DissTec

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

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Measurement technologies for secondary metallurgy

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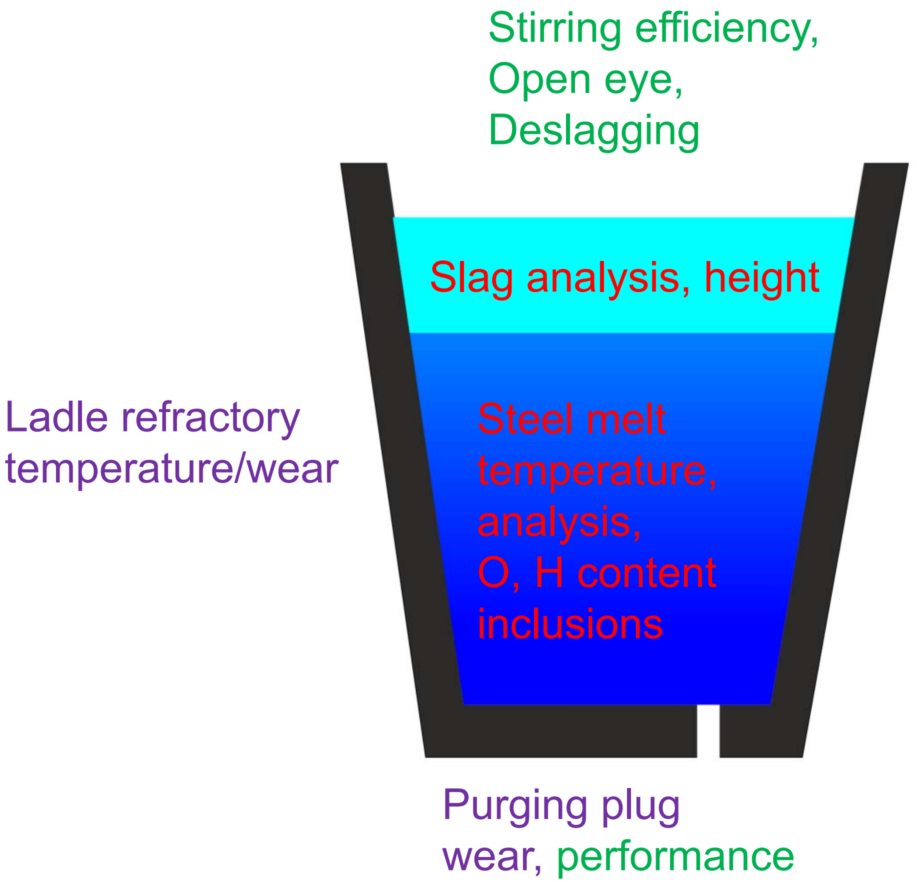
Stahl

SecMet Measurement Technologies

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



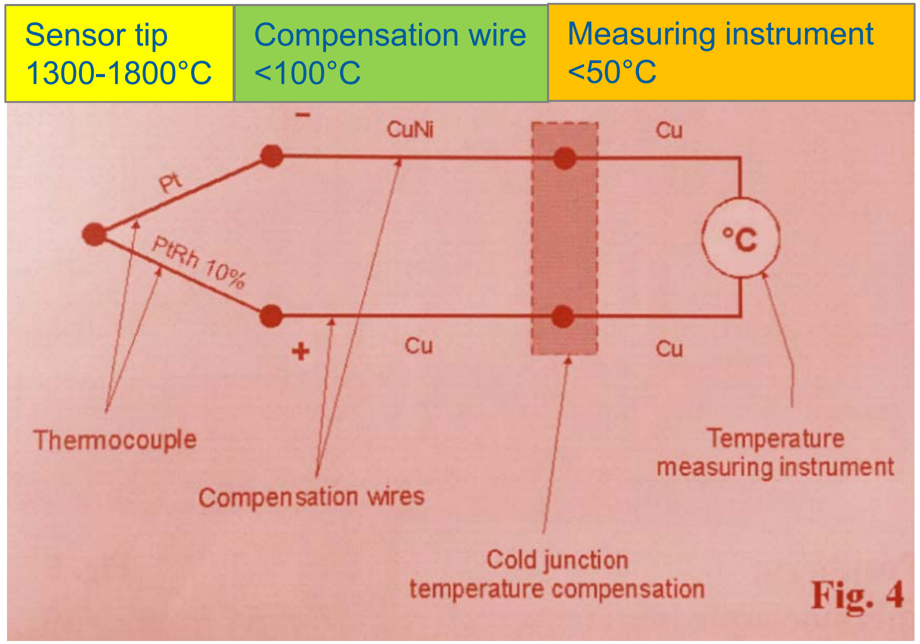
Content:

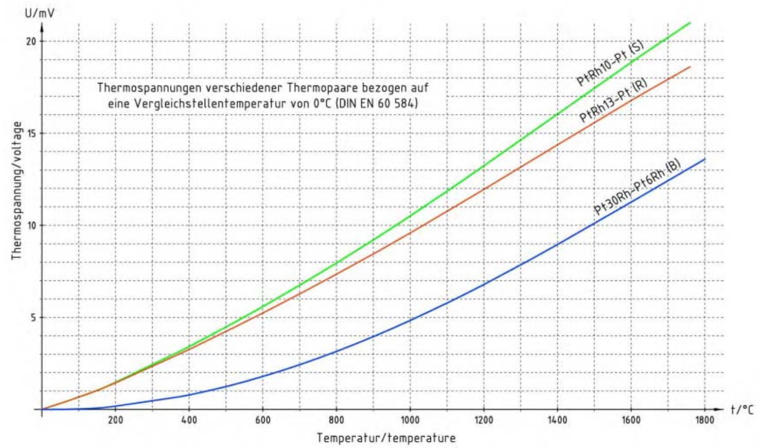
- Melt temperature (spot)
- Melt temperature (conti)
- O/H content
- Steel/Slag analysis
- Steel cleanness/inclusions
- Ladle refractory temperature/wear
- Purging plug wear
- Purging plug performance
- Stirring efficiency
- Deslagging

Melt temperature measurement (spot)

Spot melt temperature measurement by thermocouples

- Seebeck Effect: Junction of two wires of different composition generate a voltage dependent on temperature
- Type S: Pt/PtRh10, up to 1750°C, mostly used
- Dip measurements (state of the art)

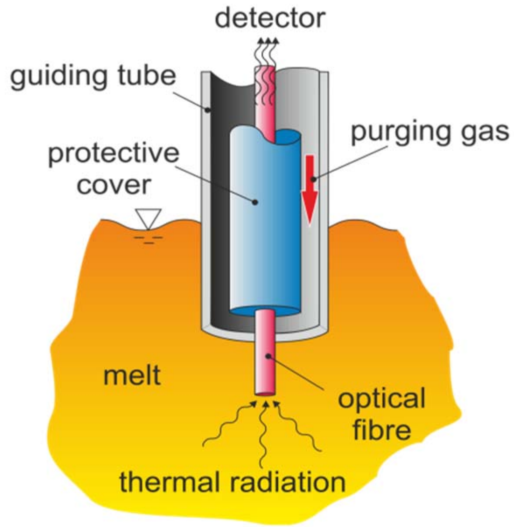




Melt temperature measurement (continuous)

Continuous melt temperature measurement DynTemp®

- Consumable optical fibre continuously fed into melt via gas purged metallurgical nozzle
- Thermal radiation is guided to a detector
- Measurement accuracy for spot measurements +/-2K
- Improved measurement accuracy by continuous measurement
- High measurement dynamics



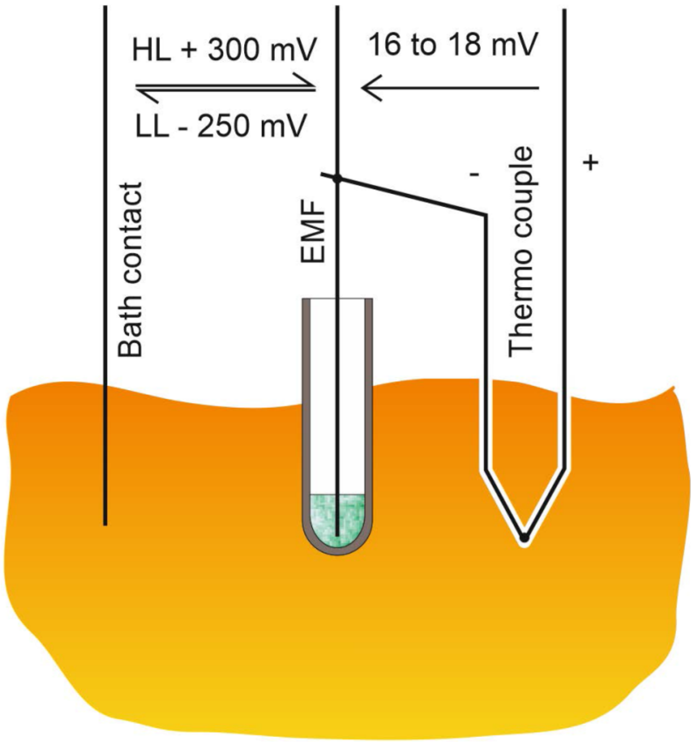
Oxygen content

Oxygen content in metallic melts

- Solved oxygen
  deteriorates steel cleanness by forming oxidic inclusions,
  reduces the efficiency of alloying elements,
  forms gas cavities during solidification
- Electrochemical measurement
  of electro motive force (EMF)

$$EMF = \frac{RT}{nF} ln \frac{c_{melt}}{c_{reference}}$$

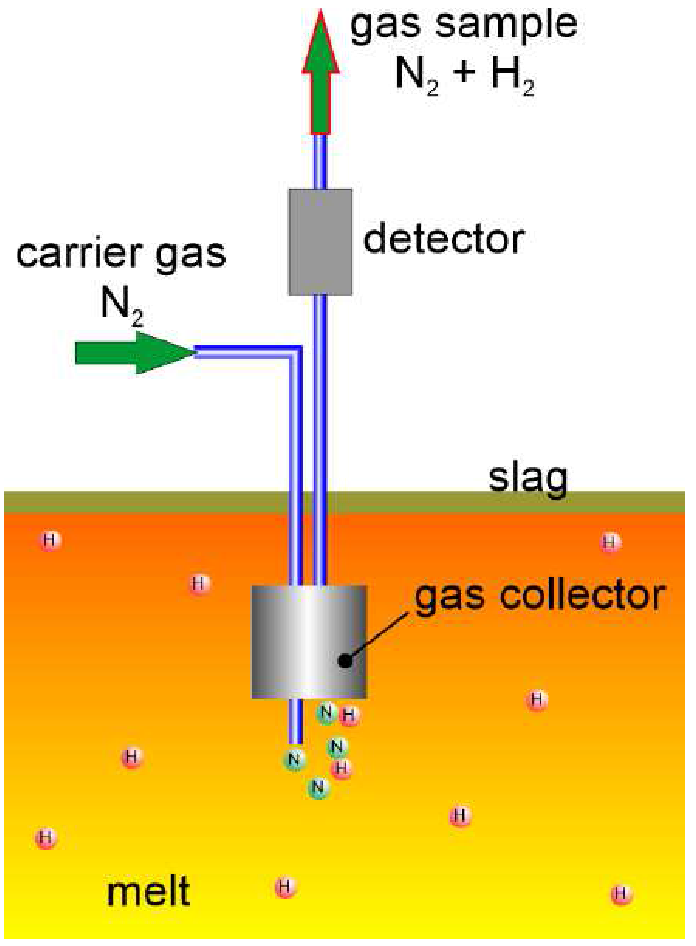
- BOF, EAF, VAC (before decarburisation):
  high level application: 600-1200ppm
- VAC, LF, CC:
  low level application: 1-10ppm
- Dip measurements for online analysis
  (State of the art)



Hydrogen content

Hydrogen content in metallic melts

- H causes embrittlement in products
- Based on thermo-conductivity of gases (for H much larger compared to other gases)
- Dip measurement for online analysis after vacuum degassing (State of the art)



Chemical analysis of steel

AMASA: On-line analysis of molten steel for automated steel production (Krupp, 1998-1991)

› Online analysis of liquid steel (C content 1%-100ppm) in the converter through an Ar tuyere

SELA: Fast multi-element on-line analysis of steel melts by means of laser technology (ILT, 1991-1993)

› LIBS of 16 elements at metal surface through lance at secondary metallurgy applying laser modulation and fibre optics

Challenges of LIBS

› Strong dependence on
  › Focus, distance
  › Melt temperature
  › Surface properties
  › Self-absorption (Ca)

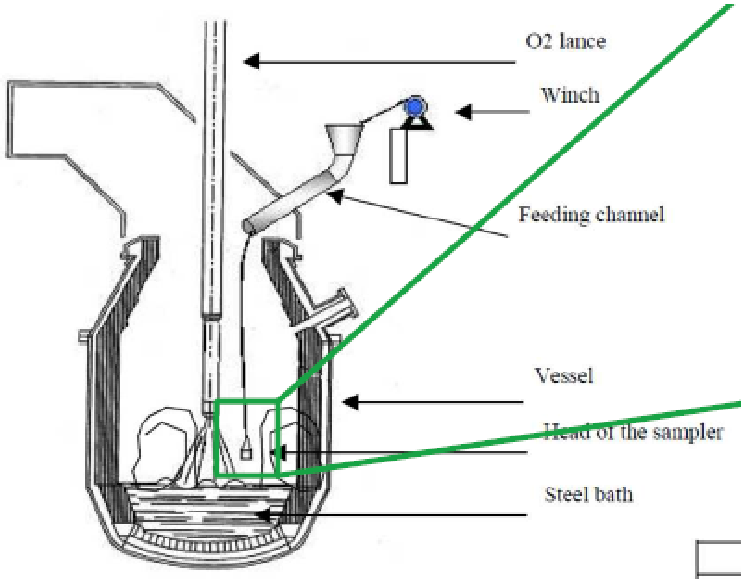
Chemical analysis of slag

AVAS: Feasibility of a fast vacuum slag analysis by laser OES in secondary metallurgy
(DH, AMMR, ILT, SAR, 2003-2006)

- Offline analysis of solid slag samples wrt SiO_2, CaO, Al_2O_3 taken from the vacuum degasser
- No reliable results

BOFDYN: Dynamic end-point control in BOF through a fast and simultaneous determination of the steel/slag composition
(CRM, HEN, AMMR, SIMR; 2003-2006)

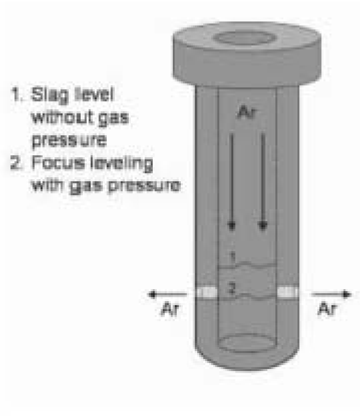
- Sampling from melt during the process
- Chemical analysis of steel and slag by LIBS (reference OES, XRF)
- Samples need surface preparation for analysis
- Cross-coupling of steel and slag analysis



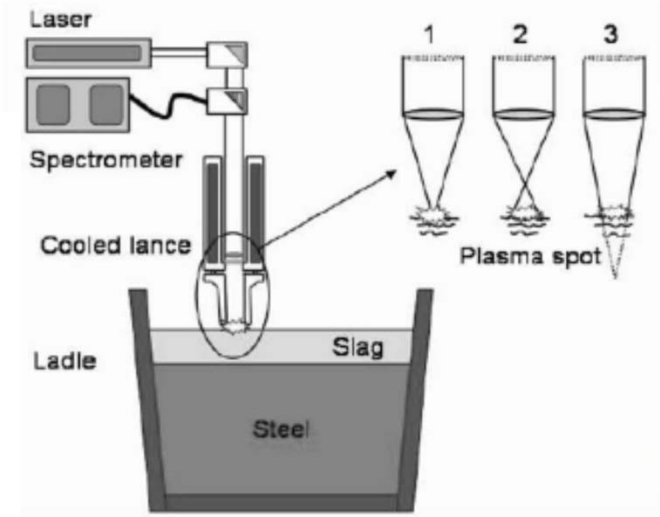
Chemical analysis of slag

INQUISS: Insitu, quick sensing system for measurements of process-critical components in steelmaking slags
(RWTH, Aceralia, Acerinox, Hellsinki Halyvourgia, Uni Malaga, Uni Patras; 2001-2004)

- Chemical analysis of slags with respect to Ca, Al, Si, Mg, Fe, Cr by LIBS
- Application at EAF, BOF and ladle
- Main issue:
  Focussing the laser beam on a waving slag surface
  Influence of the melt temperature



Special graphite nozzle for auto-focus action



Three cases of plasma spot positions (Rem.: n° 1 is correct)

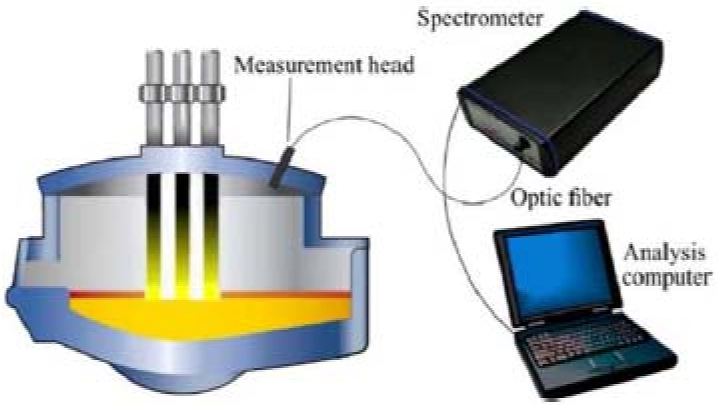
Chemical analysis of slag

Analysis of emission spectra from electric arc

- Laboratory investigation at DC EAF (Uni Oulu, Helsinki)
- Trials at pilot AC-EAF of RWTH (Uni Oulu, RWTH)
- Trials at industrial 140t EAF (Uni Oulu, Outokumpu)

OSCANEAF: On-line slag composition analysis for electric arc furnaces (RWTH, Oulu, KTH, Lux Met, Osoy, DEW; 2016-2019)

- Online analysis of Cr_2O_3, MnO, Fe_xO_y, CaO, SiO_2, Al_2O_3, MgO, and CaF content of the slag for stainless and carbon steel grades in the EAF and LF.



Steel cleanness

Laser Induced breakdown Spectroscopy (LIBS)

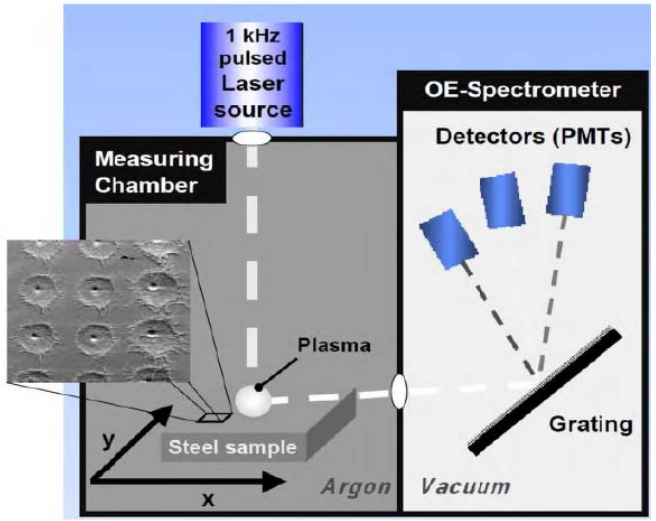
- LIBS is a quick and powerful micro-analytical technique for mapping of local element distributions

Pulsed Discrimination Analysis-Optical Emission Spectroscopy (PDA-OES)

- PDA-OES is widely used in steel plants, since it is available for chemical analysis of steel

Comments

- Both techniques analyse inclusions offline at cold samples giving the results after distinct time delay
- Reference SEM, Identification of inclusion: Peak higher than $\langle I \rangle + n\sigma$, $3<n<5$
- Surface preparation by milling: Size is systematically smaller compared to bulk
- Number/density of inclusions: One peak ‡ one inclusion



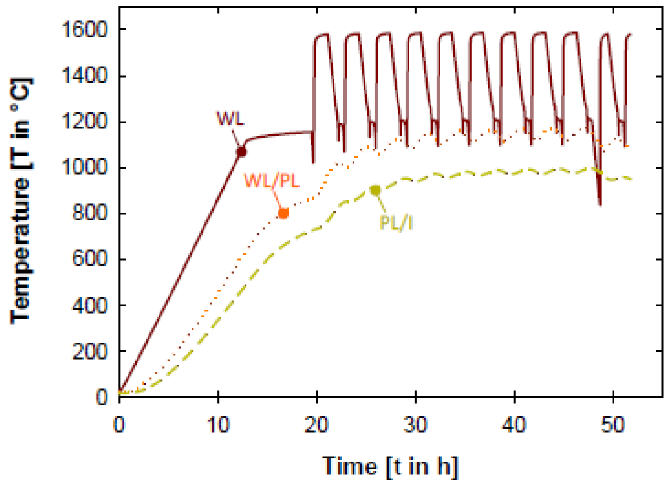
(7210-PR-168) Improved production control through rapid characterisation of non-metallic inclusions in steel

(7210-PR-300) In-line assessment of steel cleanness during the secondary steelmaking process

Ladle refractory wear

LadLife: Enhanced steel ladle life by improving the resistance of lining to thermal, thermomechanical and thermo-chemical alterations (2009-2012)

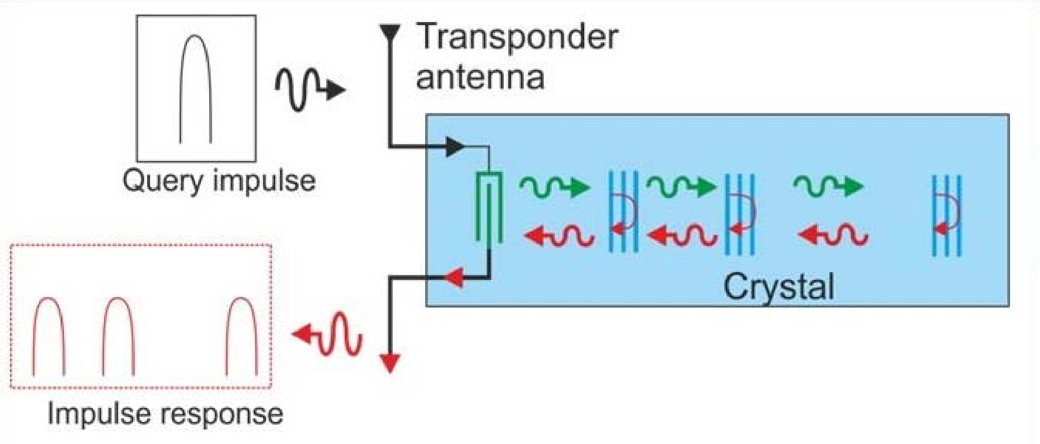
- Improvement of ladle refractory life
- Temperature and stress distribution calculated by FEM simulation for different ladle geometries and process conditions
- Recommendations for optimum refractory materials and operational practices



Ladle refractory temperature

LadTherm: Improving steelmaking process by enhancing thermal state ladle management (2014-2017)

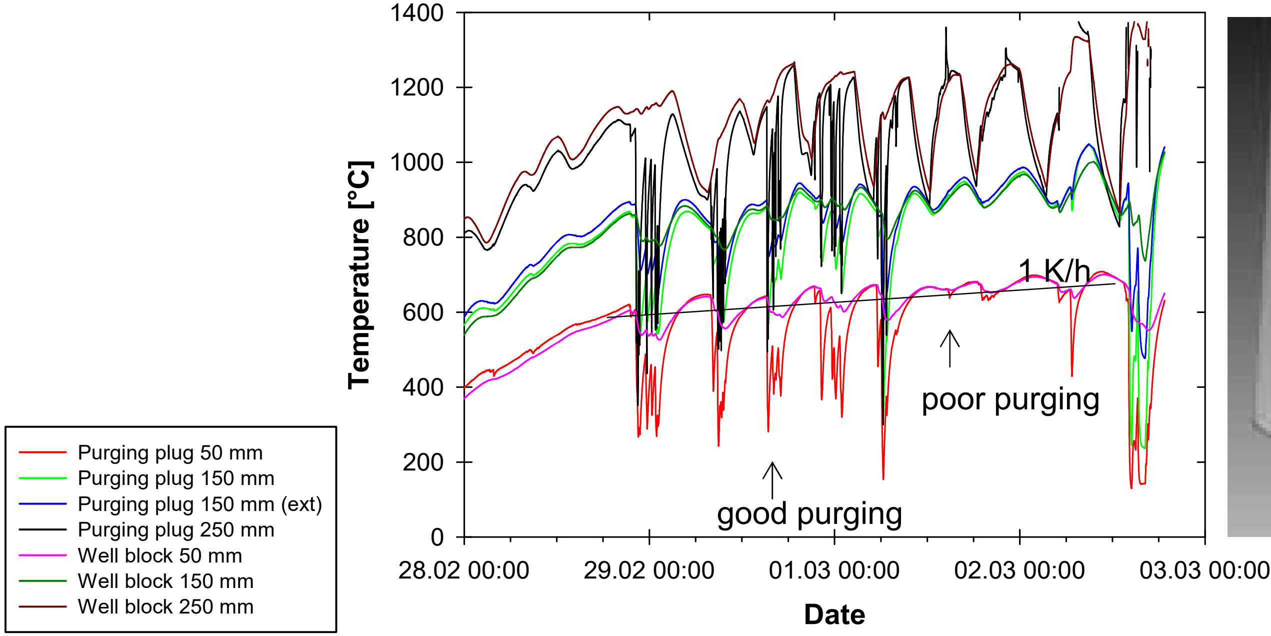
- Monitoring the thermal state of ladles to improve existing liquid steel temperature models
- Surface acoustic wave (SAW) tag is a passive ceramic sensor, which can withstand 400°C
- Antenna sends EM pulse,
  response contains information on the temperature
- Industrial application difficult, range limited

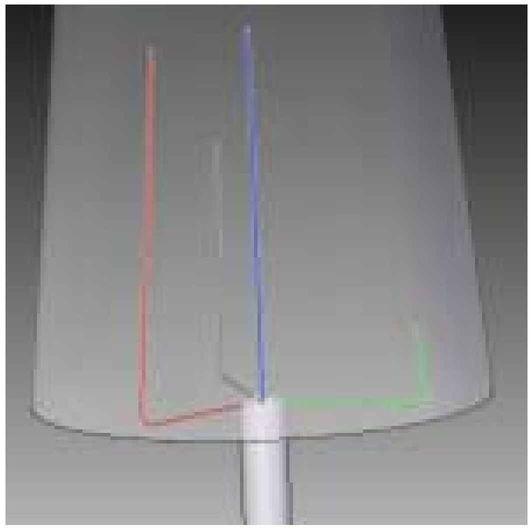


Purging plug wear

ImPurgingAr: Improvement of purging plug wear by investigation on material, process analysis and continuous monitoring (2005-2009)

- Monitoring of purging plug wear
  by temperature measurements within the plug refractory at fixed position utilising the temperature dependent electric resistivity and by 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)

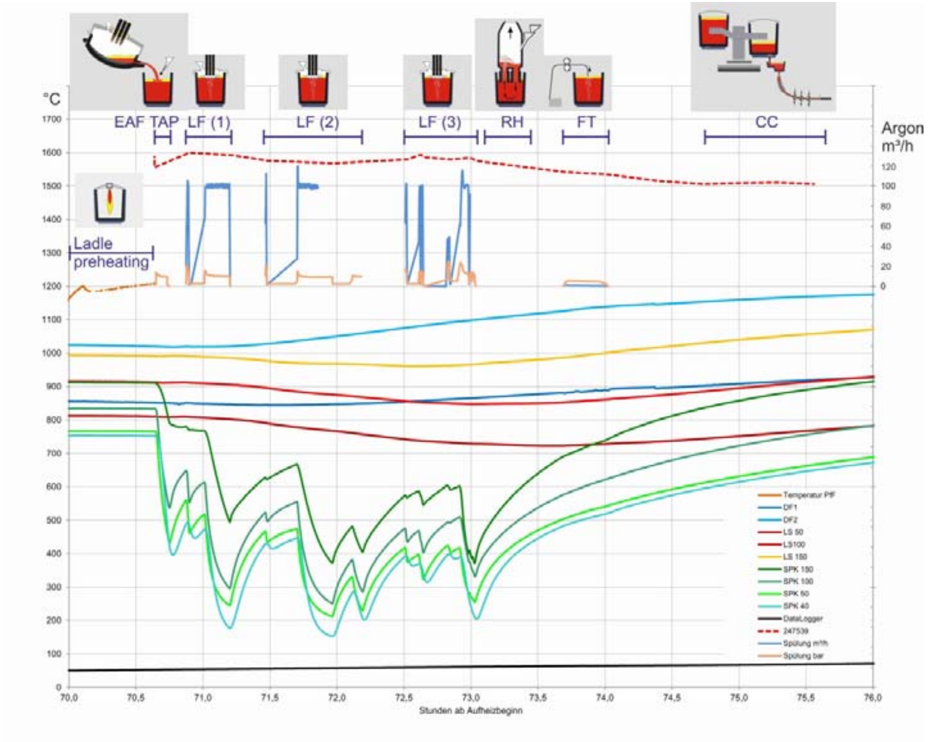




Purging plug performance

PlugWatch: Stirring plug monitoring system for improvement of plug availability and stirring performance (2012-2015)

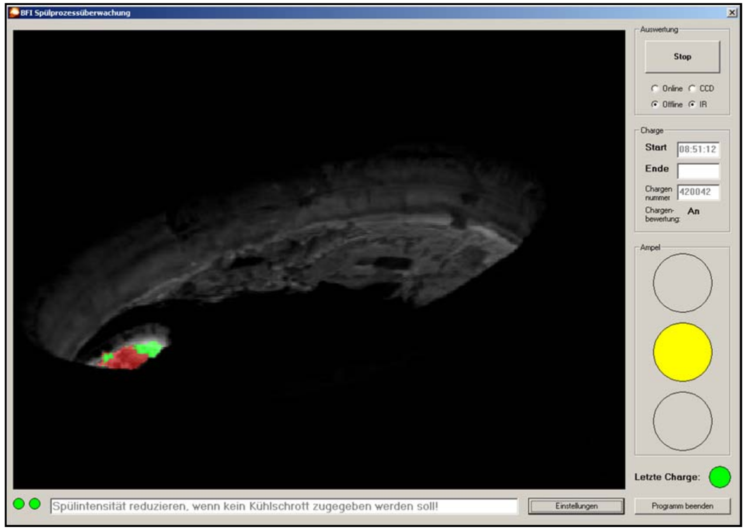
- Temperature decrease of plug refractory is indicator for amount of purging gas passing through the plug
- Improve the performance of purging processes (improved reliability)
- Avoid non-purging events (improved availability)
- Generate decisions about purging plug maintenance operations
- Improved knowledge on purging processes and their effect on plug wear

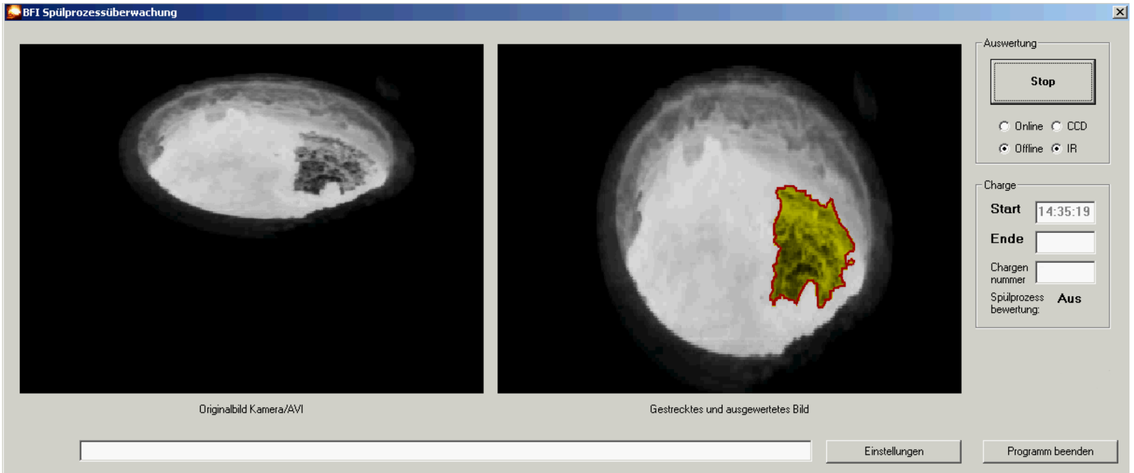


Stirring efficiency

StImprove: Improvement of ladle stirring to minimise slag emulsification and reoxidation during alloying and rinsing (2007-2010)

- Stirring gas flow rate no reliable process control parameter
- Camera image and image analysis allows to
  - determine the actual stirring efficiency
  - adapt gas flow rate for soft stirring
- Automated image analysis to determine size of open eye and length of steel-slag contour
- Permanent installation in different industrial sites

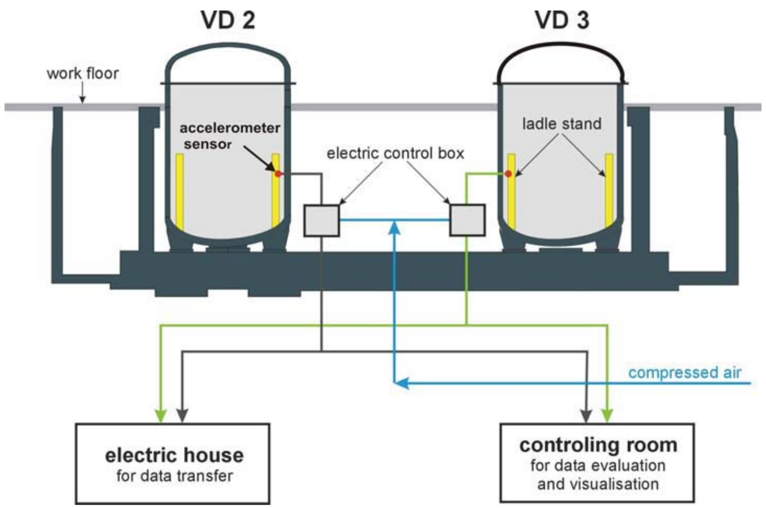


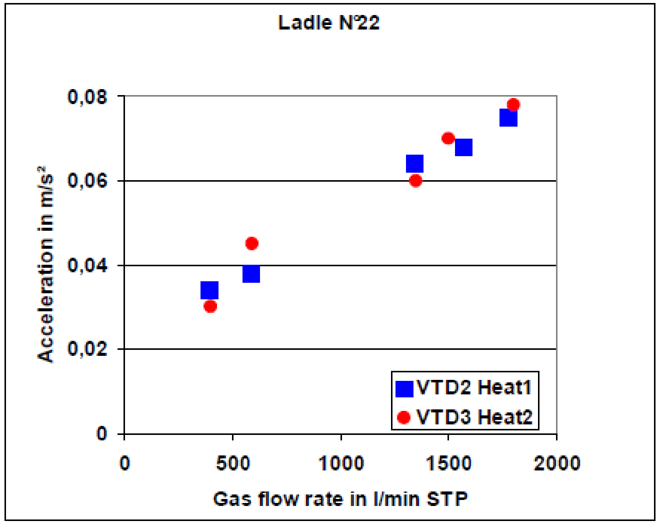


Stirring efficiency

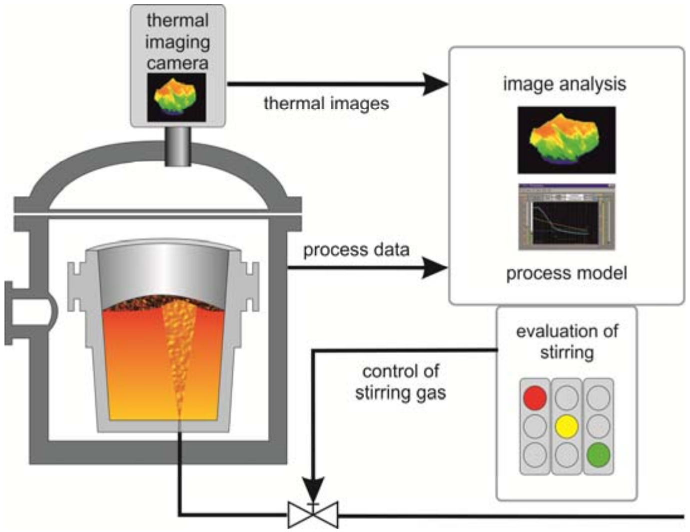
ONDECO: Online control of desulphurisation and degassing through ladle bubbling under vacuum (2007-2010)

- Vibration sensors and cameras were installed to monitor effect of stirring during vacuum degassing and LF respectively
- Use purging index from camera image to increase reliability of online desulphurisation model
- Use vibration index to increase reliability of online desulphurisation model and degassing performance (H, N removal)



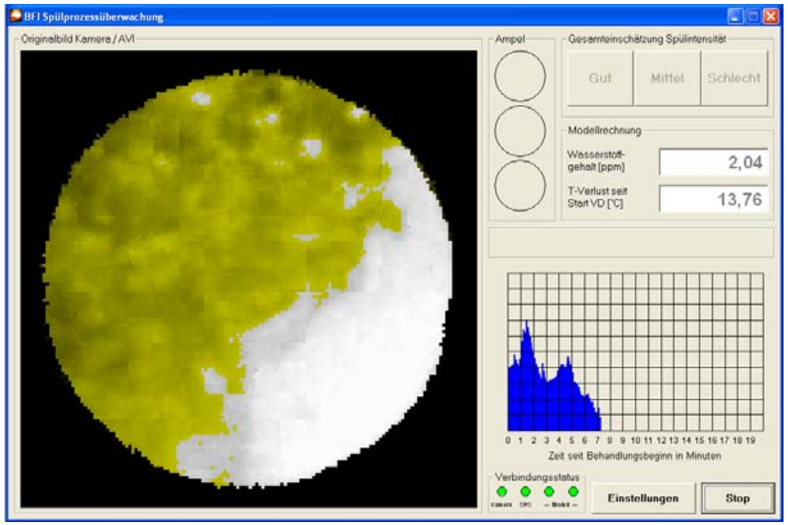


Stirring gas reliability



LaRefMon: Enhanced reliability in ladle refining processes by improved on-line process monitoring and control (2008-2011)

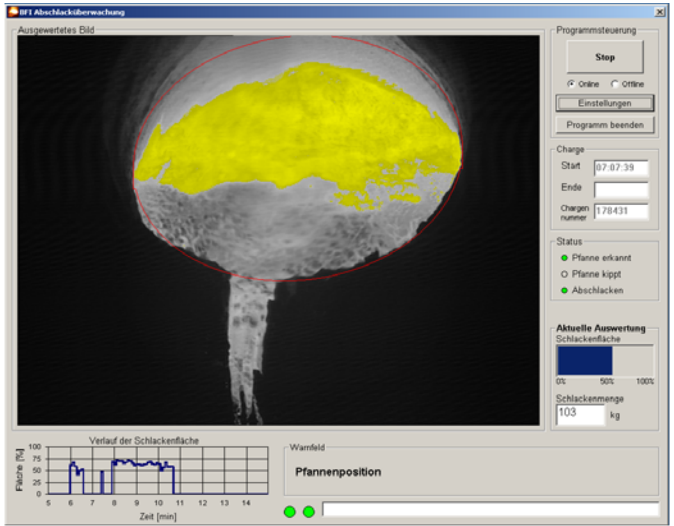
- Based on IR images steel and slag melt at equal temperature can be differentiated
- Online monitoring of melt bath surface during VD treatment
- Improvement of quality and cleanness of liquid steel,
- Reduction of treatment times leading to lower energy losses
- Improved productivity



Deslagging efficiency

OptDeslag: Increased yield and enhanced steel quality by improved deslagging and slag conditioning (2010-2013)

- Different camera systems (Vis, IR) supported, Software customised for plant conditions
- Adaptive routines to respond to changing environmental conditions
- Monitoring the deslagging process to minimise slag carry-over
- Remaining slag amount estimated from the slag area
- Process models calculate the amount of slag formers based on calculated slag composition and estimated amount of slag carry-over



Measurement technologies for secondary metallurgy

Summary:

- Spot melt temperature, O,H content are industrial standard
- Continuous melt temperature industrial demonstrator available
- Online analysis of steel/slag composition still not satisfactory solved
- Offline analysis of steel cleanness
- Ladle temperature/wear, purging plug wear/performance available in campaigns to optimise aggregate/process
- Online stirring monitoring (IR/VIS camera, vibration) in permanent industrial use
- Online deslagging monitoring in permanent industrial use

Measurement technologies for secondary metallurgy

Outlook:

- Continuous online monitoring of steel/slag temperature/ composition for closed loop process control of individual batches at small sequence length, fluctuating energy availability, changing raw material quality
- Trace performance of components/aggregates and use sensors information for predictive maintenance
- Use reliable sensor information for monitoring also for process control to extend automation
- Extend camera supervision of production processes for process automation, process documentation, health and safety
- Combine measurements technology and model information to smart sensors
- Combine/compare different/redundant (smart) sensor information for verification/quality checks
- Sensors for Industry4.0/IoT applications

Thank you very much for your attention !

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