DissTec

Valorisation and dissemination of technologies for measurement, modelling and control in secondary metallurgy

Measurement Techniques for Secondary Metallurgy

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SecMet Measurement Techniques at BFI

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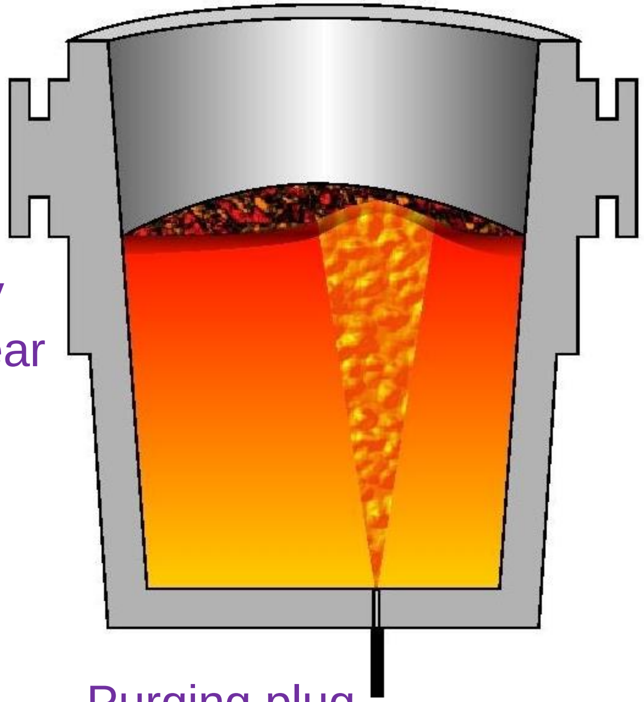
Online measurement of parameters monitoring the actual state of product, process and aggregate.

Stirring efficiency, Open eye, Deslagging



Ladle refractory temperature/wear

Purging plug wear, performance

Content:

- Ladle refractory temperature/wear
- Purging plug wear
- Purging plug performance
- Stirring efficiency
- Deslagging
- Steel melt temperature Presentation Minkon

SecMet Measurement Technologies - Topics

- **Thermocouples** and **surface acoustic wave (SAW) sensors**
  - also in combination with FEM simulation –
  are used for monitoring of the status of aggregates like
  - Ladle thermal state
  - Ladle lifetime/ refractory wear
  - Plug wear and performance
- **Cameras** in the infrared and visual spectral range
  - in combination with automatic image analysis -
  are used for online monitoring of the status of the process like
  - Stirring, Refining
  - Deslagging

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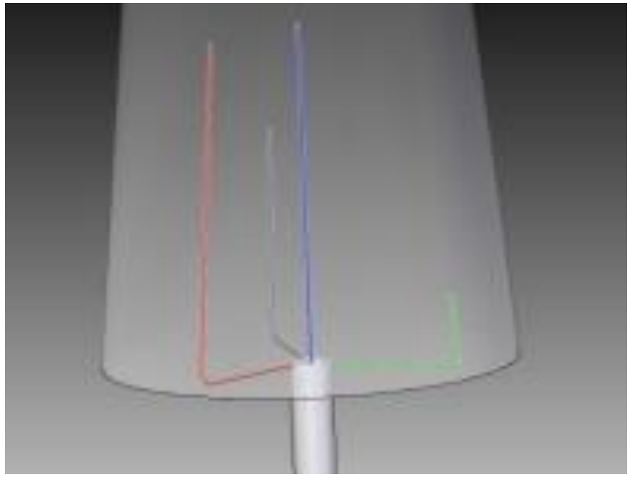
Temperature measurements – Basic principles

- **Thermocouples** for refractory and stirring plug temperature monitoring
  - Thermocouples are standard electric sensors made of two metallic wires of different chemical compositions which produce a voltage depending of the temperature at the junction.
  - Thermocouples were installed within the ladle refractory or the stirring plug to monitor the temperature at the sensor tip.



Temperature measurements – Basic principles

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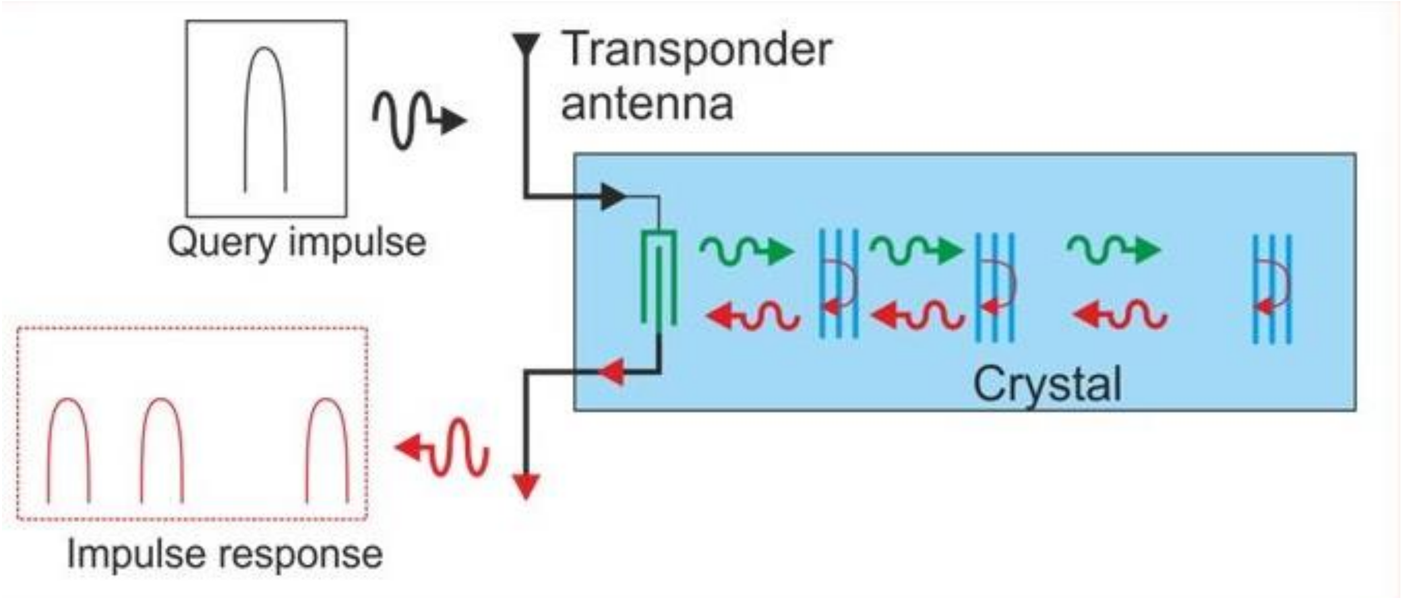
- **SAW sensors** for refractory temperature monitoring
  - A SAW sensor is a passive ceramic sensor which can withstand 400°C
  - An antenna sends an electromagnetic pulse,
    at the ceramic sensor the received pulse is converted into a surface acoustic wave (SAW)
  - The echo contains information of the tag temperature.



Ladle thermal state

Objectives:

- Monitoring the thermal state of steelmaking ladles during secondary steelmaking operations.
- Knowledge of actual thermal status of ladle are used to improve existing liquid steel temperature models.
- Optimising the use of the thermal energy stored in ladle lining in order to
  - Decrease tapping temperature
  - Reduce ladle reheating durations
  - Better match the target casting temperature

Ways and means:

- Continuous measurement of ladle lining temperature via wireless SAW sensor or thermographic/pyrometric sensors
- Calculation of the actual total ladle heat content Q that is stored in the ladle lining using thermal models
- Introduction of Q as a new input parameter for ladle thermal state monitoring systems, steel temperature prediction models and advisory systems for best ladle practices

Ladle thermal state

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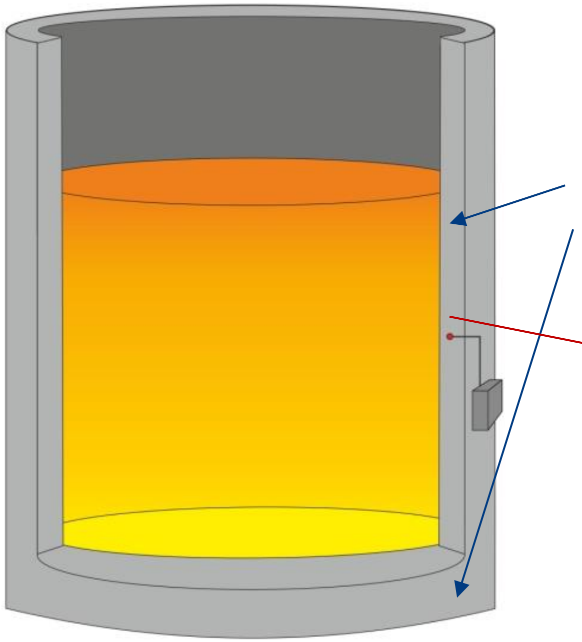
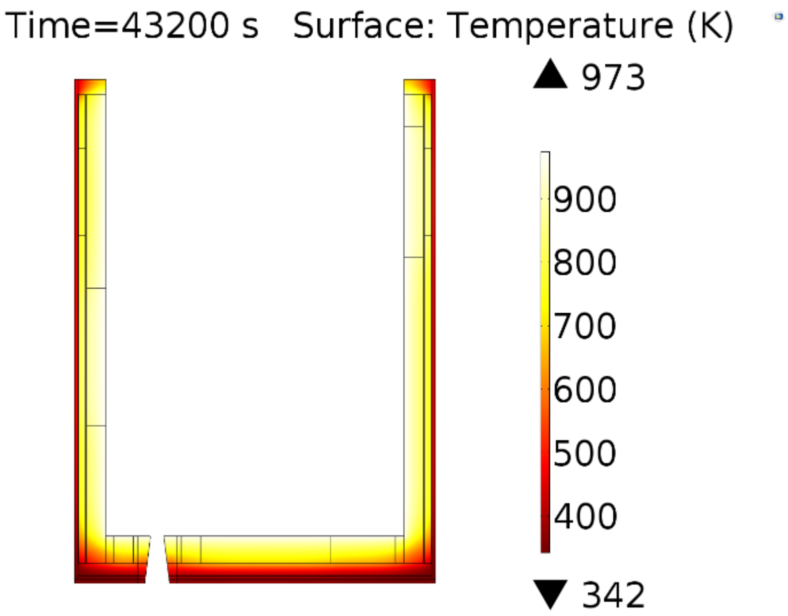
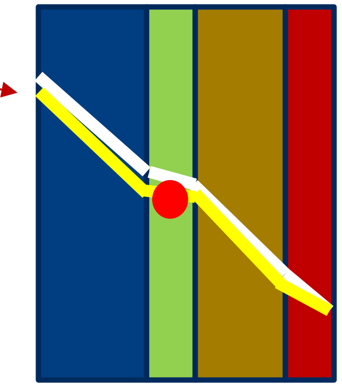
- Temperature measurement in ladle lining using thermocouples
- FEM model used to define optimum position for sensor
- Online model is adapted during steelmaking process using measured temperatures





Two steps:

1. Use the above relationships to make correction at the same $R_{measure}$. Make correction similarly for bottom
2. Recalculate the T through the thickness



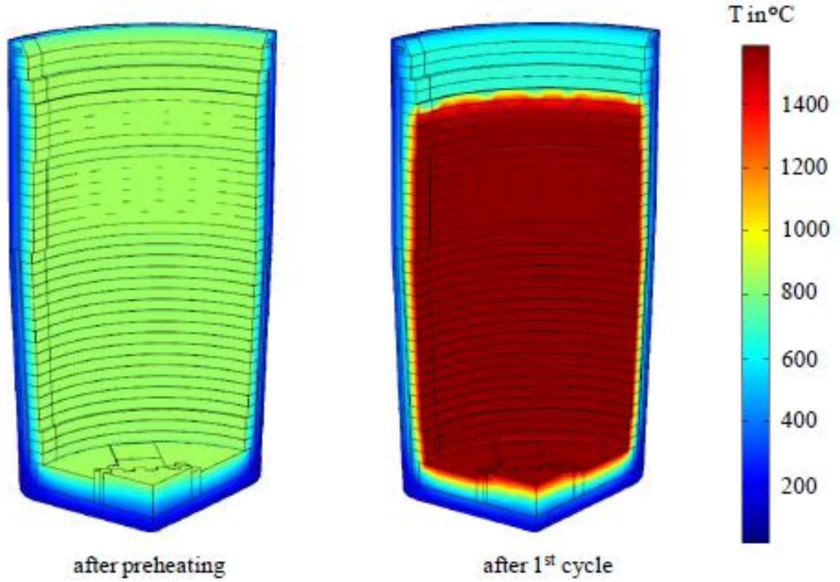
Ladle refractory wear

Main objectives:

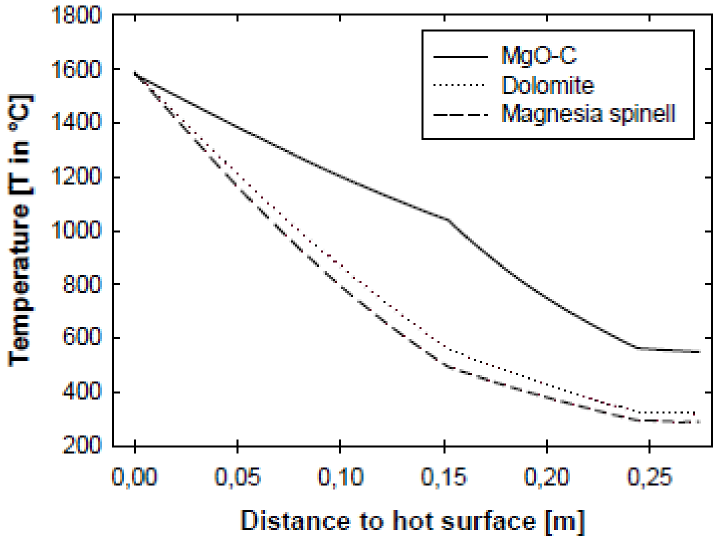
- Prolongation of the working life duration of ladle refractory lining
- Simulation of thermal, physical and chemical stress on refractory taking into account abrasion, thermo-mechanical wear, corrosion
- Determination and application of process rules and optimum materials for operation

Ways and means:

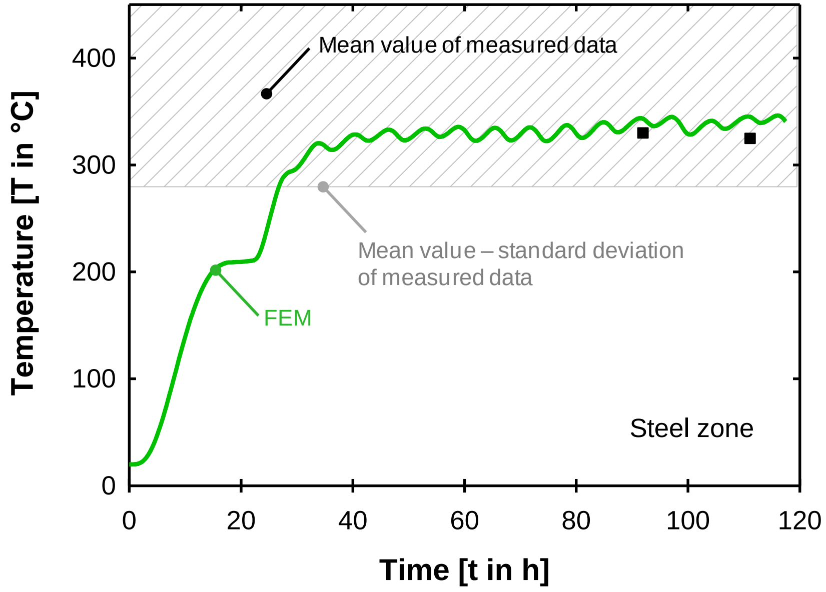
- FEM simulation of the temperature and stress distribution in the ladle refractory to deduce the mechanical stress caused by thermal expansion
- Adaption of models to measured values
- Comparison of process data
- Laboratory experiments on chemical erosion



- Different materials simulated
- Temperature and stress distribution calculated for three ladles by FEM simulation
- Different ladle geometries and refractories, and process configurations simulated
- Most conclusions were supported by data (temperature measurements) and experiences (thermal steady state)



Temperature over ladle wall with different working lining materials



Comparison of outer steel shell temperature calculated from FEM simulation to measured data at steel

Stirring plug wear

Objectives:

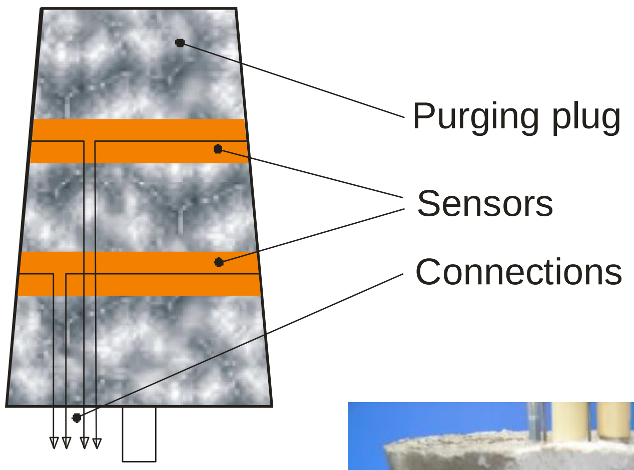
- Improve the selection and management of stirring plugs
  in order to enhance their performances
- Investigate and characterize thermo-mechanical and thermo-chemical phenomena
  that govern the degradation and wear of the stirring plugs during ladle operations

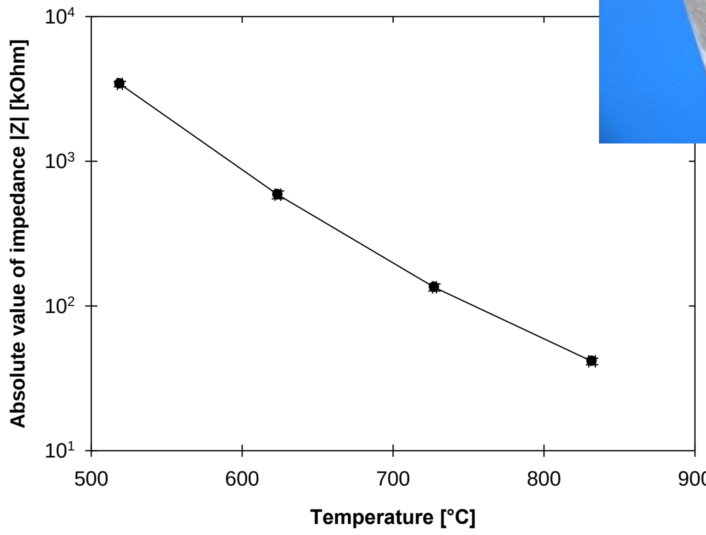
Ways and means:

- Development of a measurement system
  for on-line determination of the stirring plug wear status
  by measuring temperature along the plug

Stirring plug wear

- Wear measurement strategy was based on the temperature increase inside of stirring plugs with proceeding wear during their lifetime
- Temperature-dependant behaviour of the electric resistivity of a ceramic matrix in the sensors was determined
- Measurement system consisted of
  - sensors to be mounted at the stirring plug, and
  - an electronic evaluation unit
- Sensors worked reliably and reproducible up to 800 °C.



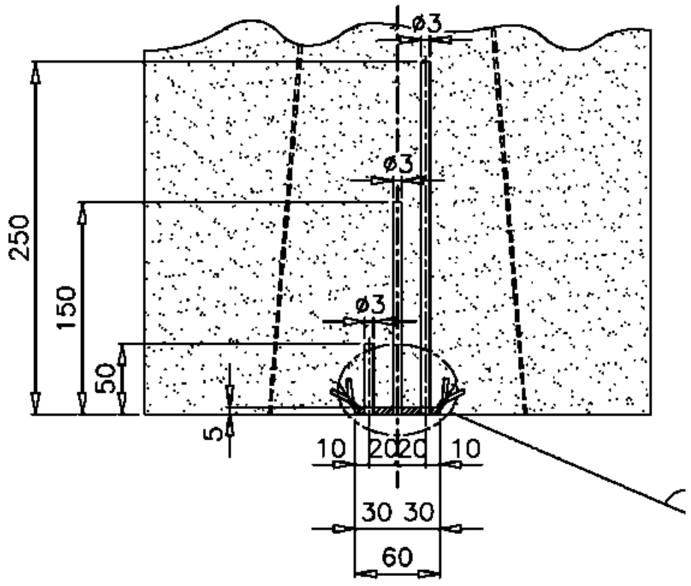


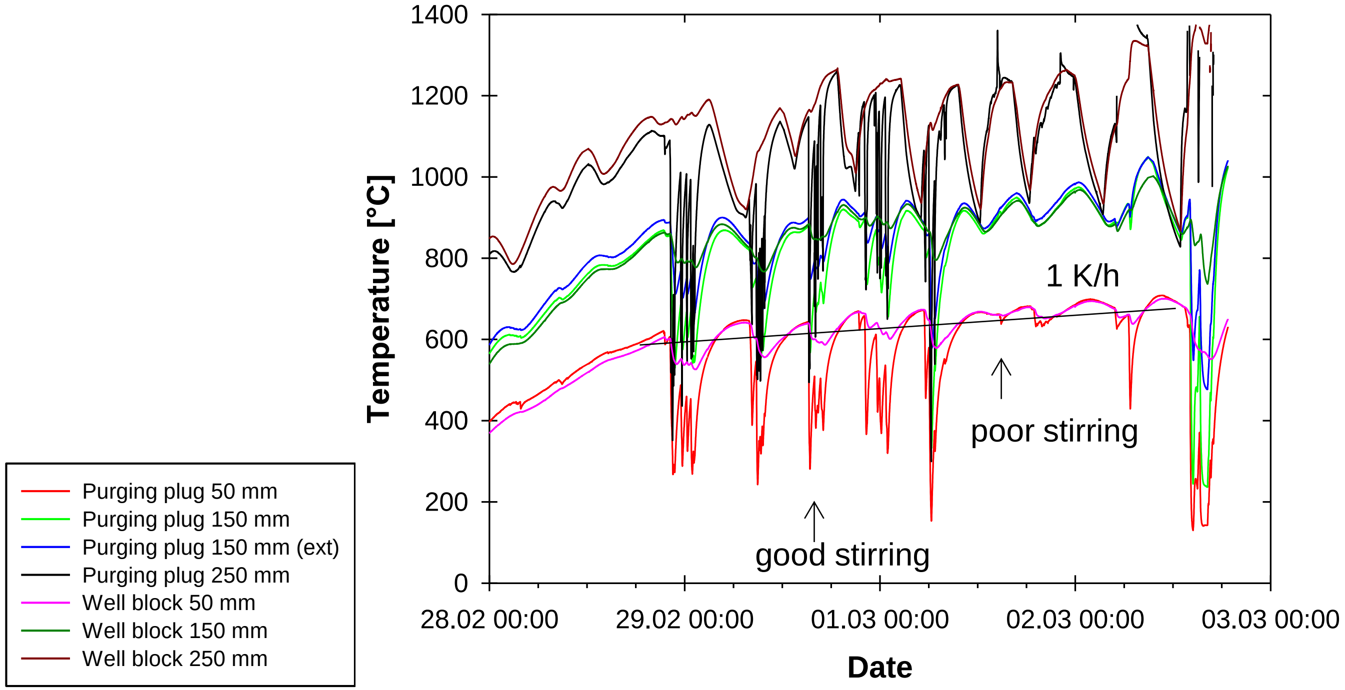
Stirring plug wear

› Temperature measurements in industrial trials with thermocouples

› Current status regarding plug maintenance and plug selection was monitored and compared to improve plug maintenance practices (plug cleaning etc) and
to improve stirring plug (material, manufacturing process etc).

› Stirring plug wear can be identified from the rising maximum temperature of the thermocouples during the heats





Stirring plug performance

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Objectives:

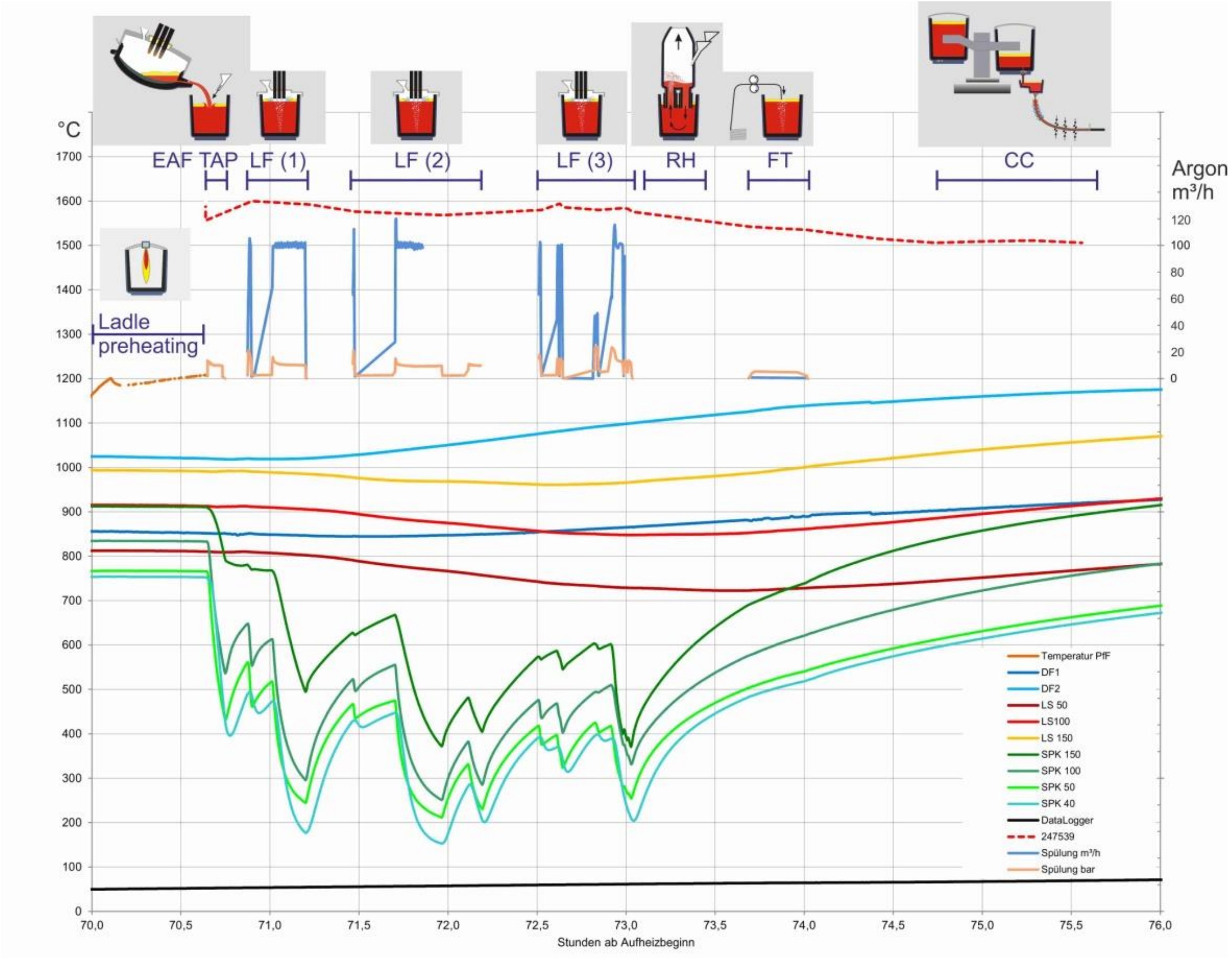
- Improve the performance of stirring processes (improved reliability)
- Avoid non-stirring events (improved availability)
- Generate decisions about stirring plug maintenance operations or renewal

Ways and means:

- Develop and establish a stirring plug monitoring system based on continuous online temperature measurements in the plug
- Numerical simulation of process induced changes in stirring plugs to determine online the wear status of stirring plugs
- Software engineering to determine and predict stirring plug availability and performance

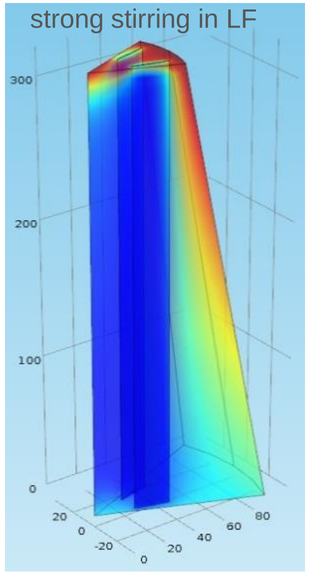
Stirring plug performance

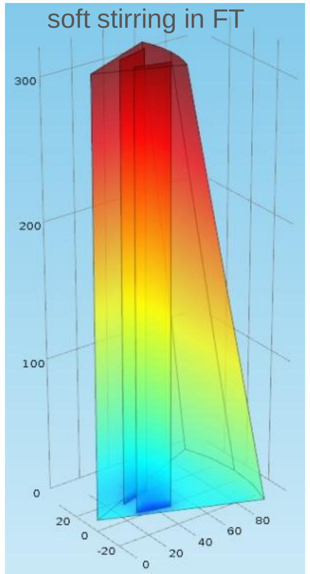
- Temperature measurements in stirring plug, well block and ladle bottom during several heats after relining and in used ladle performed, process route including LF+RH or LF+VOD
- Plug life is strongly affected by temperature gradients resulting in high thermal stresses
  - High cooling rate in one position (up to 600 °C within 50 s)
  - High temperature gradients within stirring plug height (up to 1400 K within 210 mm)

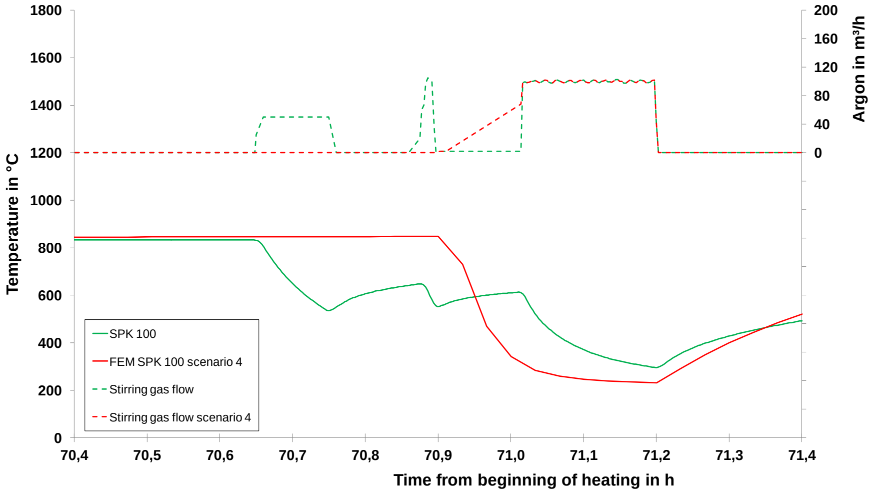


Stirring plug performance

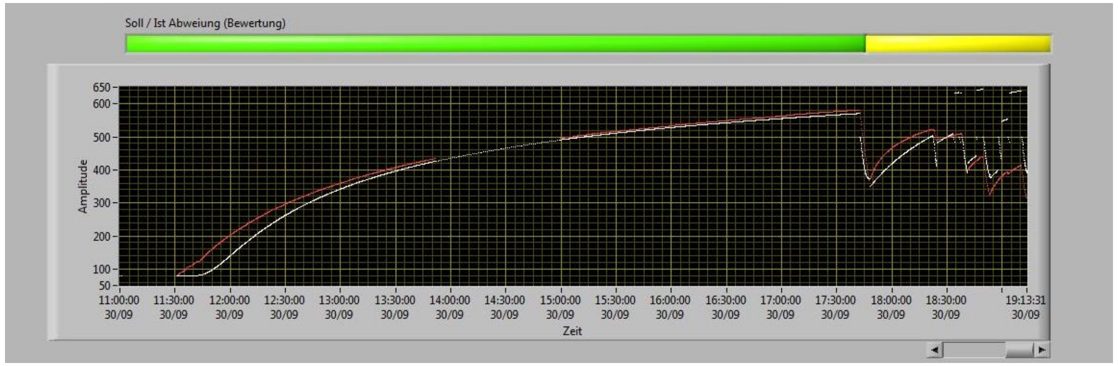
- Temperature decrease of plug refractory is indicator for amount of stirring gas passing through the plug
- Development of monitoring systems for evaluating plug performance and plug wear:
  Support operator in decision when to change plug
- Prediction of plug availability from analysis of previous heats







FEM example for comparison of temperature progress when stirring plug is blocked (red) to expected temperature progress when stirring plug shows good performance (green)



Temperature measured with thermocouples and temperature calculated from BFI software for stirring plug monitoring

Conclusions on refractory temperature and wear

- Online evaluation of ladle thermal status enables:
  - Improvement of existing liquid steel temperature models
  - Optimising the use of the thermal energy stored in ladle lining
- Online temperature measurements in stirring plug enables:
  - Online monitoring of plug wear status and plug performance
  - Direct support to steel production to react in time
  - Minimization of time for maintenance to check, clean or change the stirring plug
- Temperature measurements applicable at different aggregates (steel ladle, converter, RH snorkel) and components (wall lining, bottom lining, stirring plug, well block)
- Improved knowledge on refractory/steel/slag systems
- Increased life time of refractory lining and of stirring plugs
- Higher productivity
- Lower maintenance costs

References

- Dillinger Hütte (2006)
- Terni (2009)
- Deutsche Edelstahlwerke (2013, 2014, 2015)
- ArcelorMittal Bremen (2015+2017)

SecMet Measurement Technologies - Topics

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- **Thermocouples** and **surface acoustic wave (SAW) sensors**
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- **Cameras** in the infrared and visual spectral range in combination with automatic image analysis are used for online monitoring of the status of the process like
  - Stirring, Refining
  - Deslagging

Stirring control – Basic principles

- Bottom stirring is predominant method for homogenization and purification
- Stirring plug requirements:
  - High plug availability at the beginning of the treatment
  - Reliable performance during the whole treatment
  - High wear resistance
- Stirring plugs are strongly affected by thermal, mechanical, and chemical stresses
- It is normal practice to remove stirring plugs earlier than necessary due to safety reasons
- Analysis and control of the ladle stirring process:
  Stirring gas flow rate is commonly used as relevant process parameter
- Online monitoring of stirring process at BFI is based on cameras in the infrared and visual spectral range in combination with automatic image analysis

Stirring control – Benefits

- Differentiation between steel and slag at equal temperature is possible based on infrared images. This helps to **avoid steel losses** during deslagging.
- Camera monitoring and image analysis allows to **adapt gas flow rate** for soft stirring to avoid reoxidation at open eyes
- Camera monitoring and image analysis allow to determine the **actual stirring efficiency**, which is more reliable than measurement of the stirring gas flow rate

- Monitoring the real stirring efficiency helps to improve
  - Inclusion removal
  - Degassing
  - Melting of alloying additions
  - Homogenisation of the bath before measurement (T,O) and sampling
  - Avoiding reoxidation

Stirring control – Technology in operation

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- Camera technology
  - Conventional CCD or CMOS cameras
  - Infrared cameras
- Image processing
  - Online evaluation and determination of relevant process parameters
  - Image processing is adapted to each individual stirring process
  - Adaptive routines to respond to changing environmental conditions
- Integration into process control
  - Linked to process control systems using standard TCP/IP
  - Data exchange using individually laid-out protocols

Camera-based online monitoring at the stirring stand

Objectives:

- Improve steel metallurgy and steel quality
- By minimising slag emulsification and reoxidation
- During stirring in secondary metallurgy (rinsing & strong stirring)

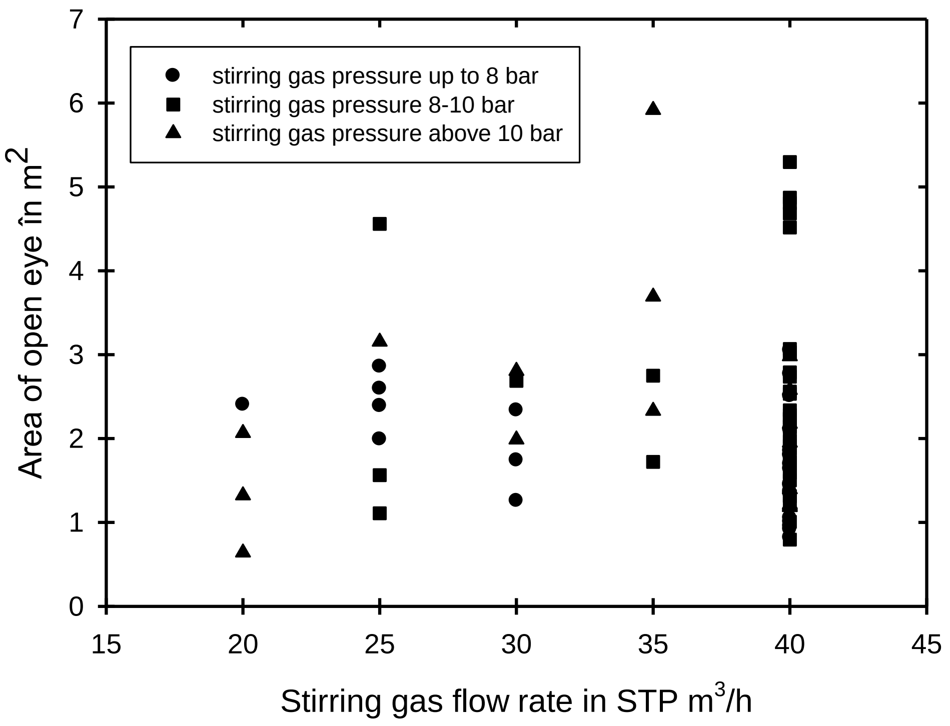
Way and means:

- Optimisation of the complete ladle stirring practices with regard to alloying and rinsing
- A camera-based monitoring system for stirring processes developed to monitor alloying and melting on the melt bath surface as well as the open-eye formation during ladle stirring

Camera-based online monitoring at the stirring stand

Stirring monitoring and control:

- Area of the open eye and the stirring gas flow rate as adjusted at the flow-meter do not correlate
- The stirring gas flow rate is no suitable indicator of the actual stirring intensity during ladle treatment
  - Leaky pipe joints
  - Stirring gas escapes into the refractory of the ladle

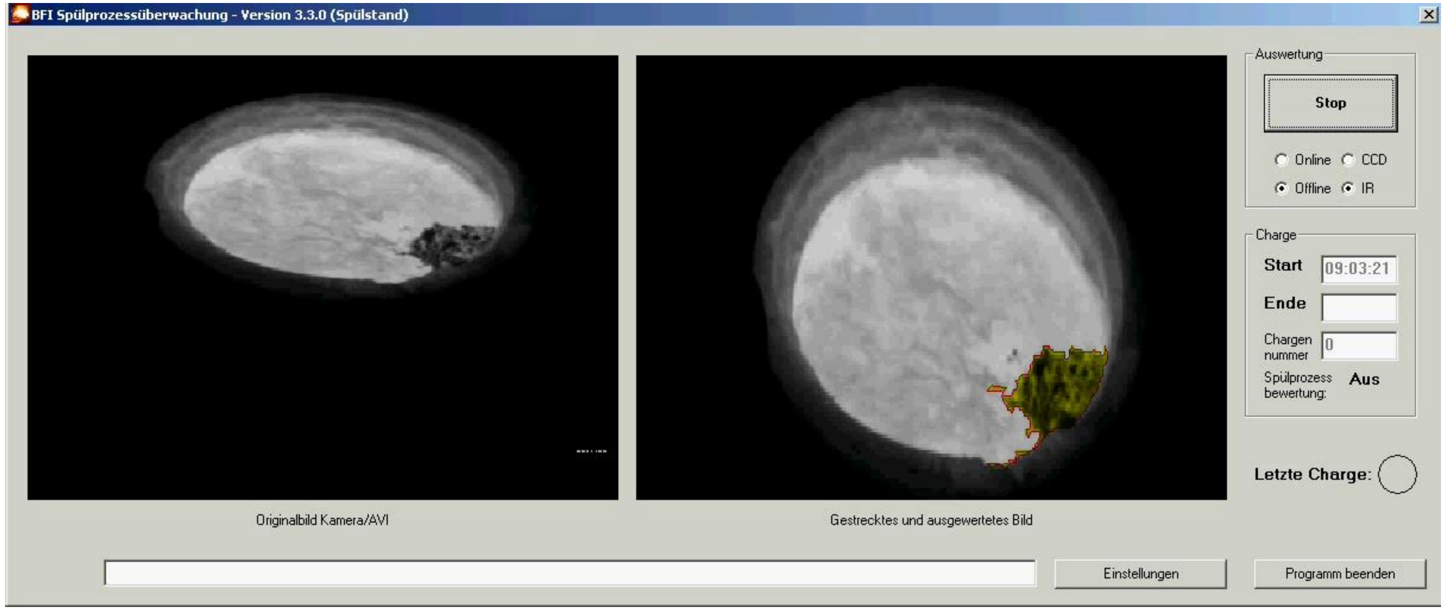


Area of the open eye against the stirring gas flow rate for 82 heats: no correlation

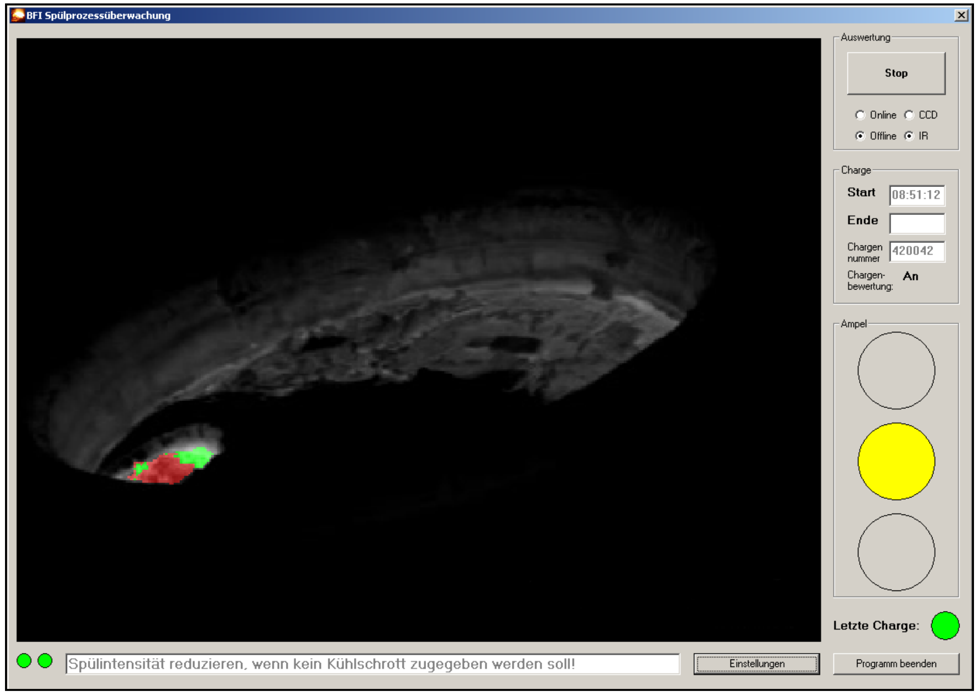
Camera-based online monitoring at the stirring stand

Stirring monitoring and control:

- Image processing system was developed and applied to analyse images taken during stirring treatments with an IR camera and determine online
  - the size of the open eye, and
  - the length of the steel-slag contour.



Monitoring software for strong stirring



Monitoring software for soft stirring

Camera-based online monitoring at VD, VOD, and LF

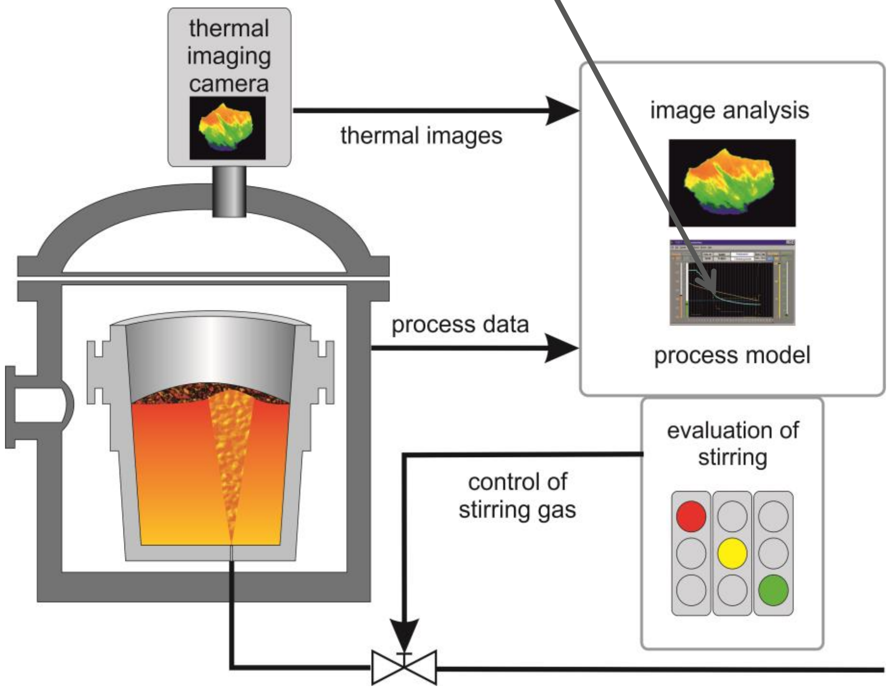
Objectives:

- Reliable control and improved performance
  of the main metallurgical operations during ladle refining:
  - Improvement of quality and cleanness of liquid steel
  - Reduction of treatment times leading to lower energy losses
  - Improved productivity

Ways and means:

- Development and application of an enhanced on-line monitoring and control system for reliable operation of different ladle refining processes:
  - Thermal imaging based evaluation of stirring efficiency
  - Improved dynamic process models

Process model also described in DissTec workshop on process models - see www.bfi.de/en/projects/disstec/



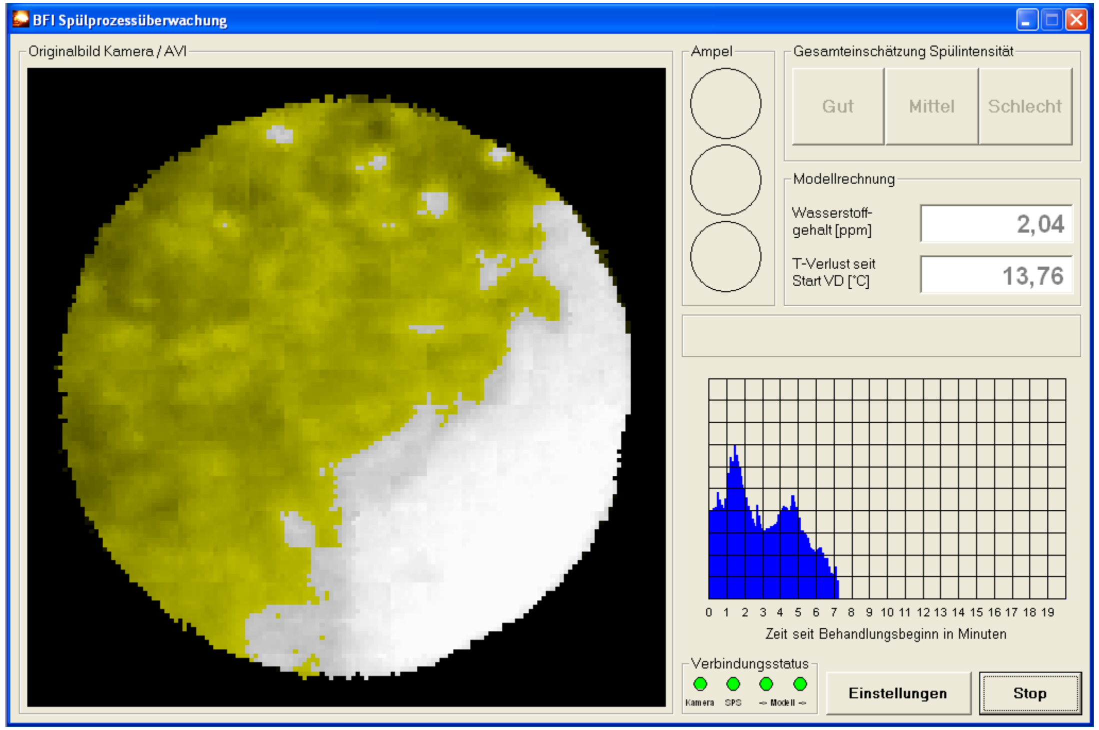
Concept for closed-loop control of stirring gas flow rates at VD plant

Camera-based online monitoring at VD station

- Developed and installed imaging systems became an important tool for process control
- BFI image analysis software to monitor online the melt bath surface during VD treatments is permanently applied at the VD plant. Operators use effective stirring intensity to control the actual stirring gas flow.

Benefits

- Objective judgement of stirring intensity during VD treatment
- Control the stirring gas flow rate from control room
- No further heats with H content exceeding target value observed after implementation of the stirring efficiency monitoring system



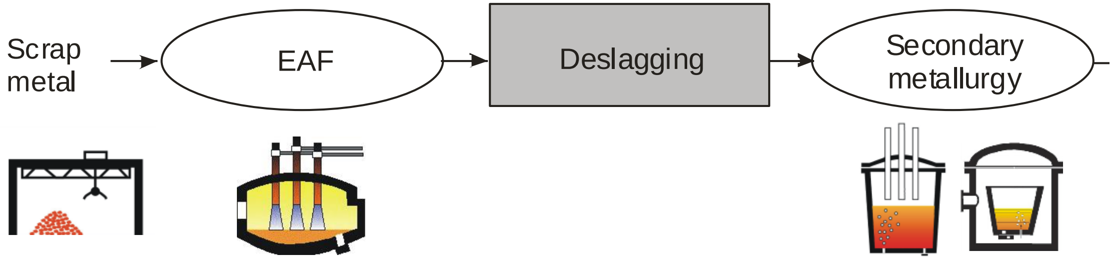
Camera-based online monitoring at deslagging

Objectives:

- Improve deslagging and slag conditioning
- Monitoring and control of deslagging operations
- Dynamic online process models to monitor and control the slag properties throughout the production route of steelmaking
  - Estimate amount and composition of slag
  - Predict impact of remaining slag on metallurgical operations
  - Calculate set-points for slag conditioning

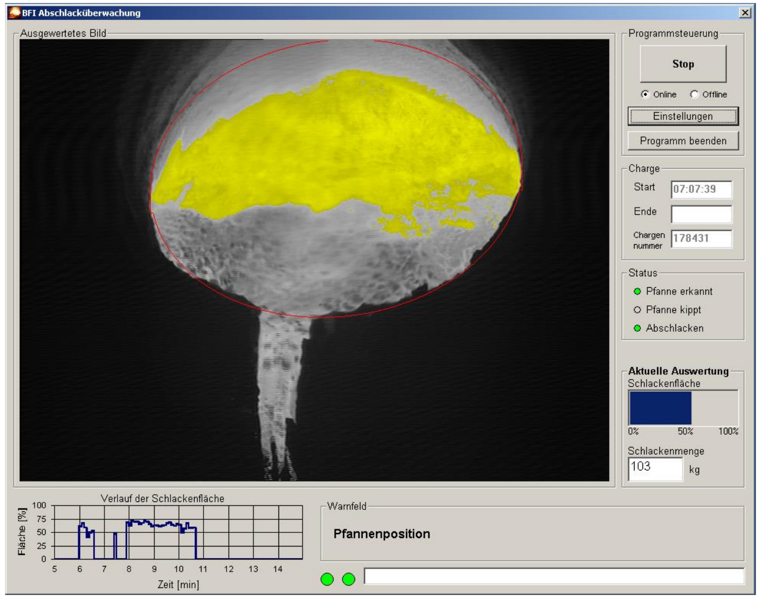
Ways and means:

- CCD and IR monitoring of deslagging operations
- Development of dynamic online process models
- Sampling and analysis for verification



Camera-based online monitoring at deslagging

- Monitoring systems combine
  - camera installations,
  - image analysis,
  - new sensor information (stirring gas flow rate and pressure at EAF plant) and
  - process models
- Image analysis systems provide images of each deslagging process as well as slag area, estimated remaining slag amount and notifications for the operator (EAF plant)
- Process models at EAF plant calculate online
  - slag composition and slag amount for the production steps following the deslagging, as well as
  - amount of slag former additions



BFI image analysis software for monitoring deslagging

Conclusions camera-based online monitoring

- Objective online evaluation of stirring process with BFI software
  - Online monitoring of stirring activity (instead of monitoring stirring gas flow rate)
  - Online feedback to the operator
  - Objective evaluation and résumé of stirring processes including documentation
- Monitoring software supports all established camera types
- Application at various stirring processes, both strong stirring (e.g. at LF) and soft stirring
- Tighter process control
- Documentation of the process
- Optimized metallurgy
- Shorter treatment times
- Reduced stirring gas consumption

References

- Saarstahl (2009)
- ArcelorMittal Ruhrort (2010)
- Salzgitter (2012)
- Saarschmiede (2013)
- Deutsche Edelstahlwerke (2014)

Thank you very much for your attention !

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