of tolerance
	°C	°C	%	%
I T in LF	8.5	4.9	60	57
Last T in Lf	8.5	7.5	67	23

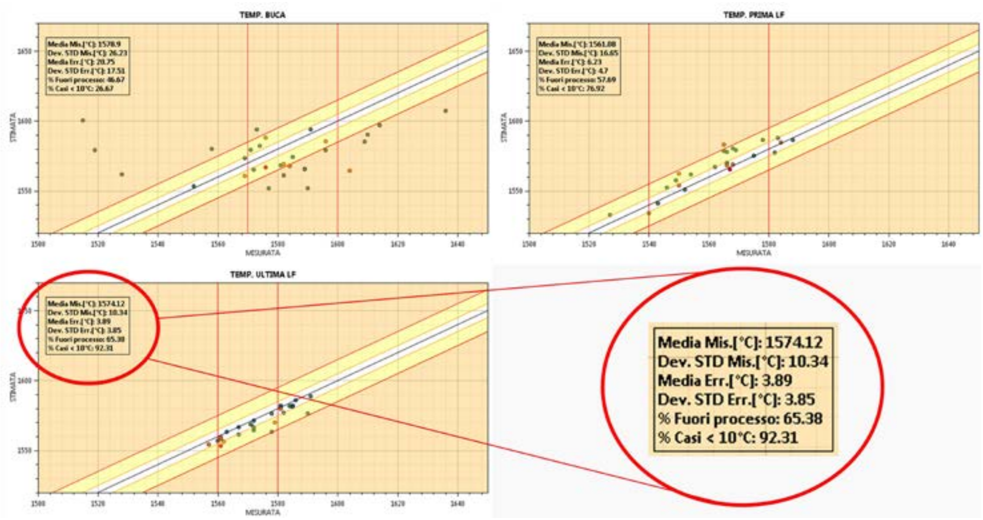

Fig.16 - On-line accuracy monitoring of steel temperature estimation for different positions.

Based on steel temperature predicted alert functions are active to support the operators to evaluate if uncorrect steel temperatures are coming for subsequent process steps in LF from EAF and in continuous casting from LF (Figure 16)
In particular depending by actual temperature estimated and production cicle conditions are predicted:

- Time remining to reach the next process step (to LF from EAF, To CC from LF)
- Temperature predicted of arrival to next process step (To LF, To CC)
- Indications in terms of alerts for abnormal temperature or heating necessity are shown

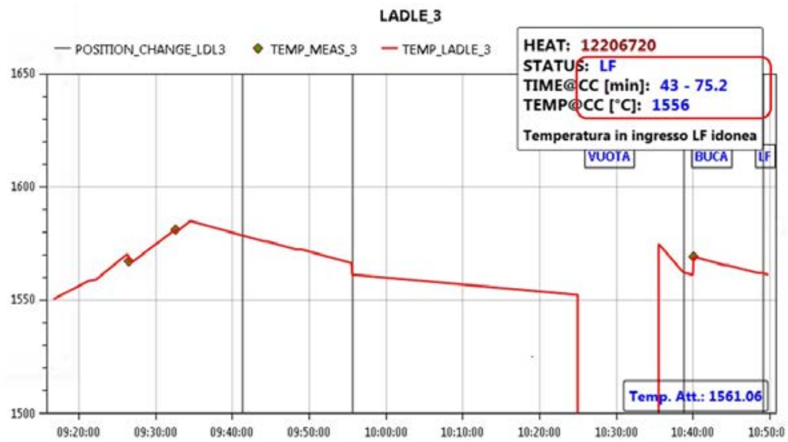

Fig.17 - Steel temperature prediction for next process steps and alerts available on-line.

CONCLUSIONS

The status of process study and meathematical representation in EAF and LF process prediction became now a relevant task in Feralpi and this enable the Feralpi technical group to support internal automation developer and as in this case also external software developers as Rina CSM expert in on-line control rules and mathematical codes implementation.

This is a first step for EAF and LF process on-line representation and will be the basis for future completion and application for time by time deeper support in process development.

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Da completare

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