

# DissTec

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



Improved purging plugs  
performances and monitoring to  
improve availability and  
performance of the gas stirring

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# Ladle stirring processes – Introduction and general considerations

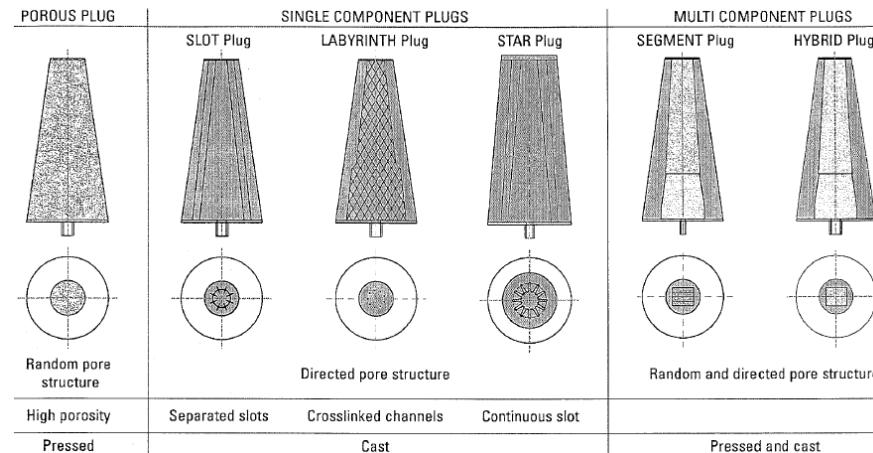
- › Ladle treatment with stirring gas is an essential issue within secondary metallurgy
- › Reliable performance of the stirring plugs in steelmaking ladles is a key factor for accurate steel production
- › Depending on the steel production routes in steel plants and produced steel grades, appropriate stirring procedures are carried out at different treatment steps and stations of secondary metallurgy
- › Disturbances due to loss of stirring efficiency and non-stirring events have impact on treatment times and achievement of steel quality requirements
- › One important topic of R&D work on Secondary metallurgy processes has been and still is the improved plug performance and the development of monitoring systems for stirring process control
- › Within this presentation the results of some selected ECSC and RFCS projects are discussed

# Selected RFCS research projects dealing with aspects of purging plugs and stirring processes

Contract Report	Title	Participants	Date Start / End	Topic regarding stirring
RFSR-CT-2005-00005	Improvement of purging plugs performances by investigations on the materials, process analysis and continuous monitoring ( <b>ImPurginAr</b> )	CSM, Terni, Calderys Italia, BFI	01.07.2005 to 30.06.2009	plugs/monitoring
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# Stirring plugs – Basic principles

- › Bottom purging is predominant method for homogenization and purification
- › Stirring plug types:



Kneis, L. et al. RHI Bulletin 1-2004

- › 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

# Stirring control – Basic principles

- › Analysis and control of the ladle stirring process:  
Stirring gas flow rate is commonly used as relevant process parameter
- › The stirring gas flow rate does not show how much gas actually enters the melt
  - › Leaky pipe joints
  - › Stirring gas escapes into the refractory of the ladle
- › Stirring gas flow rate however is regarded as suitable for control of the stirring process
- › Consequence: Stirring process is sometimes wrongly guided and often weaker than expected
  - › Poor removal of inclusions
  - › Poor melting of alloying additions
  - › Inhomogeneous temperature
  - › Possible reoxidation



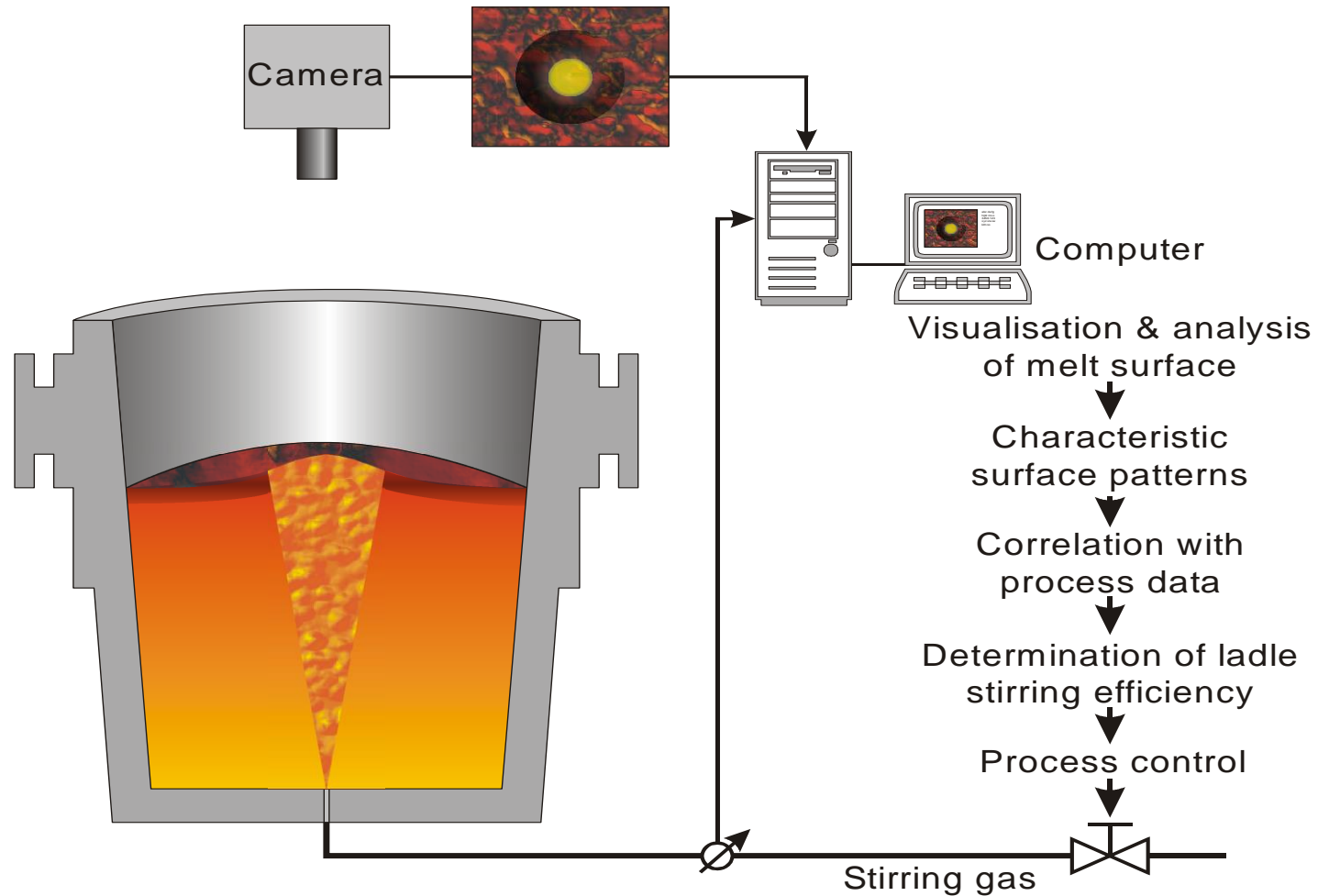
Approaches for monitoring of purging plug functionality to be discussed in the following:

- › Camera-based online monitoring of purging efficiency
- › Monitoring system based on purging plug temperature measurement and modelling

# Selected RFCS research projects dealing with aspects of stirring process monitoring

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# Layout of the system for camera-based monitoring





# 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



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

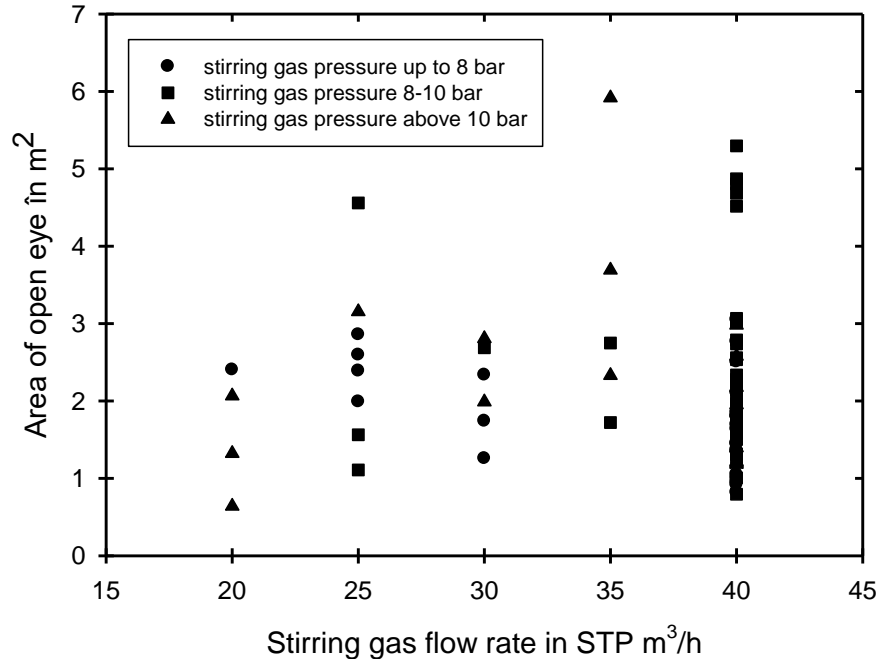
### Overall objectives:

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

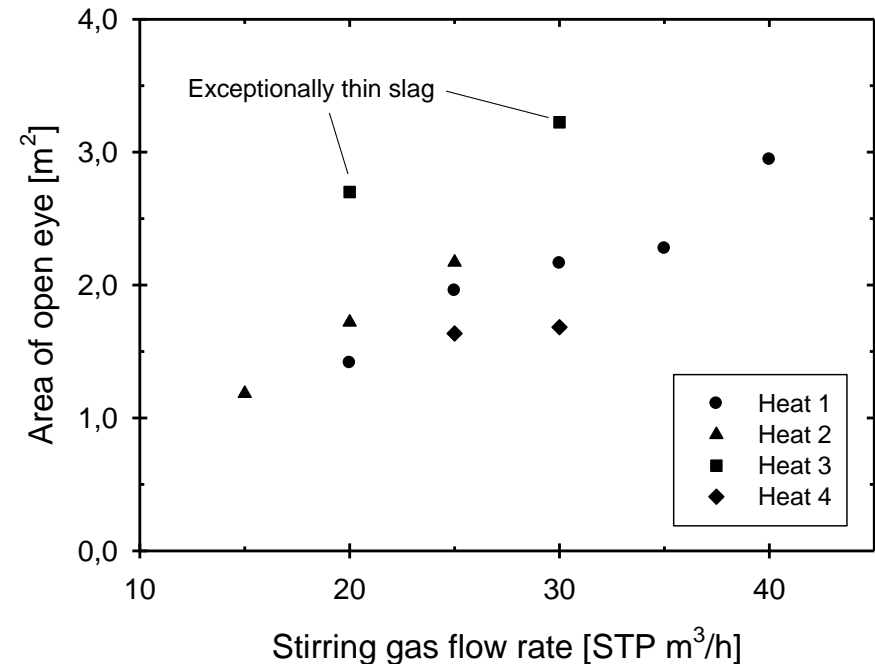
- › Investigation of the interaction between solid (alloying addition, inclusions), liquid (steel, slag) and gaseous (stirring gas, atmosphere) phases that are involved in the ladle stirring process in
  - › Alloying
  - › Emulsification
  - › Reoxidation
  - › Rinsing (soft stirring)
- › Determination of castability and cleanliness
- › Optimisation of the complete ladle stirring practices with regard to alloying and rinsing
- › Emulsification and Reoxidation studied in the laboratory and during processing of industrial heats
- › 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
- › In combination with theoretical investigations and model trials, optimised ladle stirring practices developed

## 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 indicator of the actual stirring intensity during ladle treatment



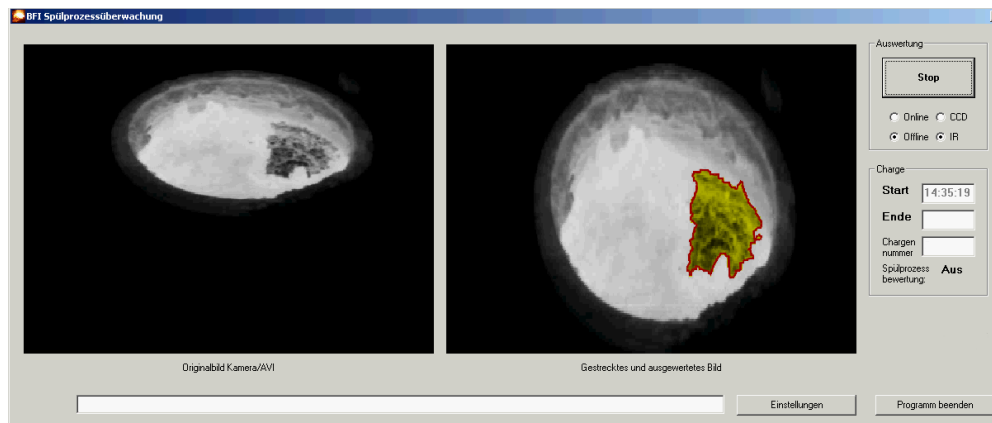
Area of the open eye against the stirring gas flow rate for 82 heats: no correlation



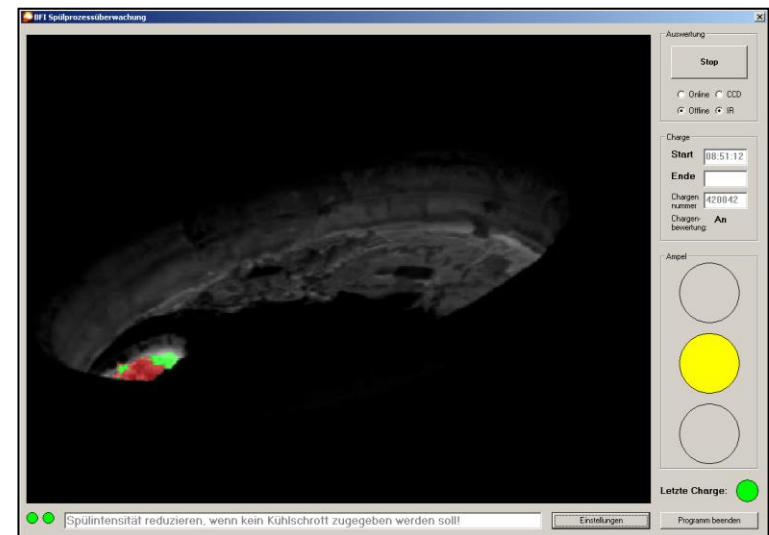
Area of the open eye vs. stirring gas flow rate (four specially treated heats)

## 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.



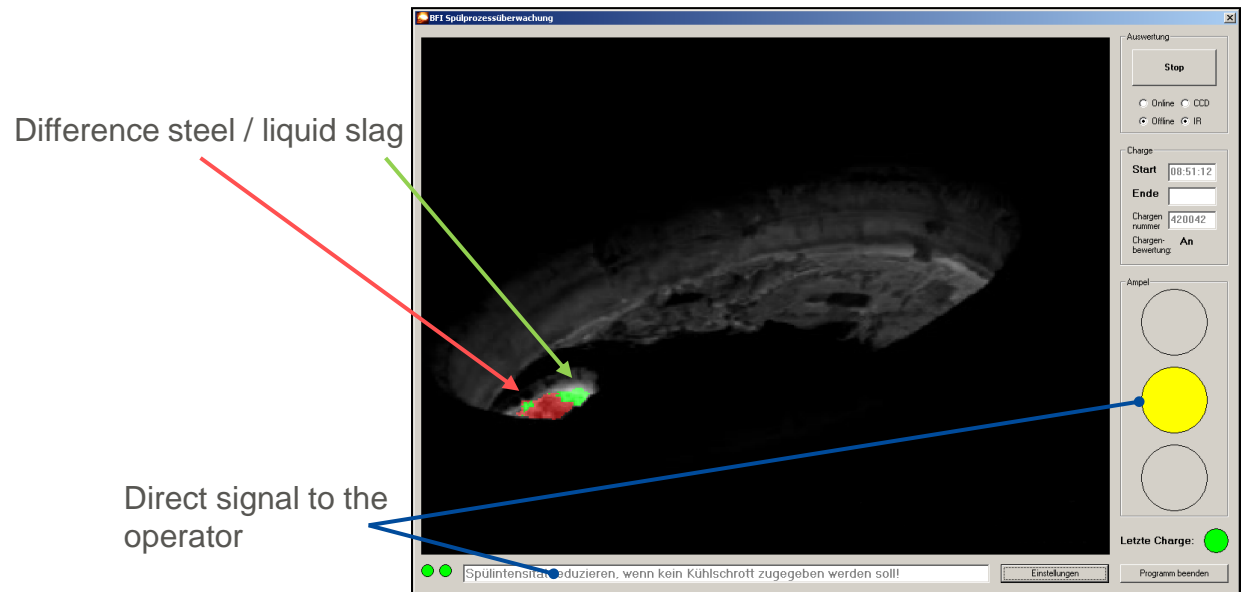
Monitoring software for strong stirring



Monitoring software for soft stirring

# Main features of BFI software

- › Process analysis and feedback
  - › Current stirring intensity is continuously analysed
  - › Graphic display for immediate evaluation of the stirring process
- › Alarm on deviations from normal conditions
  - › Triggered when stirring efficiency deviates from pre-set boundary values
  - › Displayed on a signal light for immediate recognition
  - › Optional alarm message delivered to process control system



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  - › Displayed on a signal light for immediate recognition
  - › Optional alarm message delivered to process control system
  
- › Summary of the stirring treatment
  - › At the end of the treatment of each heat
  - › Documentation of the stirring behaviour during the complete treatment
  - › Video archive for documentation purposes
  
- › Heat clearance
  - › Based on the summary of the stirring treatment
  - › Suggestion for clearance of the heat

### Optimised stirring practices:

- › Suggestions collected based on theoretical calculations, physical modelling and monitored industrial trials
- › Main result: Stirring intensities (stirring gas flow rates) could be decreased without fear of detrimental effects on cleanness, also stirring duration could be reduced except for separation of inclusions
- › A reduction of stirring gas flow rate from the normally applied 35-40 STP m<sup>3</sup>/h to 20-30 STP m<sup>3</sup>/h) showed that the cleanness of the final product was not affected significantly by the reduction of the stirring gas flow rate



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

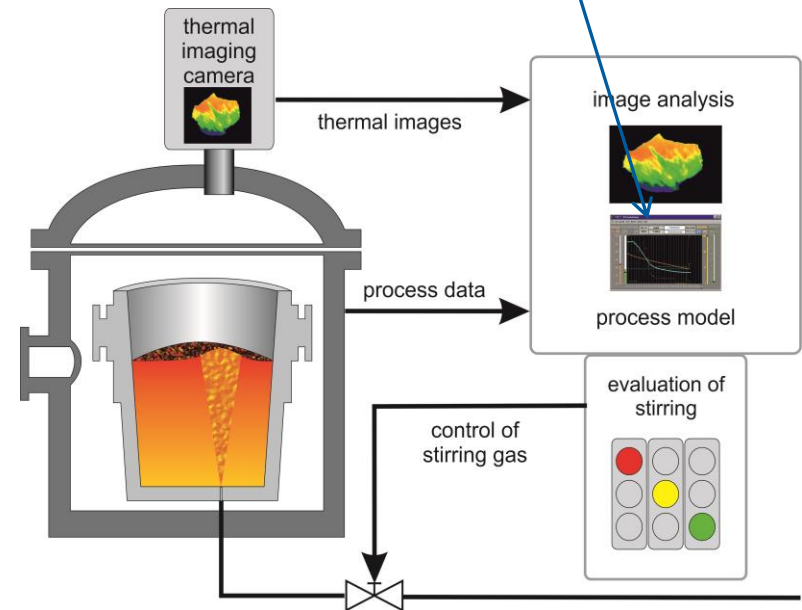
Process model also described in  
DissTec workshop on process models  
- see [www.bfi.de/en/projects/disstec/](http://www.bfi.de/en/projects/disstec/)

## 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:

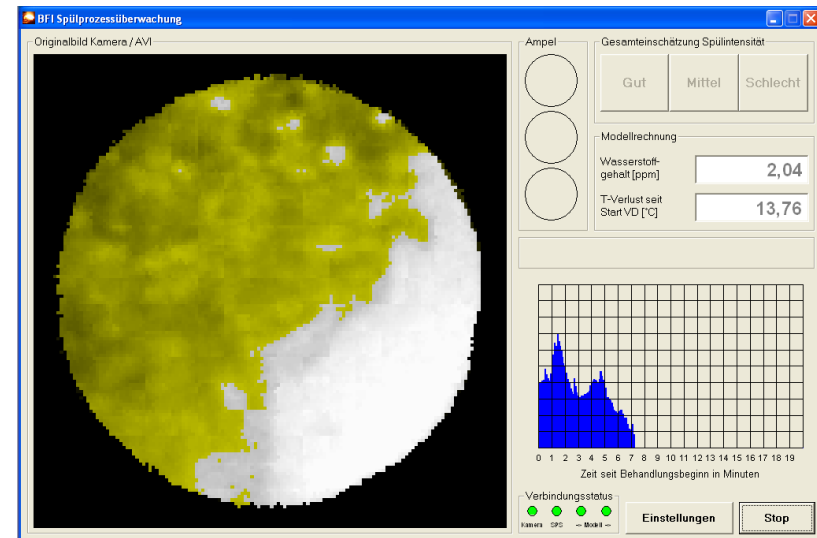
- › Development and application of an enhanced on-line monitoring and control system for reliable operation of different ladle refining processes:
  - › Thermal imaging based evaluation of stirring efficiency
  - › Improved dynamic process models
- › Analysed process steps: VD, VOD and LF



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

Monitoring of..	VD	VD/VOD	LF
stirring efficiency	yes	yes / yes	yes
de-H	yes	-	-
de-C	-	yes	-
Temperature	yes	yes	yes
Slopping	-	yes	-
Control of...	VD	VD/VOD	LF
stirring efficiency	yes	yes	yes
de-H	yes	-	-
de-C	-	-	-
Temperature	yes	-	yes
Slopping	-	yes	-
Documentation of ...	VD	VD/VOD	LF
stirring efficiency	yes	yes	yes
de-H	yes	-	-
de-C	-	yes	-
Temperature	yes	yes	yes
Slopping	-	by videos	-

- › Developed and installed imaging systems became an important tool for process control
- › VD: 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.



Monitoring software for VD treatment

- › VOD: Slag slopping avoidance recipe is applied at VD/VOD plant, when considered as necessary.
- › LF: The dynamic process model as well as the visual inspection is integrated in the secondary steelmaking production process at LF plant.

## Improvements in process performance of ladle refining operations

- › VD/VOD plant
  - › Improved decarburisation rate
  - › Reduced process time by 5 min (90.4 min -> 85 min)
  - › Productivity increase dominates incremented Cr loss
- › LF plant
  - › Correlation between total oxygen content and stirring intensity
  - › Checking the stirring intensity before and after treatment
  - › Directly from control station -> safety
- › VD plant
  - › 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

# RFCS project OptDeslag: Increased yield and enhanced steel quality by improved deslagging and slag conditioning

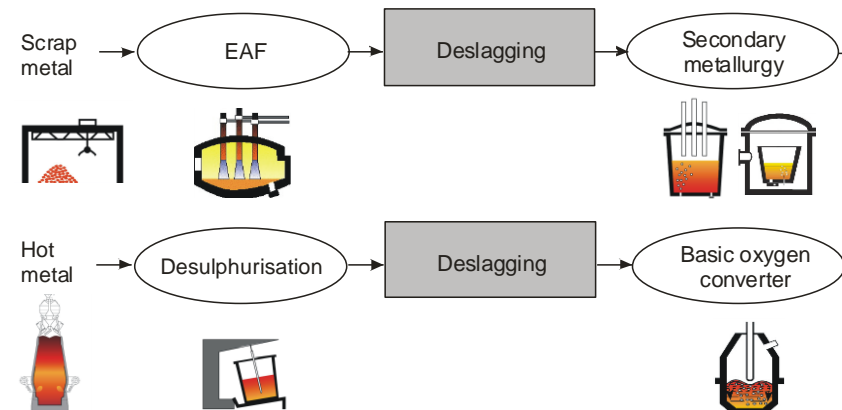
Aim: Improve deslagging and slag conditioning

See also presentation of Lars-Erik From  
on Tuesday, May 23<sup>rd</sup> 2017

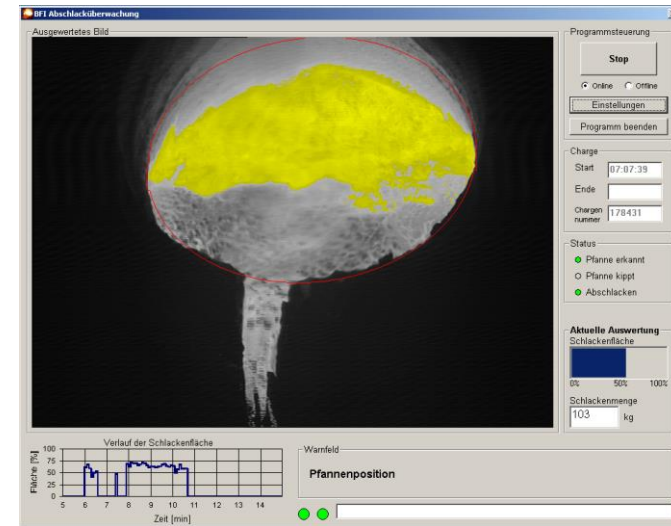
- › Monitoring and control of deslagging operations
  - › Obtain reproducible performance of the deslagging process
  - › Minimise and determine the amount of remaining slag
  - › Minimise the amount of removed iron/steel
- › Dynamic online process models to monitor and control the slag properties throughout 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



- › 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



- › 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

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## RFCS project ImPurgingAr: Improvement of purging plugs performances by investigations on the material, process analysis and continuous monitoring

### Aim:

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

### Scientific objective:

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

### Technical objective:

- › Develop and test a system to measure the purging plug wear during in ladle operations

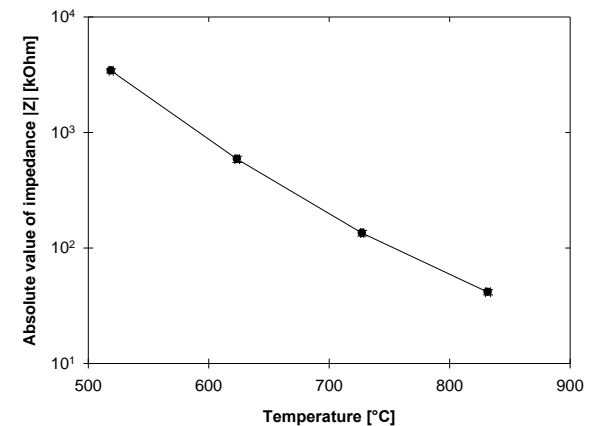
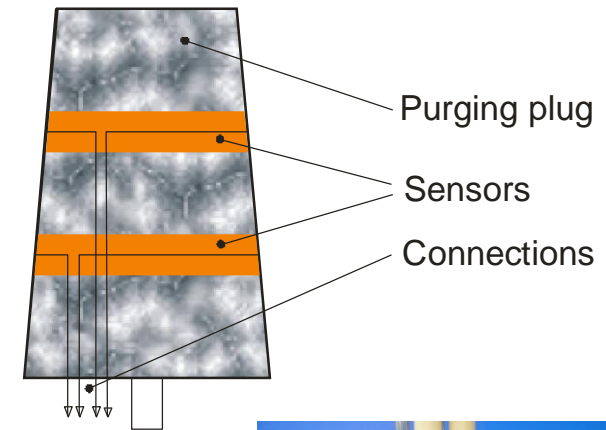
### Contribution of BFI:

- › Development of a measurement system for on-line determination of the purging plug wear status by measuring temperature along the plug
- › Extensive testing and improvement of the purging plug wear measurement system during measurement campaigns

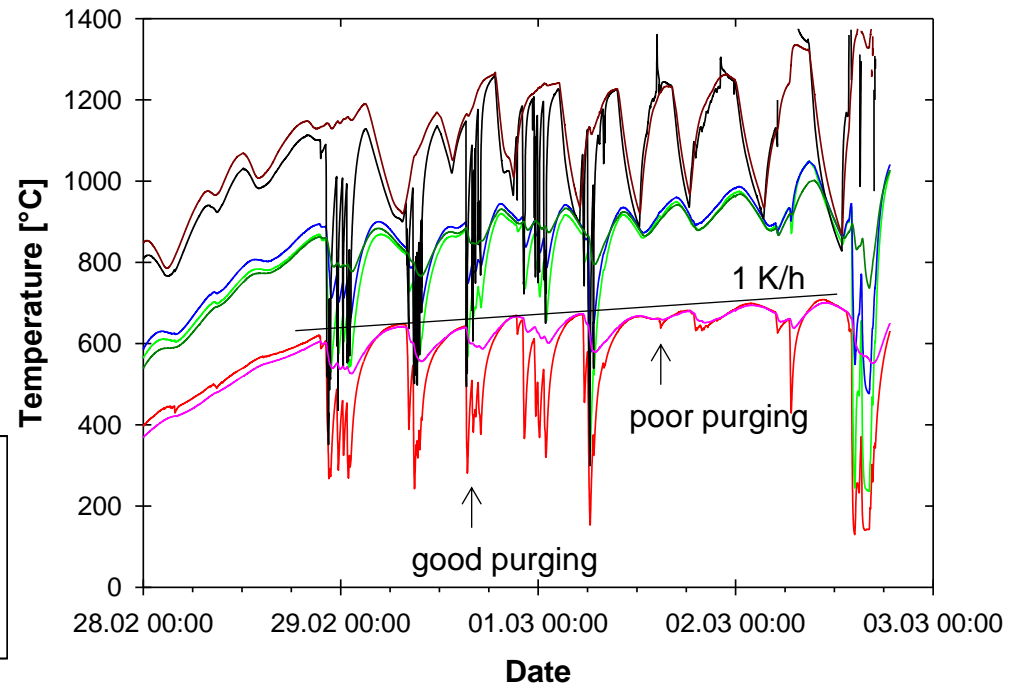
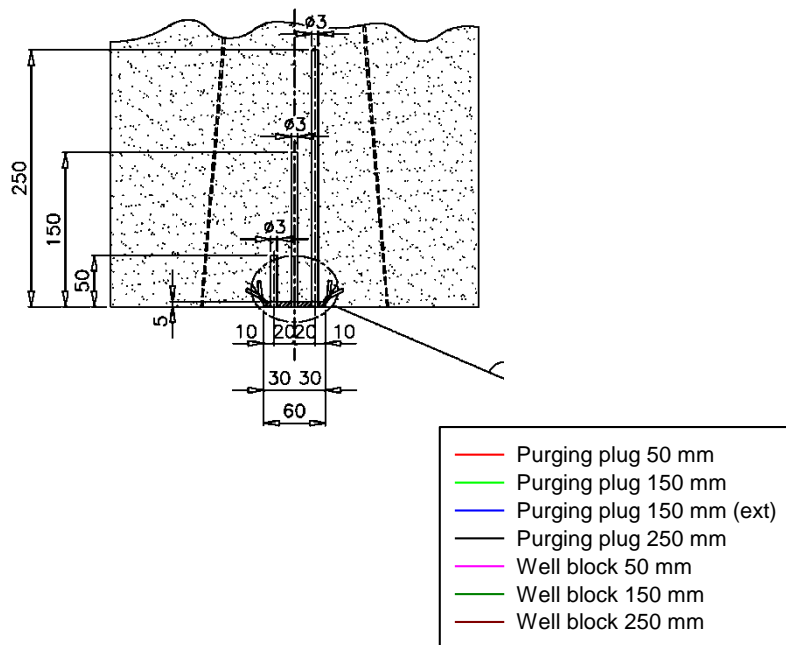


# RFCS project ImPurgingAr – Results

- › Wear measurement strategy was based on the temperature increase inside of purging 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 purging plug, and
  - › an electronic evaluation unit
- › Electronic evaluation unit developed to be rugged and basic, extensively tested in laboratory trials
- › Tested against an impedance spectrometer, system provided consistent results: Sensors worked reliably and reproducible up to 800 °C.
- › Thermal calculations and industrial campaigns proved that sensors are well suitable for the use in industrial environments



- › 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 maximum temperature of the thermocouples during the heats

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

### Objectives

- › Develop and establish a purging plug monitoring system based on continuous online temperature measurements in the plug. The main targets are to
  - › 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

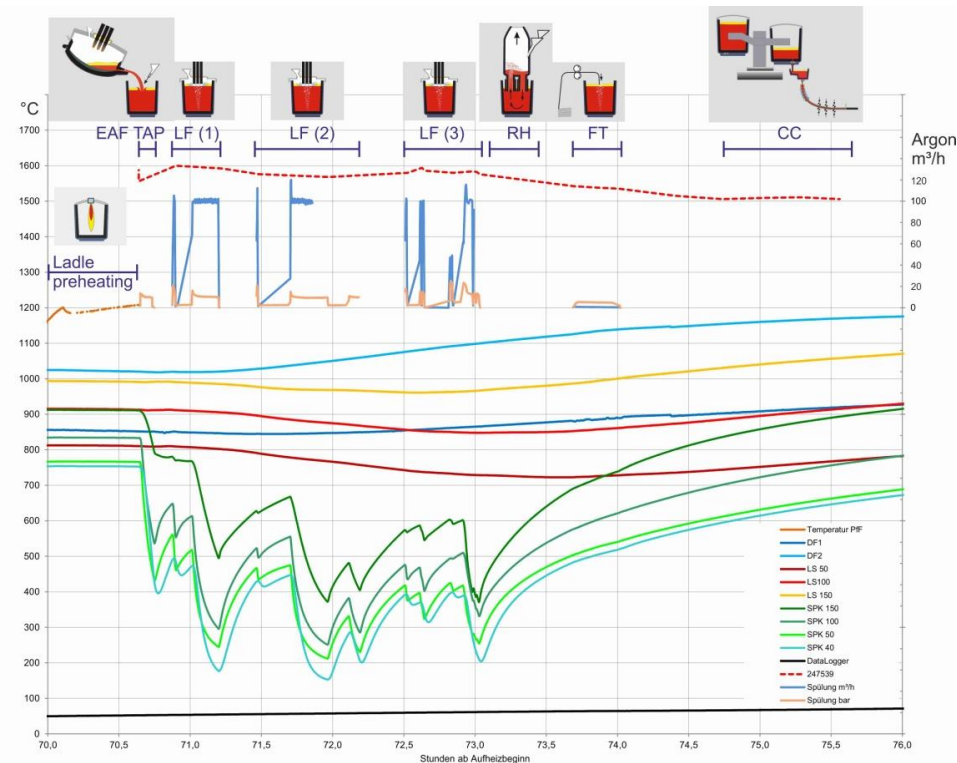
- › Measurement techniques for plug refractory temperature
  - to monitor the performance of purging plugs
- › Numerical simulation of process induced changes in purging plugs
  - to determine online the wear status of purging plugs
- › Software engineering to determine and predict purging plug availability and performance

# RFCS project PlugWatch – Results

› Temperature measurements in purging plug, well block and ladle bottom during several heats after relining and in used ladle performed, process route including LF+RH or LF+VOD

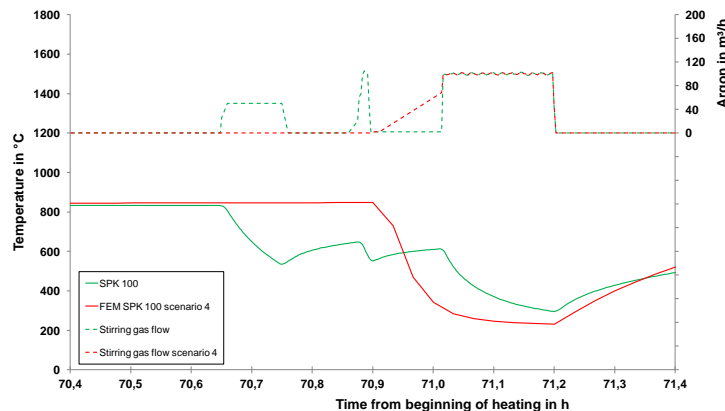
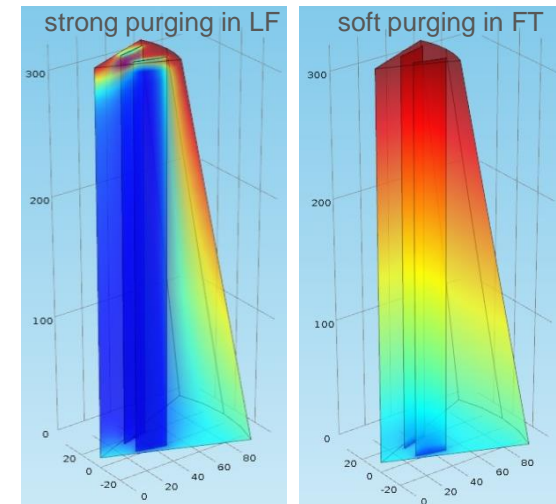
› Plug life is strongly affected by temperature gradients resulting in high thermal stresses

- › High cooling rate in one position (up to 600 °C within 50 s)
- › High temperature gradients within purging plug height (up to 1400 K within 210 mm)

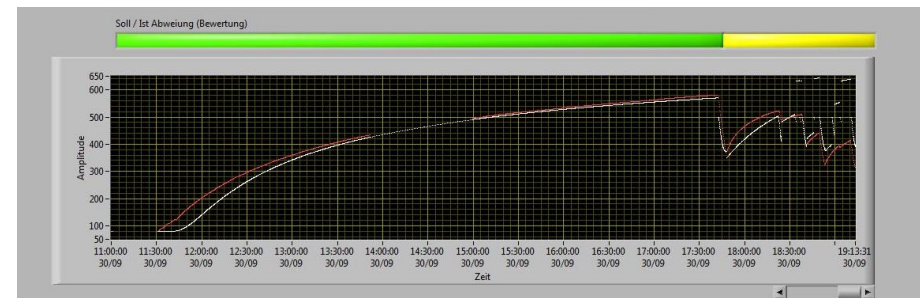


- › Improved knowledge on purging processes and their effect on plug wear
- › The longer the purging during ladle operation is, the lower will be the plug heating and the lower is the expected degradation and wear of plug refractory
  - › The more purging operations (purging switch on/off), the more wear is observed

- › 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

- › Temperature measurements in purging plug refractory showed possibility to monitor and predict plug availability and performance as well as plug wear
- › Monitoring, both camera-based and based on temperature measurement, supports the control system to produce high-quality steel
- › Support to steel production to react in time if wear status or degradation of a purging plug have negative influence on further purging procedures
- › Minimization of time for maintenance to control and change the purging plug, especially in steel plants that do not burn-free plugs
- › Prolongation of plug service life

**Thank you very much for your attention !**

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