Seminar: EAF sensors and measurement techniques
Use of sensors for EAF online process control

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Overview on sensor use for EAF online process control

- Sensors and measurement techniques provide important online information on
  - the actual properties of the EAF charge materials
  - the current process state during EAF melting and refining

- For use of the provided information for online process control, the sensor signals and measurement data
  - have to be made available and integrated in process control systems
  - can be used as additional input data for process models applied for online monitoring and control
Examples of sensor use for EAF online process control

- Optimal selection of charge materials and time of charging
- Control of energy input during scrap melting
- Control of oxygen input for post-combustion purposes based on EAF off-gas analysis
- Detection of foamy slag and control of carbon injection during refining
- End point control of EAF process
Determination of scrap properties based on statistical models: Example Cu content

Input data:
- Weights of charged scrap types
- Tap weight
- Steel analysis from a sample taken before EAF tapping
- Influence of hot heel is taken into account with the analysis of the previous heat

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Continuous tracking of scrap properties
Example: Cu content of selected scrap types

Tracking of the Cu content for E5M (turnings) over a period of 9 months
**Inline elemental characterisation of charged scrap**

- Laser-induced breakdown spectroscopy (LIBS) can in principle be used to analyse composition of scrap types.
- Only the surface of a scrap layer can be analysed.
- More than a scrap sample can only be analysed during charging by conveyor like in a Consteel furnace.
- Application of this technology in two RFCS projects: LCS and IPRO.

![Diagram showing scrap charging area, pendulum conveyor, and EAF with laser analyser.](image)

![Graph showing Si mass fraction by LIBS, moving average of 200 values C fraction with high Si scrap added (heat 1452).](image)

*LCS measurement campaign at ORI Martin*
Hot heel level assessment with dip sensors and camera systems

Steel bath level measurement with dip sensor
- Probe mounted on lance manipulator

Liquid bath level has to be converted into amount of hot heel, e.g. by using information on furnace hearth refractory wear status

Monitoring of the liquid bath level after tapping of the furnace with opened furnace roof
- Several cameras from different angles of view
- Subsequent image analysis
Scrap mix optimisation

- Cost optimal scrap mix is calculated for different steel qualities with defined target tap analysis.
- Optimal Scrap mix and allocation into the two baskets is suggested.
- Expected steel analysis at tapping is compared to target analysis.
Monitoring of scrap basket loading

- Footbridge for sensors
- Scrap loading crane
- Railway wagons for scrap supply
- Scrap Charging Hall at the ARES – Schifflange Steelplant
- Sensor scanning the round basket
- Scrap basket train
Scrap basket filling level assessment with line scanner and imaging system

- Basket filling degree can be assessed
- Scrap volume can be determined
- Average effective density of every scrap type can be calculated
- More reliable determination of the optimal charging point for the 2nd scrap basket
- Information on density important for distribution of optimal scrap mix to two baskets

Imaging system or line scanner to monitor the topology of the scrap surface in the basket

Also possible for every scrap layer when performed during basket loading
Dynamic energy and mass balance model for the EAF process

- The energy and mass balance of the EAF comprises a large number of energy and material inputs and losses.
- For optimisation of the energy and resource efficiency of the EAF process, a continuous and as far as possible complete data acquisition and on-line dynamic modeling is required.

→ Development of dynamic energy and mass balance models:
- for on-line observation and validation of the energetic EAF performance
- for online calculation of the actual melt temperature and chemical composition, especially the carbon and oxygen content
- for a precise determination of the process end-point
- for model-based process control, e.g. regarding the chemical energy inputs
On-line energy and mass balance for observation of the EAF process state with respect to melt temperature and composition (mainly Carbon and Oxygen content)
Close the energy balance with off-gas measurement

- Continuous off-gas sampling at the roof elbow
- Off-gas analysis by a mass spectrometer (all relevant off-gas components are assessable)
- Determination of the off-gas and leakage air flow rate by argon and nitrogen balances
- Off-gas temperature measurement by a pyrometer
- Calculation of the off-gas losses
  - Sensible heat losses via flow rate and temperature
  - Chemical energy via flow rate and CO- / H₂-content
Input data of the energy balance for an example heat

- **Energy inputs**
  - Electrical energy
  - Gas burners
  - Oxygen injection via jets and door lances
  - Oxygen for post-combustion of CO inside the furnace

- **Energy losses**
  - Sensible heat and chemical energy content of the off-gas
  - Cooling water losses of furnace walls and roof
  - Radiation and convection
Temperature calculation for an example heat

- Continuous real-time calculation of the melt temperature and comparison with temperature measurements
- Adaptation to the first plausible temperature measurement increases the accuracy of the model for the further treatment
- Meltdown degree is calculated from the current energy content of the melt related to the meltdown energy requirement of the charged materials
  - Optimal time to charge the next scrap basket can be derived
Example for on-line implementation of the dynamic process model for temperature calculation
Model accuracy regarding the calculation of the melt temperature

- Standard deviation of the model error for the first temperature measurement is about 25 K (blue)
- After adaptation to the first measurement the model error for further measurements is decreased to ca. 21 K (red)
- Error of the energy balance is about 7 kWh/t
- For a total energy input of about 690 kWh/t this means a relative error of the energy balance of about 1 %
- On-line calculation of the melt temperature allows a more accurate adjustment of the aim tapping temperature
- Over-heating of the melt can be avoided
Continuous Temperature measurement at the Electric Arc Furnace

Contactless optical system inside burner

- Optical sensor inside a coherent jet burner
- For measurement the slag pushed aside by a coherent inert gas stream
- Fast and safe quasi-continuous measurement with no significant needs of consumables
- Accuracy deteriorated due to uncertain emissivity of steel bath surface

Fibre optics based system

- Optical fibre immersed into the melt (independent of emissivity)
- Real continuous measurement over several minutes possible
- Consumables (optical fibre, lance tip) needed
- Accuracy comparable to conventional dip measurement
Fibre-optical continuous temperature measurement (BFI DynTemp®) using
- Lance
- Bottom nozzle
- Monitor continuously the liquid steel temperature during the refining phase
- Determine process conditions to perform representative measurements in dynamic inhomogeneous melts
- Develop enhanced dynamic process control based on novel measurements
- Develop strategies and model-based set point calculations for exact determination of control parameters for accurate EAF end point control
Process control - Scrap charging

- Combination of process model and scrap monitoring system:
- Optimisation of the moment at which the second basket is charged by correspondence between free volume inside the EAF and the basket filling degree

Layering of different scrap types in the scrap basket

EAF discretisation in different zones

Mass and thermal balance (temperature, composition, weight) for different phases
Dynamic model and offgas analysis for control of chemical energy inputs at the EAF

- Application of the dynamic model for process control
- Optimisation and control of chemical energy inputs for e.g. post-combustion based on the continuous off-gas analysis
Control of oxygen supply for CO post combustion inside the furnace

Closed-loop control

Offgas composition
CO, CO₂, O₂, H₂

Offgas analysis with mass spectrometer or other equipment

Oxygen supply for post combustion with sufficient CO amount in the offgas

Offgas sampling at the elbow

Dedicated injectors for well distributed oxygen supply

EAF

20 sec.

Offgas composition
CO, CO₂, O₂, H₂

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Dedicated injectors for well distributed oxygen supply

EAF
Control of the post-combustion reaction in the EAF based on off-gas analysis

- Development and implementation of an automatic control for the input of post-combustion oxygen based on the off-gas analysis

- The total oxygen consumption remains more or less constant

- The more efficient input of post-combustion oxygen leads to an energetic benefit of about 20 kWh/t
In-situ off-gas measurement

- Laser based, nearly delay-free in-situ off-gas analysis installed in the elbow of the furnace
- Analysis of CO, O₂ and CO₂ possible
- Additionally measured temperature is not representative for the off-gas temperature
- For measurement of CO₂ in addition to CO a separate laser is required
Dynamic control of post-combustion oxygen supply based on off-gas analysis

Linear proportional control strategy of post combustion oxygen input depending on offgas CO / O₂ ratio

- Required oxygen input for post combustion strongly varies from heat to heat
- Efficiency of post combustion oxygen is increased by dynamic control
- Slightly reduced electrical energy consumption with less oxygen consumption
  - Net energy saving of about 8 kWh/t
- No negative impact on metallic yield

- PC-Injector [Nm³/h]
- CO₂-Laser
- O₂ [%]
- CO [%]
- Power-on door lance criteria [Nm³/h]
- PC-Injector [Nm³/h]

Minutes

Oxygen post-combustion PC1 [Nm³/h]
Infrared camera to monitor the scrap meltdown behaviour

- Infrared camera mounted inside a side wall burner for observing the process inside an EAF operating with closed slag door.

- Recordings can provide new insights into the EAF melting process:
  - the melting characteristics of different size scrap pieces; scrap-drop events; scrap melting completion
  - time; thermal contours after end-of-arcing; the extent and duration of slag foaming;
  - views of operations inside the furnace to provide the operator with improved control of the process.
Distance sensor for burner and injector control

- "Distance-to-scrap" measurement at burner tip to monitor the melting of scrap in front of each injector
- Set-up of an individual and automated control of each injector for:
  - Controlling power increase during the starting phase
  - Switching off each burner when efficiency decreases (no more scrap)
  - Moving from burner to lancing mode
  - Alarming the operators in blow-back hazard situation
Arc brightness detection with optical devices

- Optical sensors can measure the UV light radiation emitted from the electric arc
- Control of electrical parameters (step down of voltage tap) to protect the water-cooled panels from over-heating by unshielded arc
Foamy slag detection by EAF noise and arc harmonics analysis

- The noise level produced by the furnace strongly depends on the process status and on the slag level mainly present during the refining phase.

- When the foamy slag has reached a certain optimum level above the bath, its good acoustical insulation properties let the external noise drop down to levels of 60~70 dBA.

- A signal for the detection of slag foaming can be derived from the fluctuation of electrical variables, i.e. the harmonics in currents and voltages.
Foamy slag detection by vibration and sound sensors

- The evaluation of structure-borne sound emissions in EAFs yields essential information about
  - foaming slag behavior,
  - scrap shielding of the arcs
  - condition of scrap bulk

- The different foamy slag detection signals are used to control carbon injection, for achieving and maintaining a good foamy slag throughout the refining phase

- Improves the efficiency of the electrical energy input

Source: Results of foaming slag and scrap meltdown control SIMELT CSM/FSM based on structure-borne sound in Electric Arc Furnace operation, AISTech 2012
Conclusions

- Sensors and measurement techniques can provide important online information on EAF charge and process state during EAF melting and refining.

- In combination with process models for set-point calculation they allow a dynamic control of the EAF process with respect to:
  - Material input: Charge materials, carbon injection
  - Energy input: Electrical and chemical
  - End point control

- A heat individual dynamic control for an energy and resource efficient operation of the EAF is only possible with online application of sensors and measurement techniques.
Thank you very much for your attention!

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