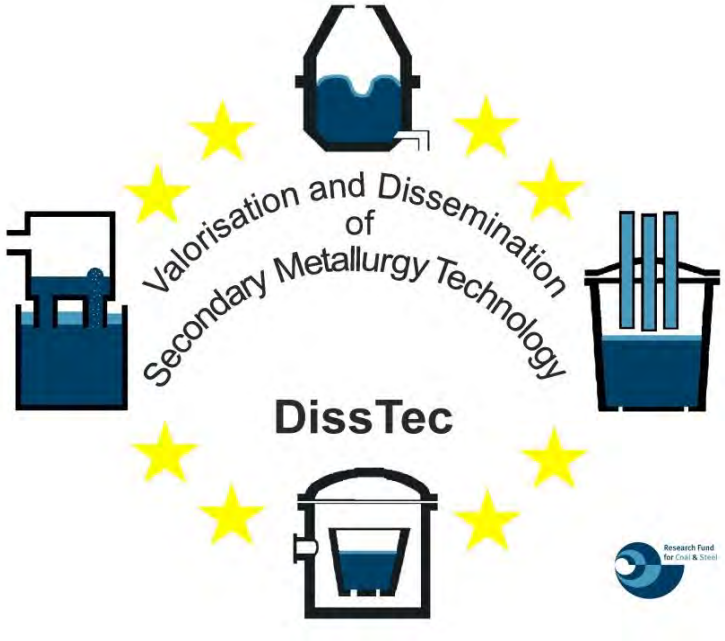
DissTec

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



SecMet measurement technologies in ECSC and RFCS research projects

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Stahl

SecMet Measurement Technologies – Introduction

- A measurement gives information on the actual status of
  - the product (e.g. melt temperature (Minkon), melt composition (CRM)),
  - the process (e.g. melt stirring by gas injection) or
  - the aggregate (e.g. ladle heat content)
- Operators use the online information to operate the process and adjust the product properties.
- The information is the basis for automated process control, process modelling, or simulation as it is used as starting value or boundary condition of the real process.

SecMet Measurement Technologies - Topics

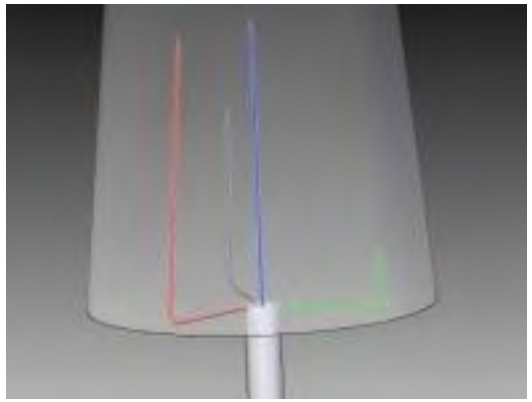
- **Thermocouples** and **surface acoustic wave (SAW) sensors**
  - sometimes in combination with FEM simulation –
  were used for monitoring of the status of aggregates like
  - Ladle thermal state
  - Ladle lifetime/ lining erosion
  - Purging plug performance
- **Cameras** in the infrared and visual spectral range in combination with automatic image analysis were used for online monitoring of the status of the process like
  - Stirring, refining
  - Deslagging
- **Vibration sensors** (accelerometers, laser vibrometers)
  are used to monitor the status of the process like
  - desulfurisation,
  - degassing

Selected RFCS research projects on temperature measurement

Contract Report	Title	Participants	Sensor	Topic
RFSR-CT-2009-00003	Enhanced steel ladle life by improving the resistance of lining to thermal, thermo-mechanical and thermo-chemical alteration (**LadLife**)	Sidenor, CSM, BFI, Lucchini	Thermocouples, FEM	ladle refractory life
RFSR-CT-2014-00006	Improving steelmaking processes by enhancing thermal state ladle management (**LadTherm**)	BFI, AMB, Sidenor, KTH	SAW, Thermocouples, FEM	ladle thermal state
RFSR-CT-2005-00005	Improvement of purging plugs performances by investigations on the materials, process analysis and continuous monitoring (**ImPurginAr**)	CSM, Terni, Calderys Italia, BFI	Thermocouples	Purging plug wear
RFSR-CT-2012-00005	Stirring plug monitoring system for improvement of plug availability and stirring performance (**PlugWatch**)	Terni, CSM, DEW, Gerdau, BFI	Thermocouples	Purging plug performance

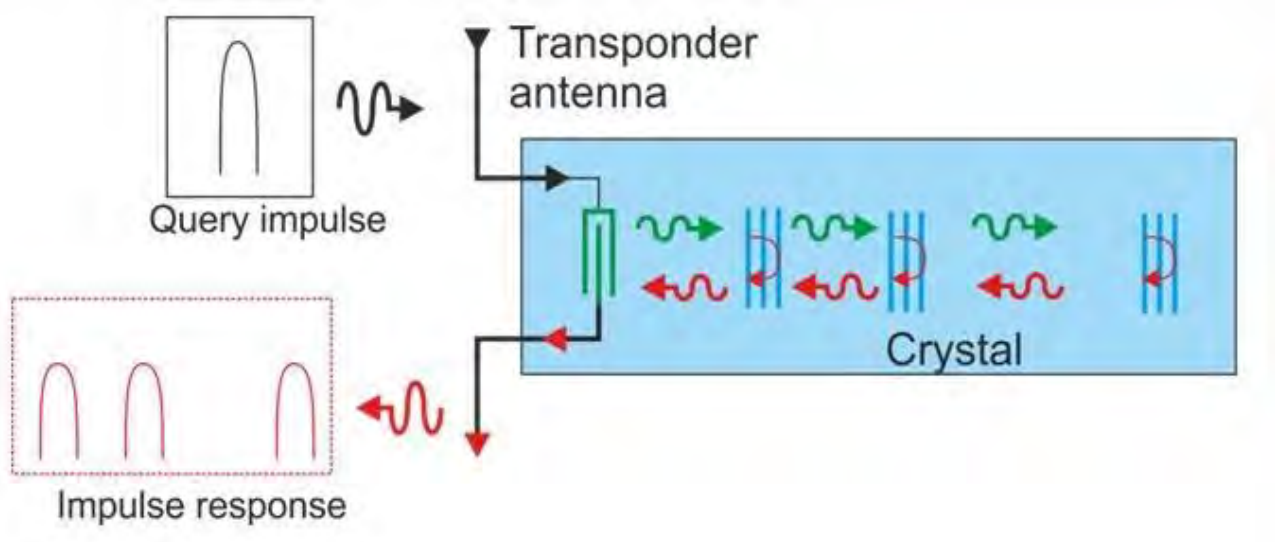
SecMet Measurement Technologies – Basic principles

- **Thermocouples** for ladle refractory lining and purging 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 have been installed within the ladle refractory or the purging plug to monitor the temperature.



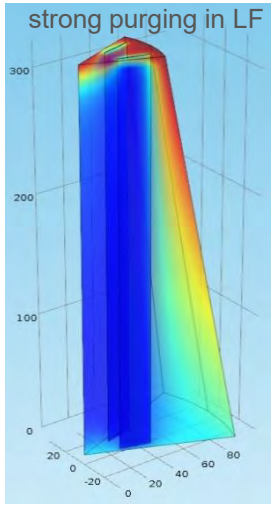
SecMet Measurement Technologies – Basic principles

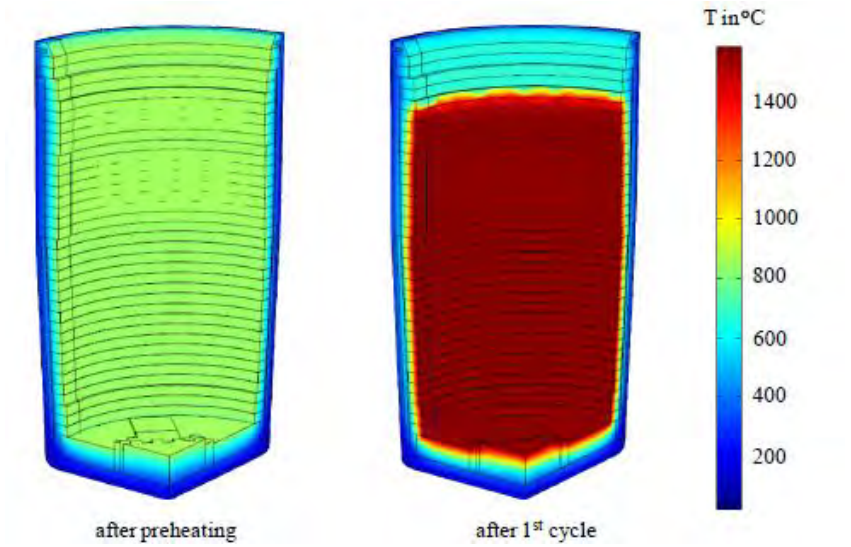
- **SAW sensors** for refractory temperature monitoring
  - A SAW sensor is a passive ceramic sensor which can withstand 400°C.
  - An antenna sends an electromagnetic pulse,
    at the ceramic sensor the received pulse is converted into a surface acoustic wave which is sensitive to the surface temperature.
    The response received by the antenna contains information on the sensor temperature.



SecMet Measurement Technologies – Basic principles

- **FEM** for global temperature and stress simulation in ladle
  - Finite element modelling was used to simulate the refractory temperature not only at the measurement position, but also in the entire aggregate.
  - The FEM simulation can also deduce the mechanical stress caused by thermal expansion.





Ladle thermal state

LadTherm:

Objectives:

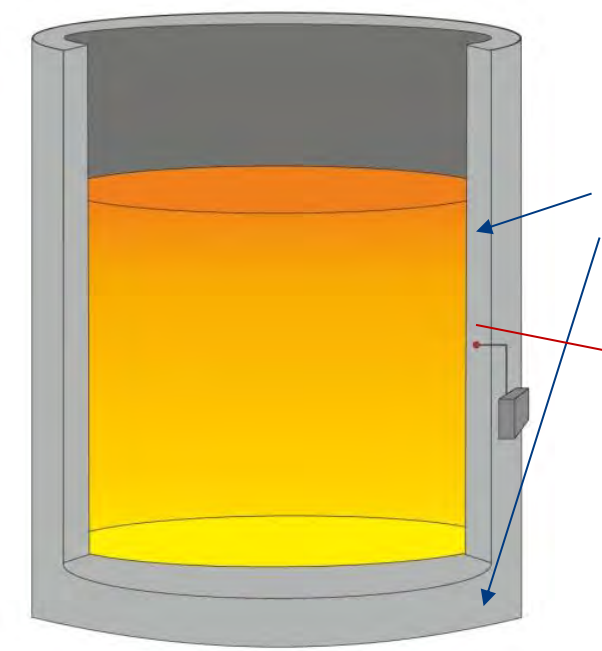
- Monitoring the thermal state of steelmaking ladles during secondary steelmaking operations.
- Knowledge of actual thermal status of ladle are used to improve existing liquid steel temperature models.
- Optimising the use of the thermal energy stored in ladle lining in order to
  - Better match the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

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

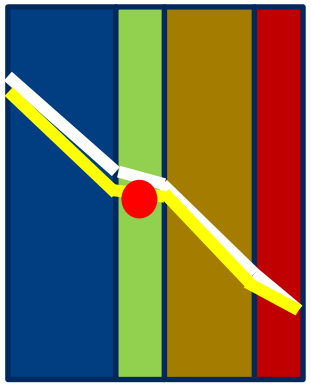
Ladle thermal state

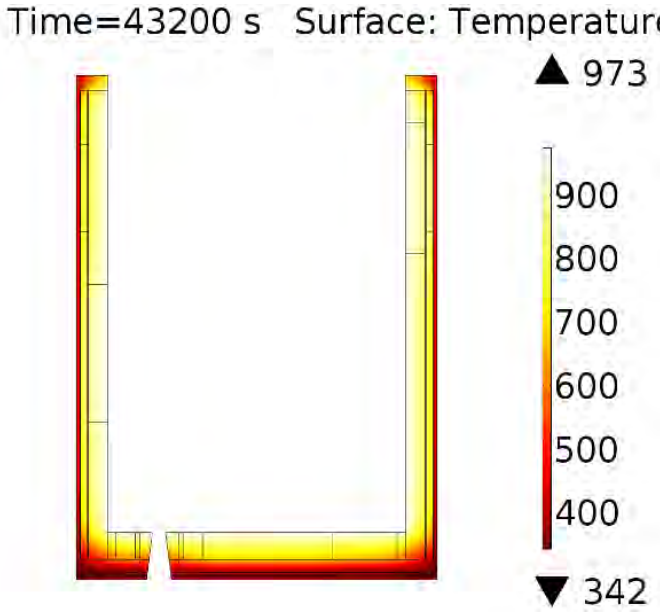
- Temperature measurement in ladle lining using thermocouples and FEM model used to define optimum position for SAW sensor
- Online model on the thermal state developed that is adapted during steelmaking process using measured temperatures



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 life

Project LadLife: Enhanced steel ladle life by improving the resistance of lining to thermal, thermo-mechanical and thermo-chemical alteration

Main objective:

› to prolong the working life of ladle refractory lining

› Simulation of thermal, physical and chemical stress on refractory taking into account abrasion, thermo-mechanical wear, corrosion

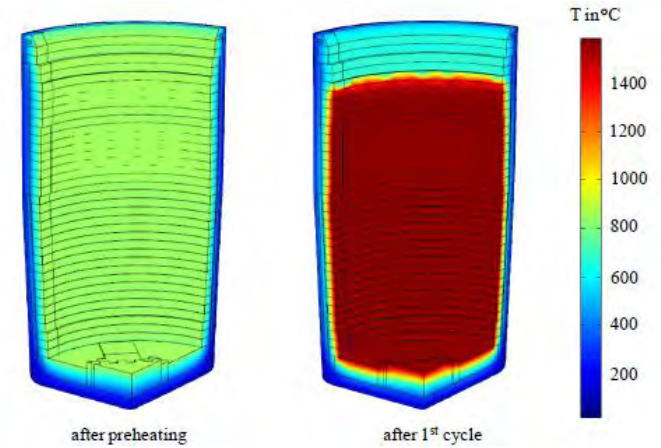
› Definition and application of process rules and optimum materials for operation

Ways and means

› FEM simulation of the temperature and stress distribution in the ladle refractory,

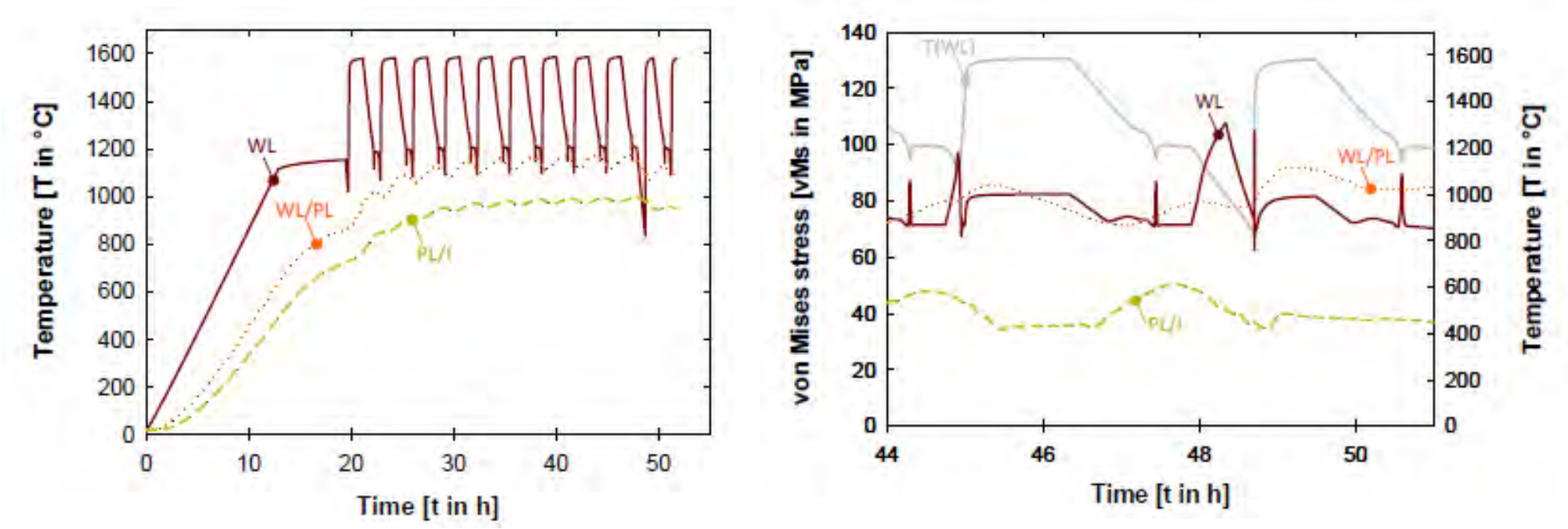
› Laboratory erosion experiments on chemical erosion,

› Comparison of process data.



Ladle refractory life

- Temperature and stress distribution calculated for three ladles by FEM simulation
- Different ladle and process configurations simulated



Temperature and stress profiles during first 10 cycles including initial preheating and a tapping delay after 9th heat at different positions in ladle III

Purging plug wear

RFCS project ImPurgingAr:

Improvement of purging plugs performances by investigations on the material, process analysis and continuous monitoring

Objectives

› Improve the purging plug selection and management in order to enhance their performances

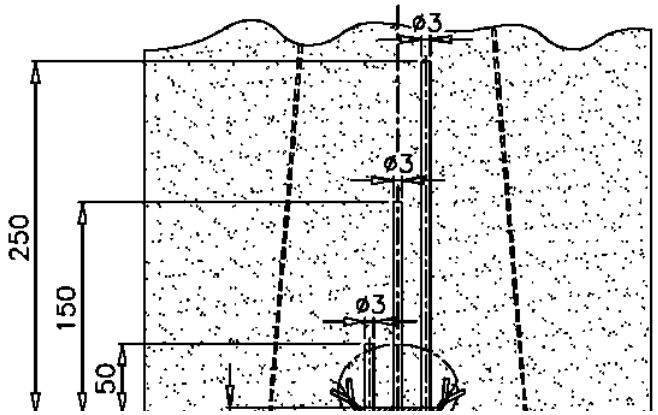
› Investigate and characterize thermo-mechanical and thermo-chemical phenomena that govern the degradation and wear of the purging plugs during ladle operations

Ways and means

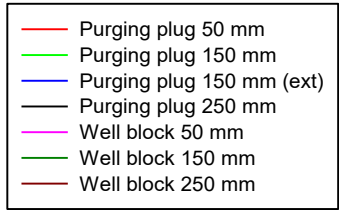
› Development of a measurement system for on-line determination of the purging plug wear status by measuring temperature along the plug

Purging plug wear

- Temperature measurements in industrial trials with thermocouples
- Current status regarding plug maintenance and plug selection was monitored and compared to improved plug maintenance practices (plug cleaning etc) and an improved purging plug (material, manufacturing process etc).
- Purging plug wear can be identified from the rising maximu the heats



Temperatures in purging plug and well block
Ladle 196, TK AST 2008



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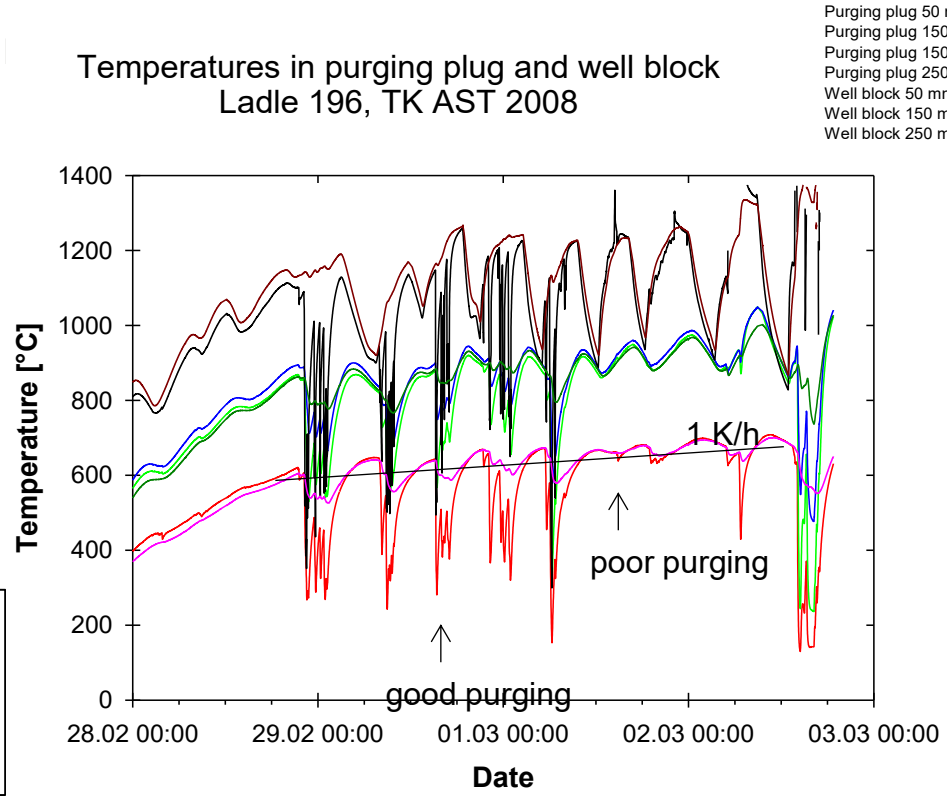


Purging plug performance

RFCS project PlugWatch:
Stirring plug monitoring system for improvement of plug availability and stirring performance

Objectives

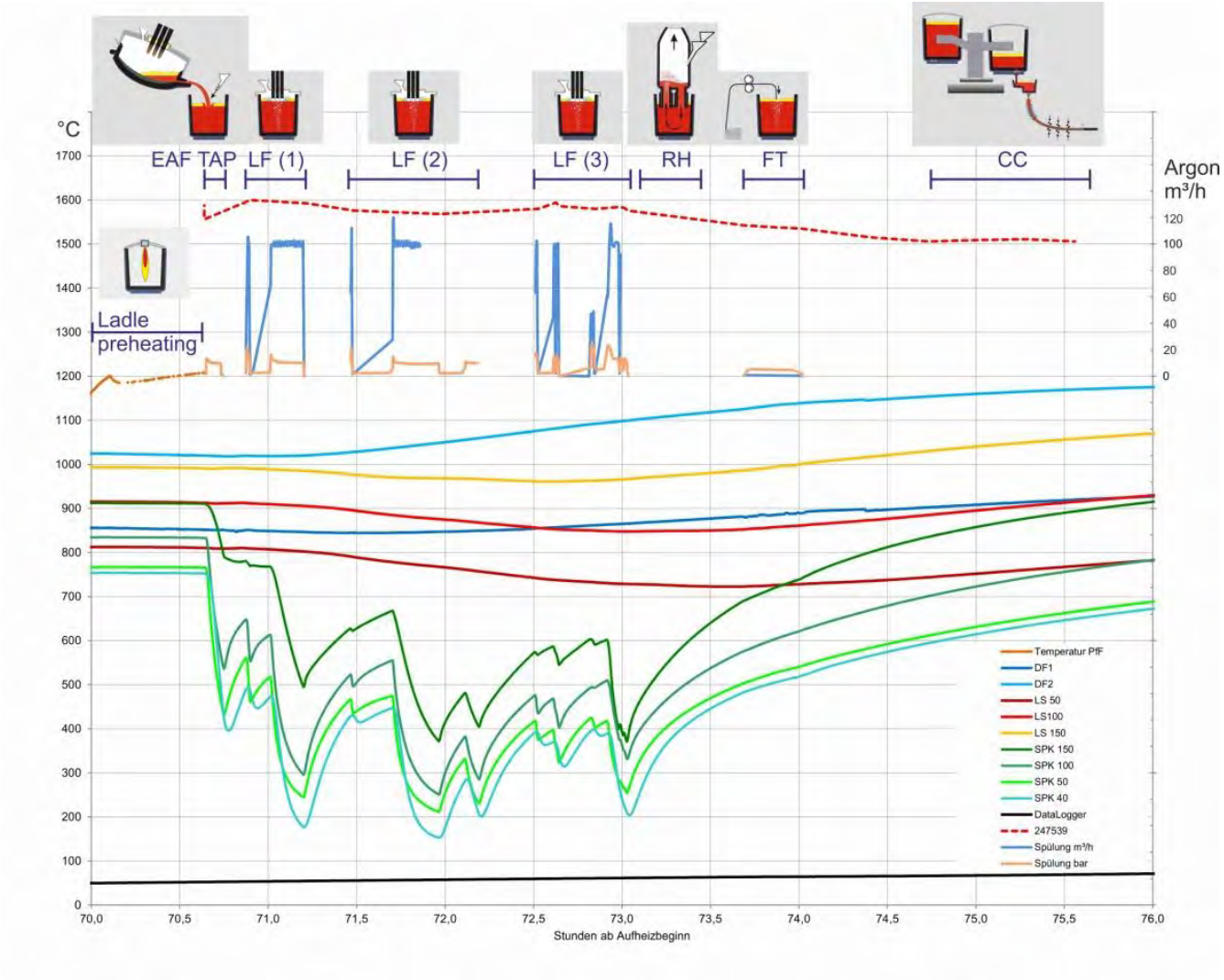
- Improve the performance of purging processes (improved reliability)
- Avoid non-purging events (improved availability)
- Generate decisions about purging plug maintenance operations or renewal

Ways and means

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

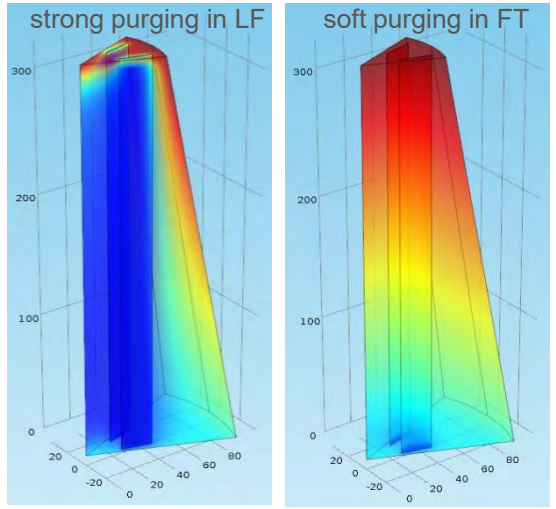
Purging plug performance

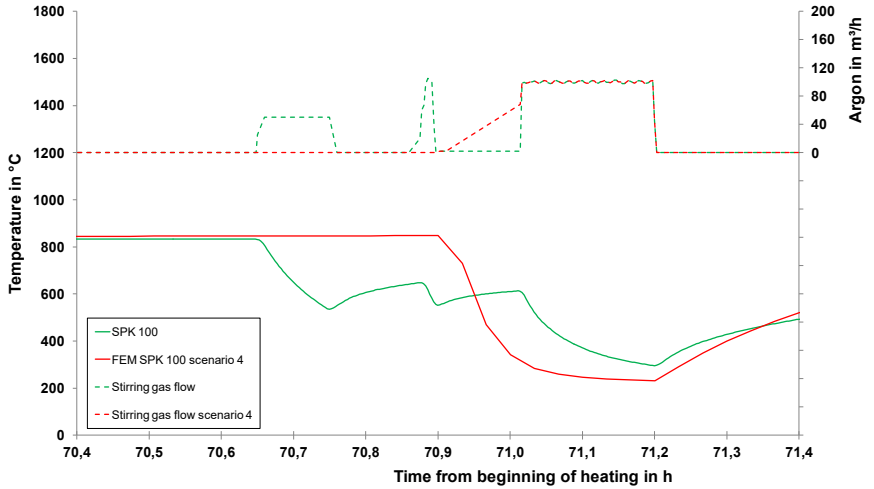
- Temperature measurements in purging plug, well block and ladle bottom during several heats after relining and in used ladle performed
- Plug life is strongly affected by temperature gradients resulting in high thermal stress
  - High cooling rate in one position (up to 600 °C within 50 s)
  - High temperature gradients through purging plug height (up to 1400 K within 210 mm)



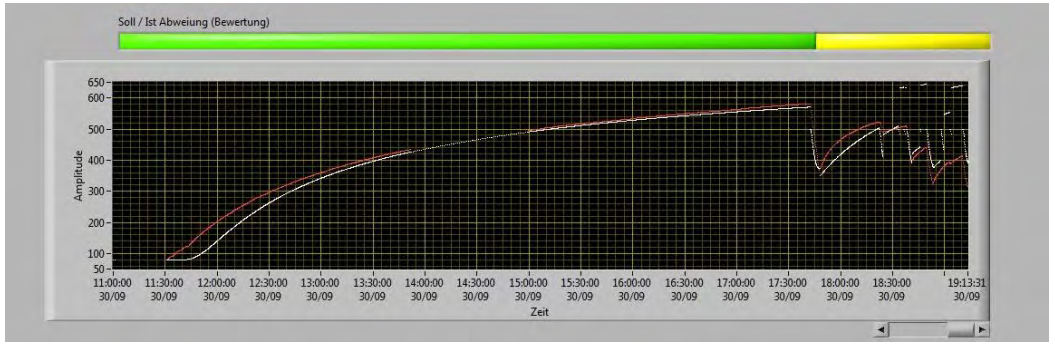
Purging plug performance

- Temperature decrease of plug refractory is indicator for amount of purging 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 purging plug is blocked (red) to expected temperature progress when purging plug shows good performance (green)



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

Selected RFCS research projects dealing with aspects of process performance

Contract Report	Title	Partners	Sensor	Information
RFSR-CT-2007-00009	Improvement of ladle stirring to minimise slag emulsification and reoxidation during alloying and rinsing (**StImprove**)	KTH, Saarstahl, Aalto Univ., BFI	Camera	Stirring
RFSR-CT-2008-00044	Enhanced reliability in ladle refining processes (VD, VOD and LF) by improved on-line process monitoring and control (**LaRefMon**)	AMR, Gerdau Voestalpine, BFI	Camera	Refining
RFSR-CT-2010-00005	Increased yield and enhanced steel quality by improved deslagging and slag conditioning (**OptDeslag**)	Mefos, Saarschmiede, SSAB, BFI	Camera	Deslagging
RFSR-CT-2007-00004	Online control of desulphurisation and degassing through ladle bubbling under vacuum (**Ondeco**)	AMMR, DH, Voestalpine	Vibration sensors	Degassing, desulphurisation

Stirring control – Basic principles

Benefits of camera based monitoring of ladle treatment

- 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

Technology in operation

- 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

Conclusions camera-based online monitoring

- Objective online evaluation of purging process with BFI software
  - Online monitoring of purging activity (instead of monitoring purging gas flow rate)
  - Online feedback to the operator
  - Objective evaluation and résumé of purging processes including documentation
- Monitoring software supports all established camera types
- Application at various purging processes, both strong purging (e.g. at LF) and soft purging
- 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)

Camera-based online monitoring at the stirring stand

RFCS project StImprove:
Improvement of ladle stirring to minimise slag emulsification and reoxidation during alloying and rinsing

Objectives

› Improve steel metallurgy and steel quality

› Optimisation of the complete ladle stirring practices with regard to alloying and rinsing

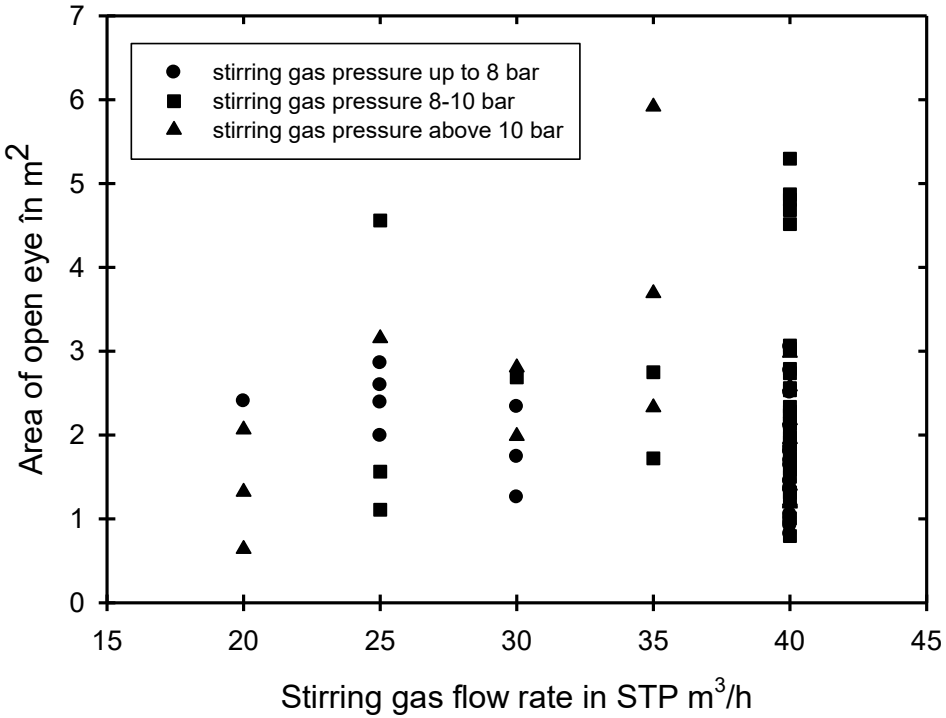
Way and means

› 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

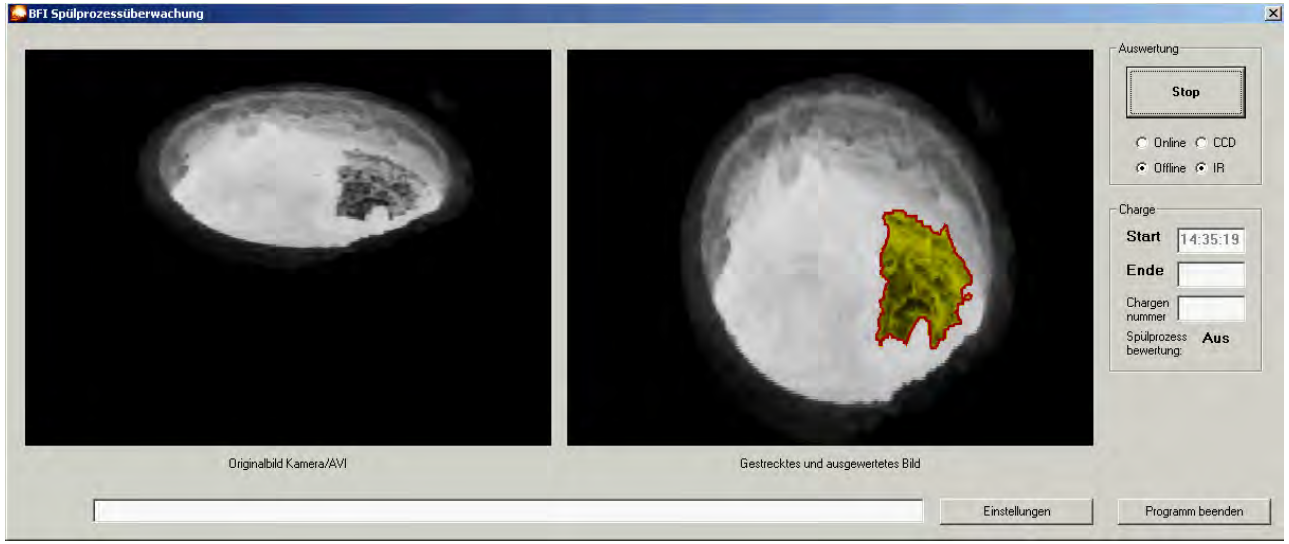


Area of the open eye against the stirring gas flow rate for 82 heats: no correlation

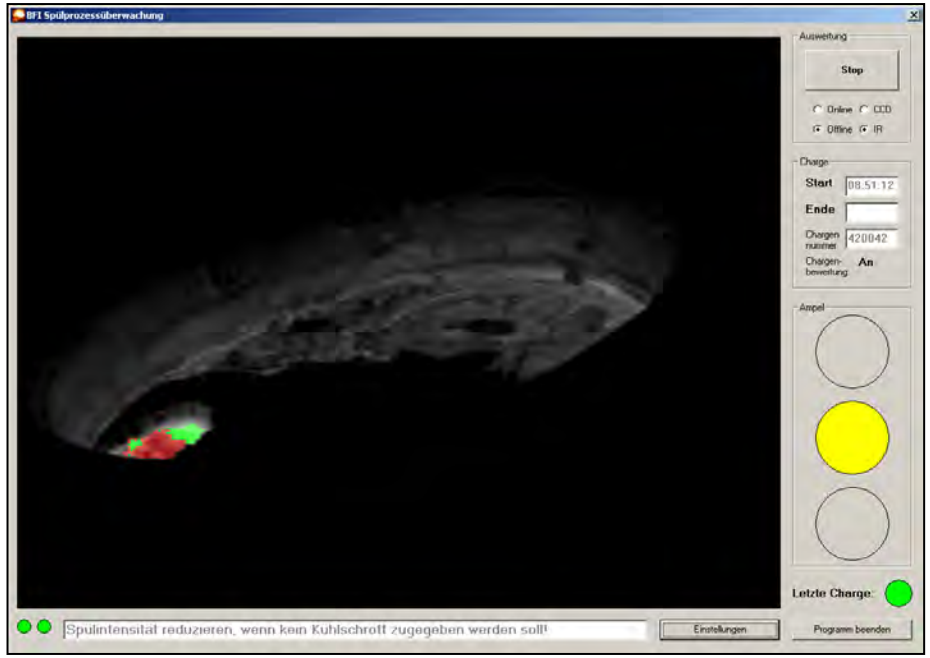
Camera-based online monitoring at the stirring stand

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 station

RFCS project LaRefMon:
Enhanced reliability in ladle refining processes (VD, VOD and LF) by improved on-line process monitoring and control

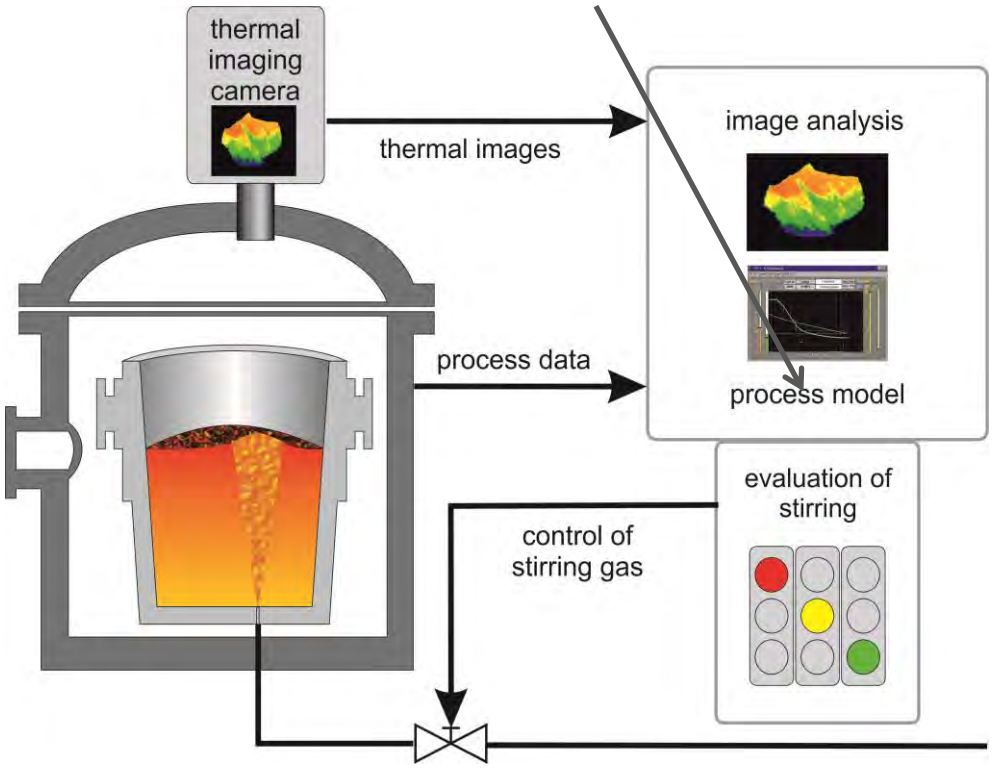
Objectives:

- 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/



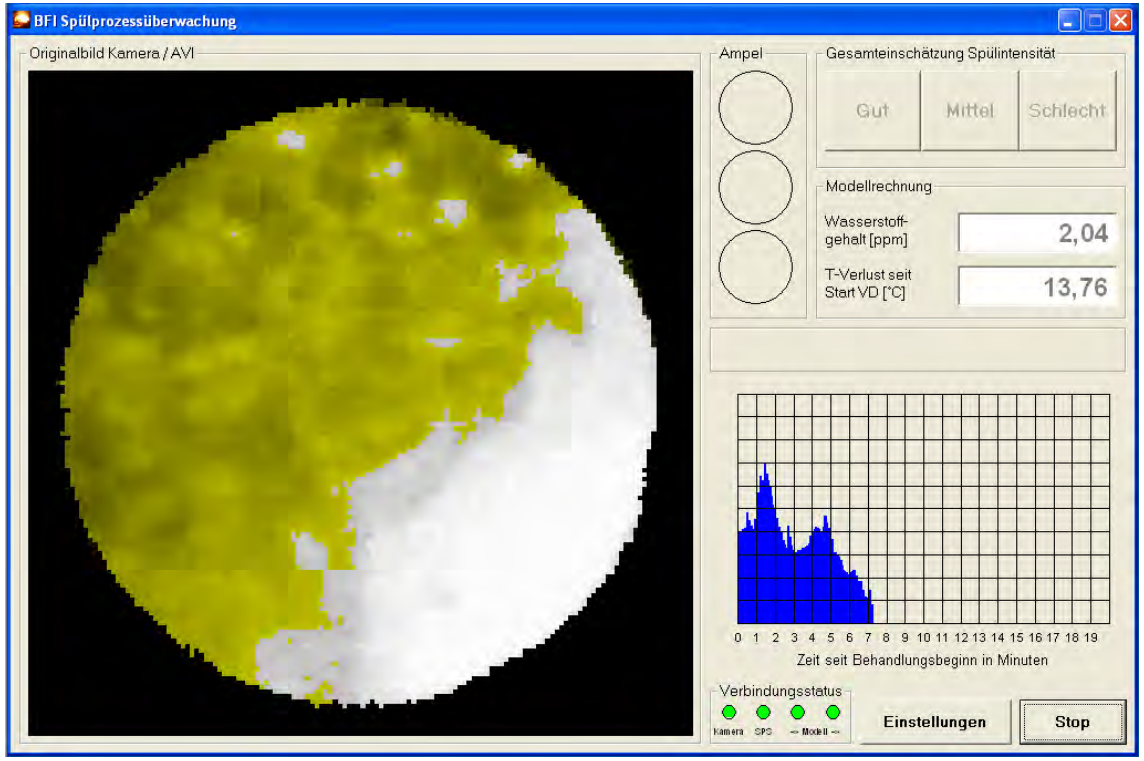
Concept for closed-loop control of stirring gas flow rates at VD plant

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

RFCS project OptDeslag:

Increased yield and enhanced steel quality by improved deslagging and slag conditioning

Objective

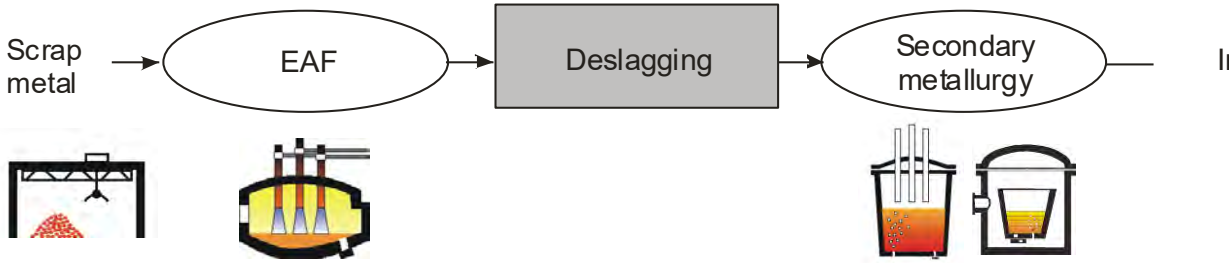
- Improve deslagging and slag conditioning
- Monitoring and control of deslagging operations
- Dynamic online process models to monitor and control the slag properties throughout the production route of steelmaking
  - Estimate amount and composition of slag
  - Predict impact of remaining slag on metallurgical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

Ways and means

- CCD and IR monitoring of deslagging operations

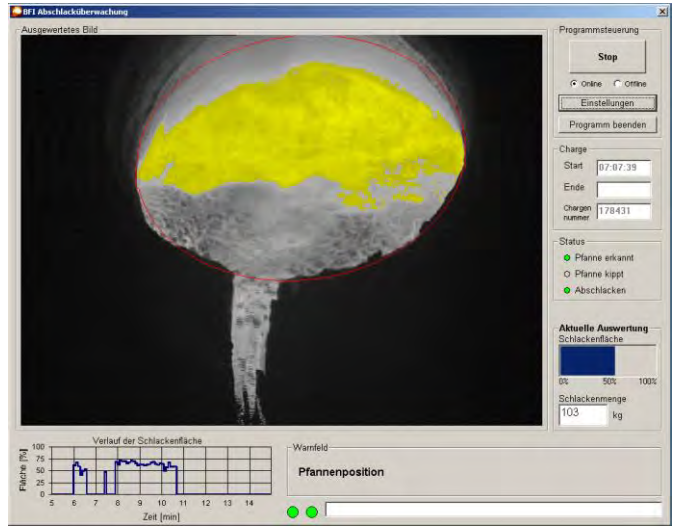
SSAB - Deslagging of hot metal after desulphurisation

Saarschmiede - Deslagging of liquid steel after EAF tappin



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 work well providing images of each deslagging process and
  - 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



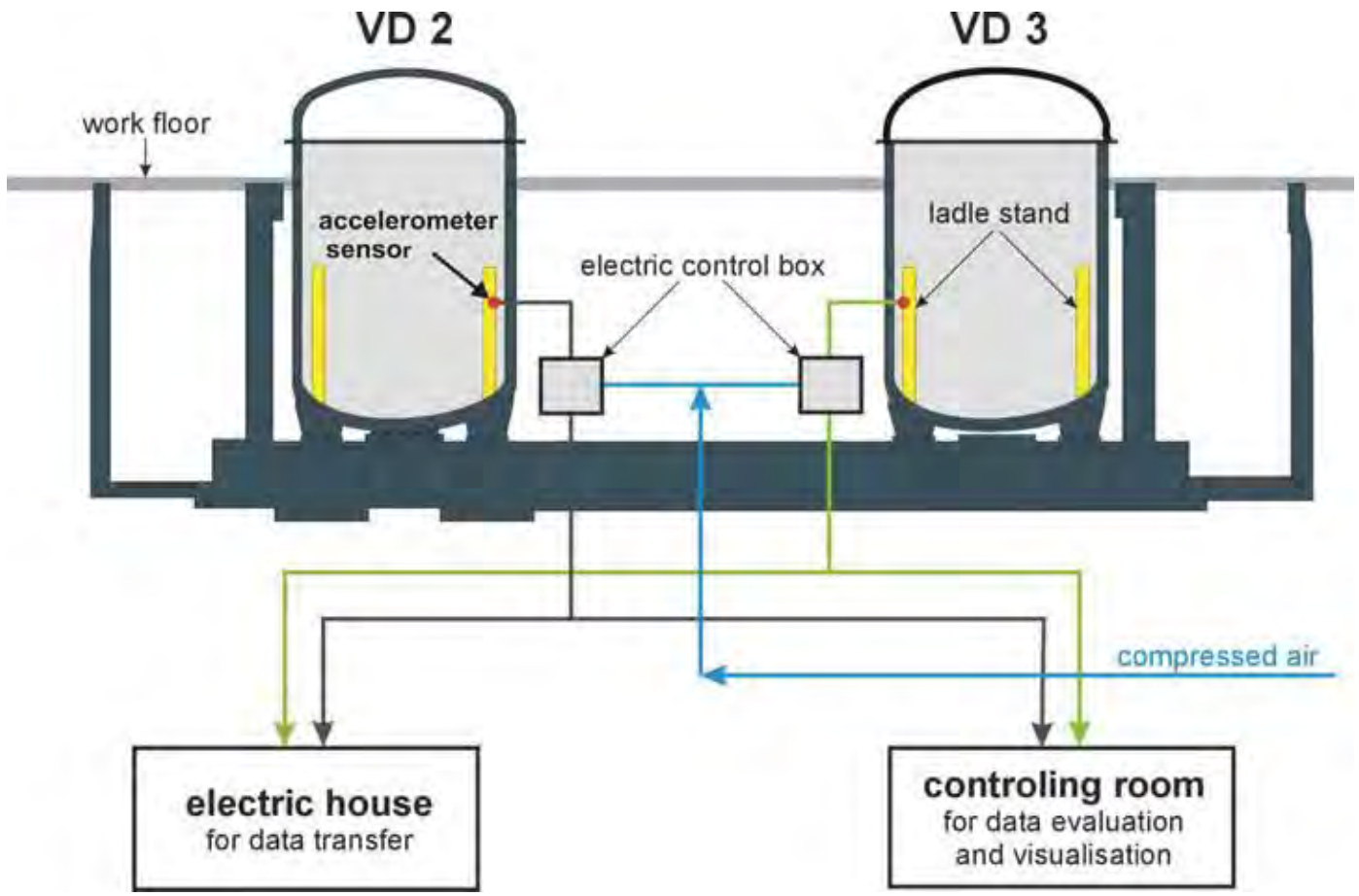
BFI image analysis software for monitoring deslagging

Vibration measurements for gas flow monitoring

- **Vibration sensors** at ladles in vacuum degassing station

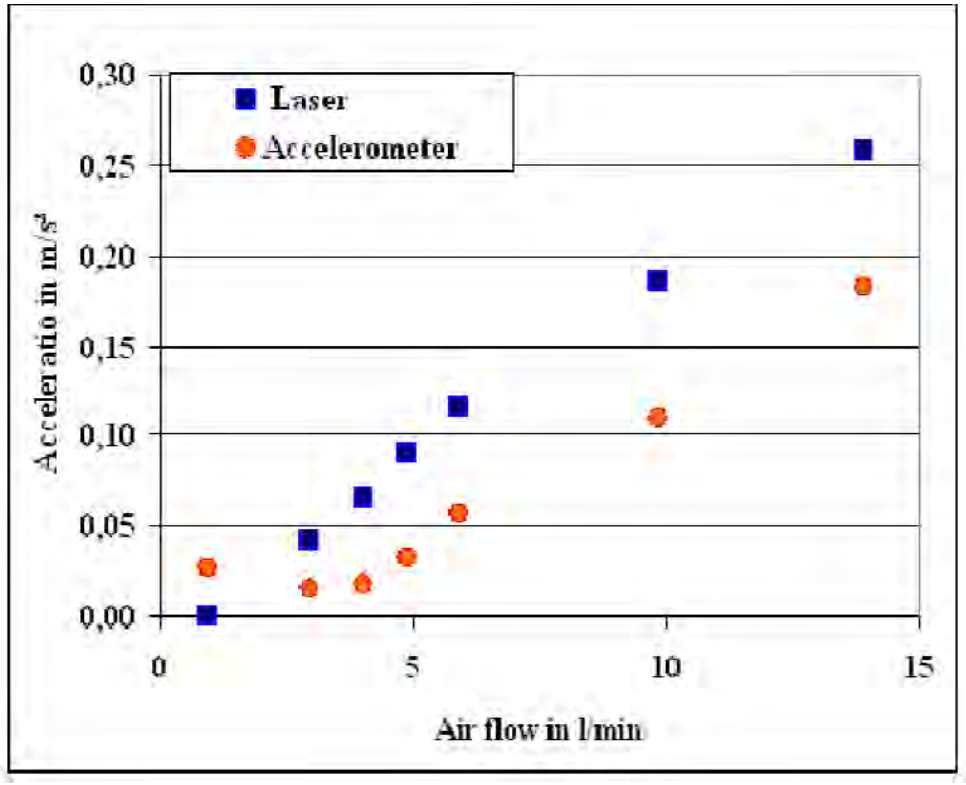
Objectives:

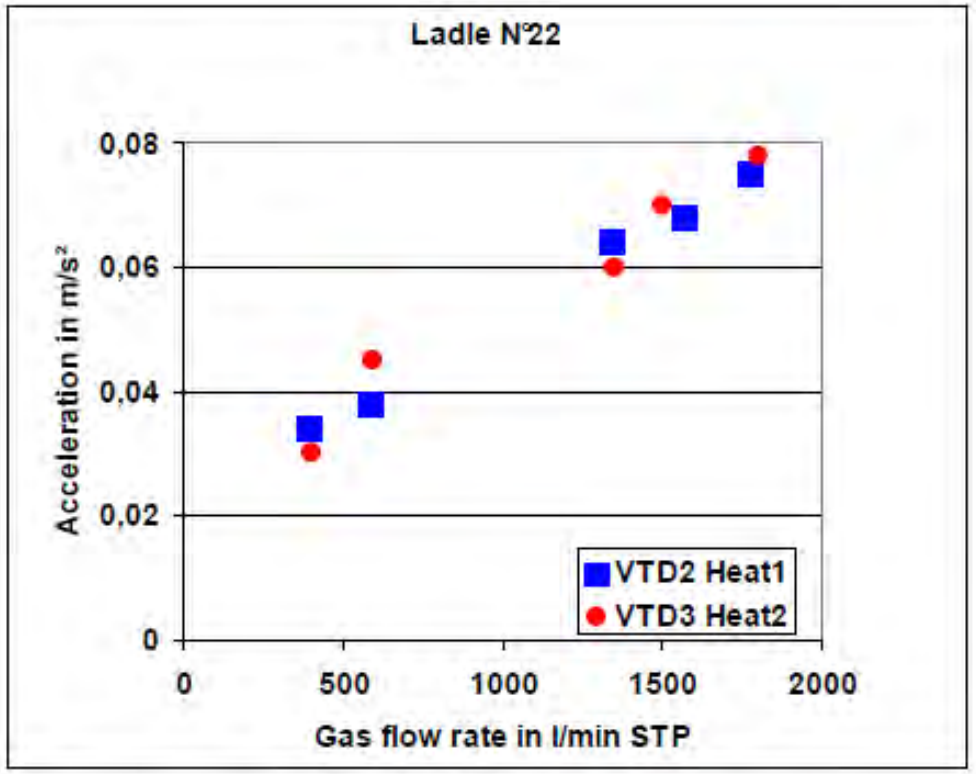
- Using appropriate vibration sensors
- to characterise the stirring state during ladle metallurgy,
- to develop innovative signal processing, obtain representative indices
- and use them as input in an on-line desulphurisation model,
- to adjust the process and contribute to the improvement of degassing performance (H, N removal).



Vibration measurements for gas flow monitoring

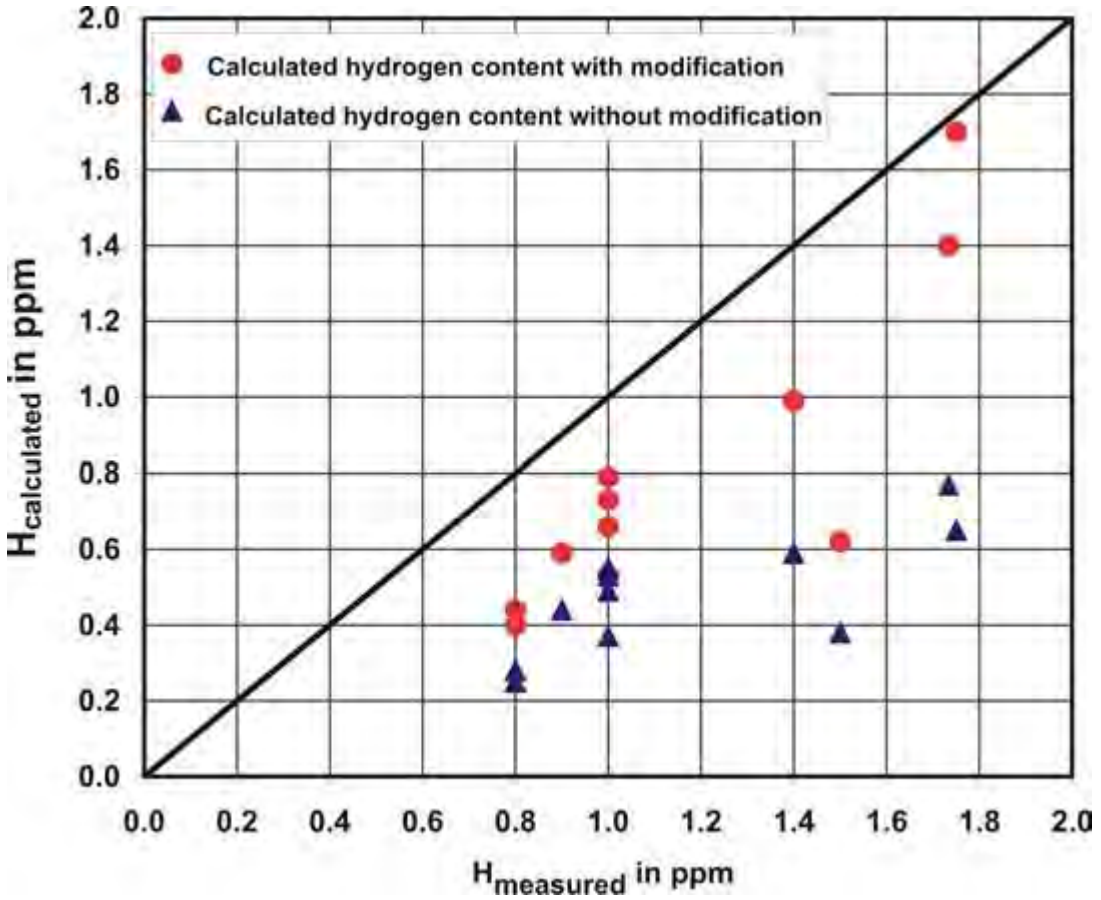
- Comparison of Laser vibrometer and accelerometer
- Comparison of vibration signals using the same ladle for both Vacuum Tank Degasser units at DH





Vibration measurements for gas flow monitoring

› Vibration based modification of the gas flow rate helps to improve the hydrogen content calculation.



Thank you very much for your attention !

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