Model-based process control for secondary metallurgical steelmaking




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Stahl

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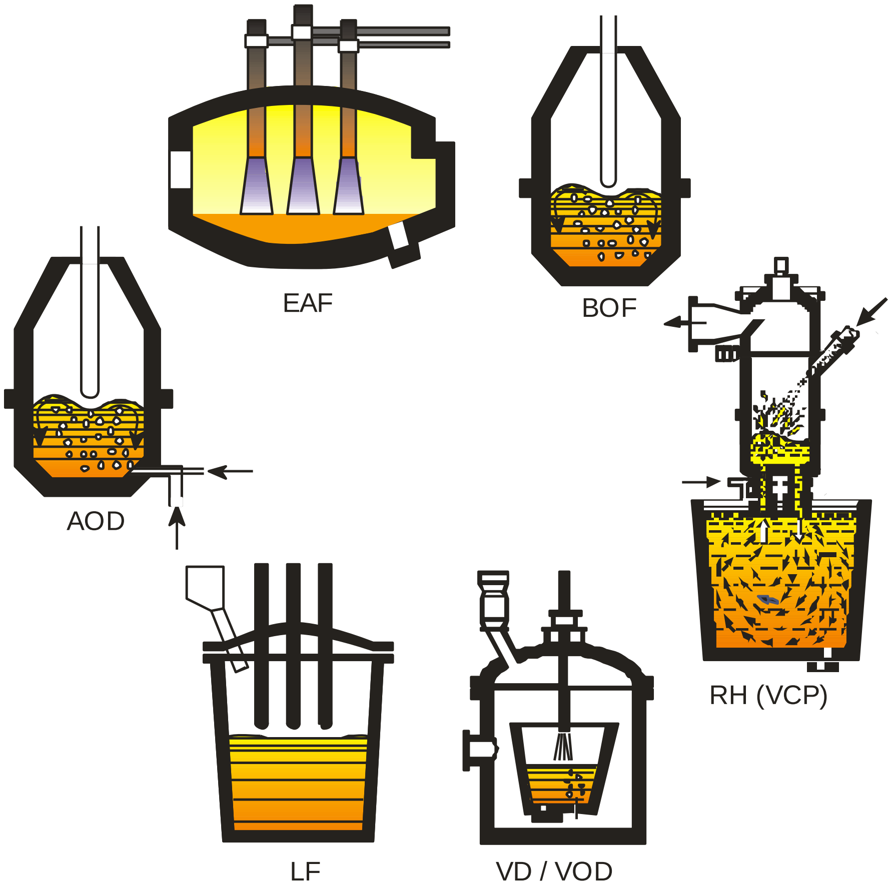
Model-based process control in liquid steelmaking

Excellence in Applied Research

Electric Steelmaking **Oxygen Steelmaking**



Secondary Metallurgy

Dynamic process models applied for:

- Model based on-line process monitoring
- Dynamic process control

With the objectives of:

- Reduced consumption of energy, material and media resources
- Reduced number of samples and measurements
- Increased productivity
- Reliable and reproducible process operation
- Improved transparency of the production process
- Improved quality of liquid steel regarding
  - Adjustment of aim temperature
  - Achievement of target analysis
  - Steel cleanness

Basic principles of dynamic process models

Dynamic process models

- are based on a cyclic calculation of energy and mass balances
- taking into account thermodynamic equilibrium conditions and reaction kinetics for the different metallurgical reactions as
  - Decarburisation
  - Hydrogen removal
  - Nitrogen removal and pick-up
  - Desulphurisation
  - Dephosphorisation
- using as inputs cyclically measured process data
  - process gas flow rates, vessel pressure, off-gas data etc.
- and data of acyclic process events
  - material additions, steel and slag analyses, steel temperature measurements etc.

Applications of dynamic process models

Off-line applications

- Process analysis and optimisation by simulation of process behaviour based on historical process data
- Process layout and optimisation of operating parameters by simulation of heat state evolution under systematically varied operating conditions

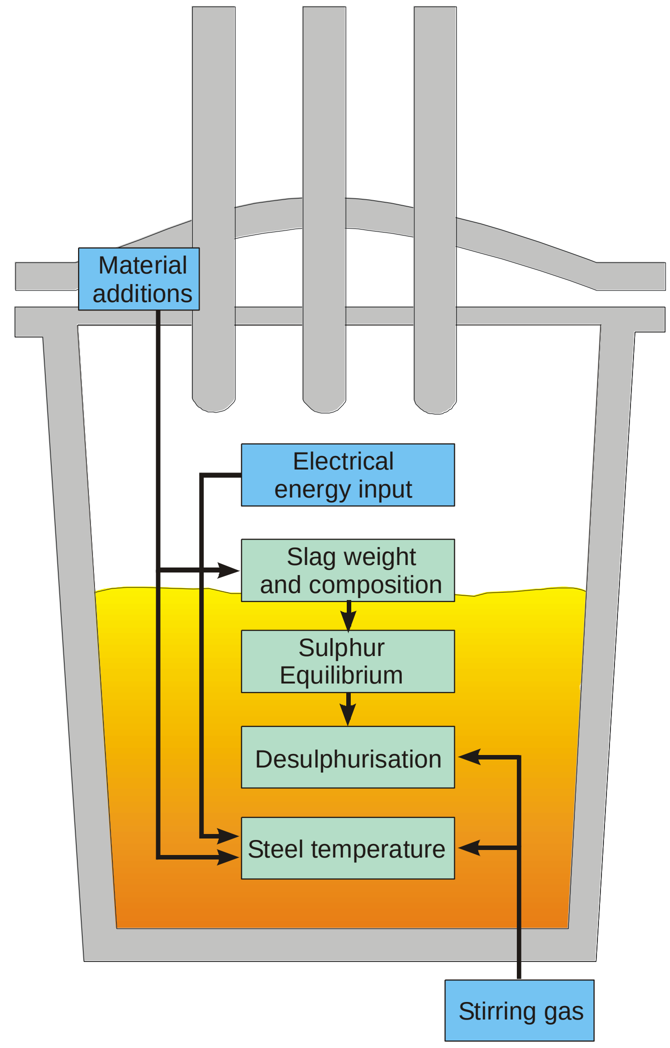
On-line applications

- Continuous on-line monitoring of the actual heat status regarding weight, temperature and composition of steel and slag
- Prediction of the further evolution of the heat status, e.g. for end-point control
- Calculation of set-points for process control at single aggregates, e.g.:
  - of electrical and chemical energy input (EAF, LF)
  - of oxygen supply for decarburisation, dephosphorisation and temperature control (BOF, RH, VD/VOD, AOD)
  - of addition of alloy materials, slag formers, cooling, heating and reduction materials
  - cost and quality optimal calculation of charge materials (EAF, BOF)
- Through-process modelling, control and multi-criterial optimisation for the complete process route in electric and oxygen steelmaking

Model-based control of the Ladle Furnace

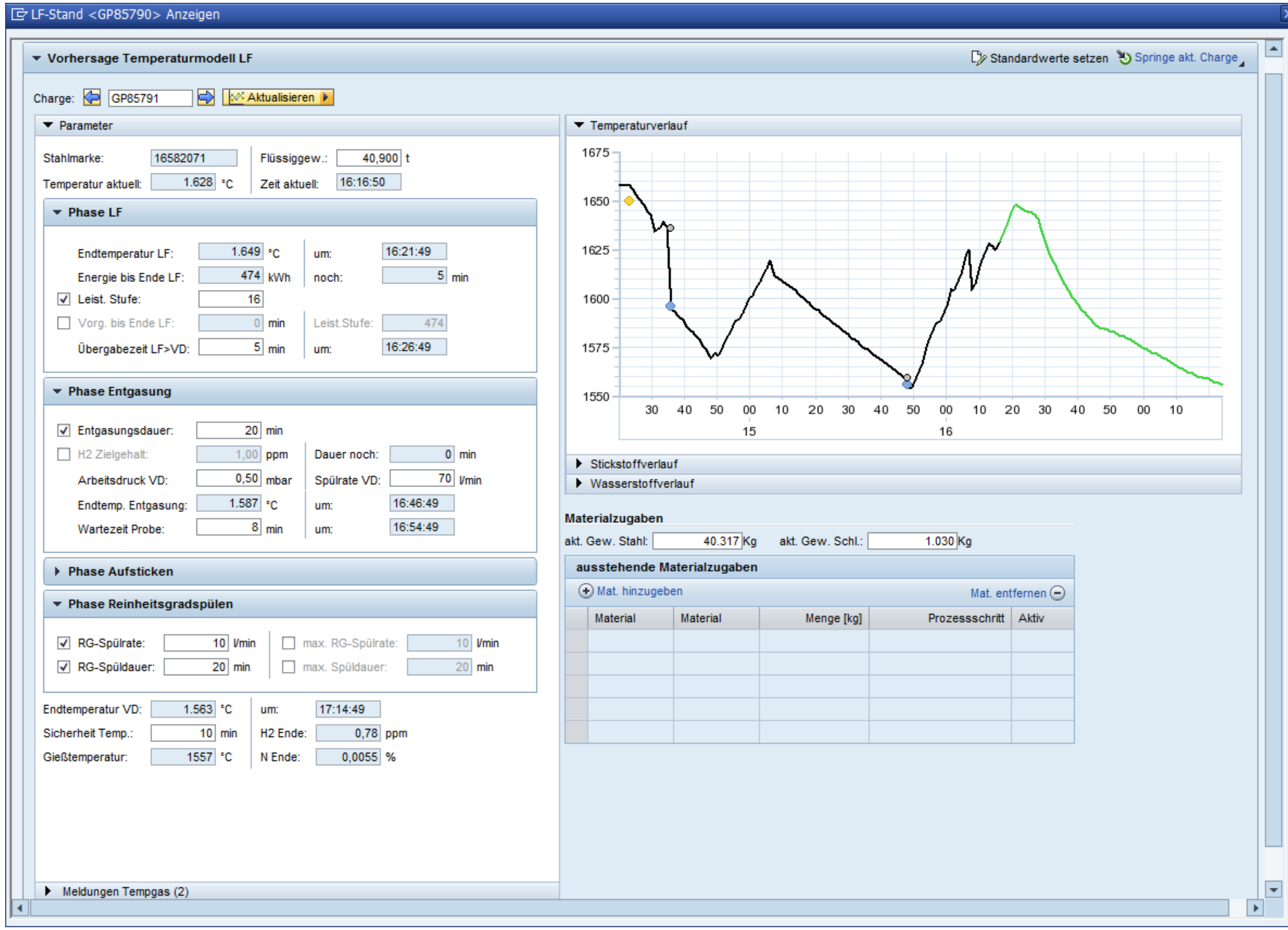
Functions of the process model

- On-line observation of:
  - steel temperature
  - steel analysis with focus on desulphurisation
  - slag amount and analysis based on a slag balance calculation
- Dynamic prediction of temperature evolution during remaining treatment time, including the effects of
  - Alloying
  - Desulphurisation
  - Stirring
  - Thermal status of the ladle
  - Treatment in following aggregates (e.g VD)
- Dynamic control of electric energy input (amount, heating rate, voltage tap) to achieve the aim temperature at the aim delivery time for the next secondary metallurgy plant or the continuous caster



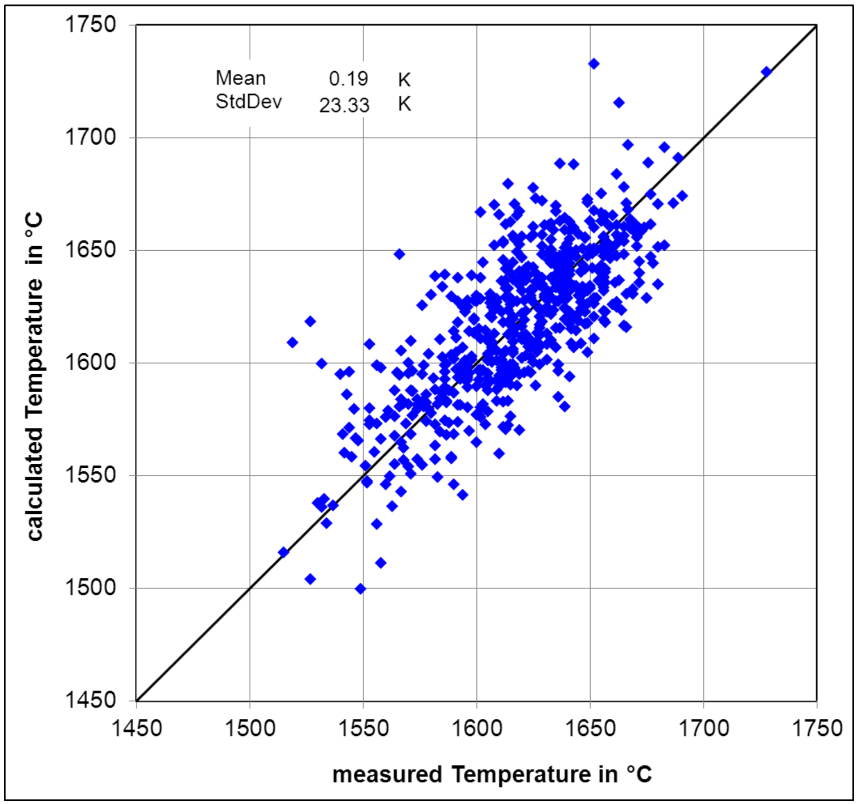
On-line monitoring and prediction of temperature evolution

- Prediction of temperature losses with standard values for treatment duration and stirring rate at the aggregates of the process route
- $T_{final} < T_{Target}$
  Set-point for electrical energy input LF
- $T_{final} > T_{Target}$
  Set-point for waiting time in LF (without heating) and / or duration resp. Stirring rate for cleanness stirring

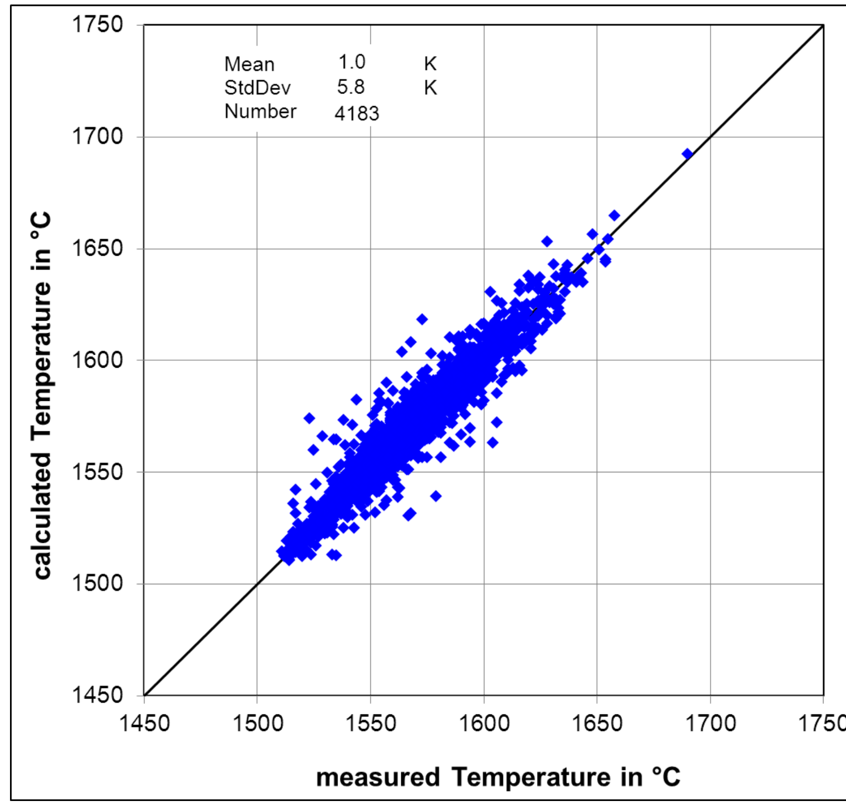


Model accuracy for LF melt temperature calculation

First LF temperature measurement: Inaccuracies due to the EAF tapping process (radiation, deoxidation reactions)

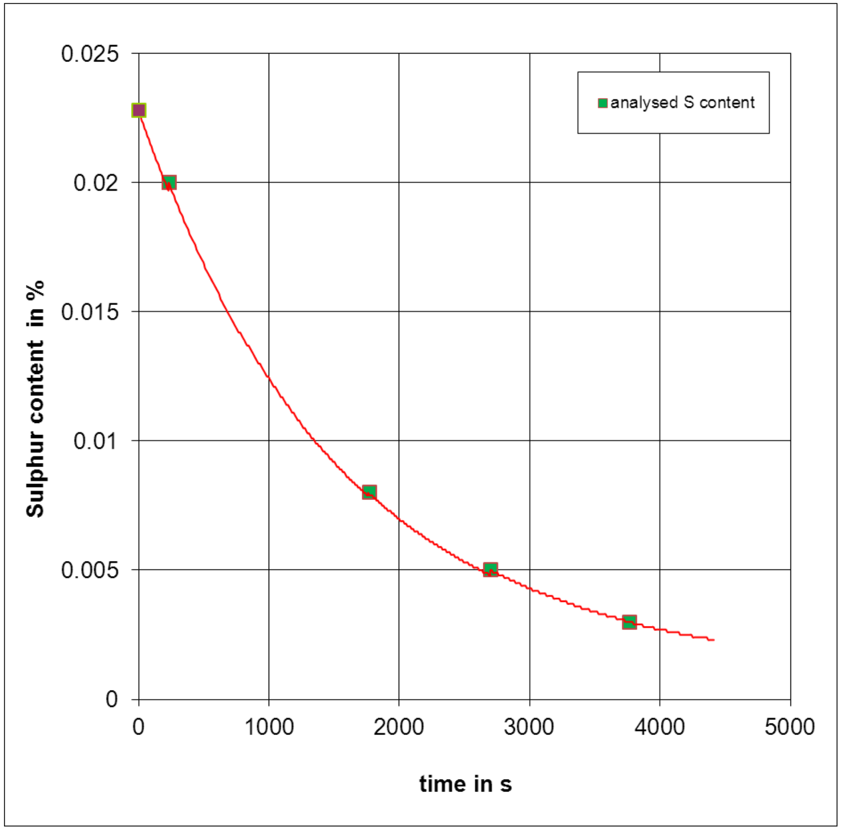


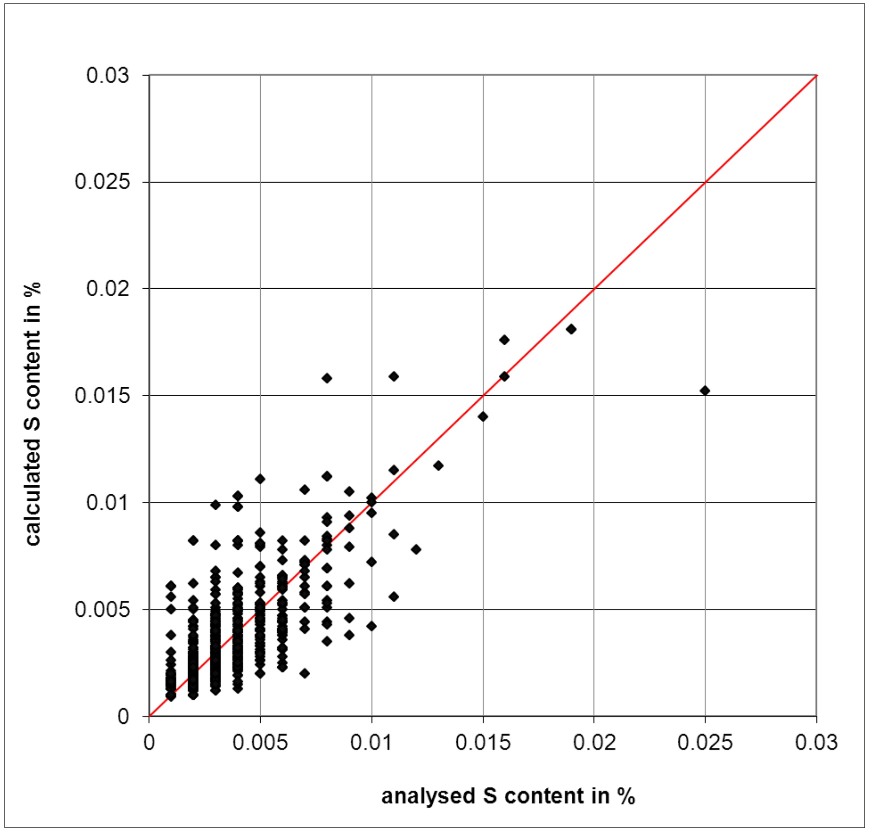
Further LF temperature measurements with adaptation to previous measurements



- Typical accuracy of Temperature model: Error standard Deviation of about 20 K for the first LF temperature measurement, and below 6 K for further measurements after adaptation

On-line monitoring of desulphurisation in the LF





- Sulphur equilibrium content calculated from dynamically monitored amount and composition of the ladle slag and the melt temperature
- Actual sulphur content reduced down to equilibrium content with 1st order kinetics
- Typical model accuracy for sulphur content: Error of around 15 % of the final content

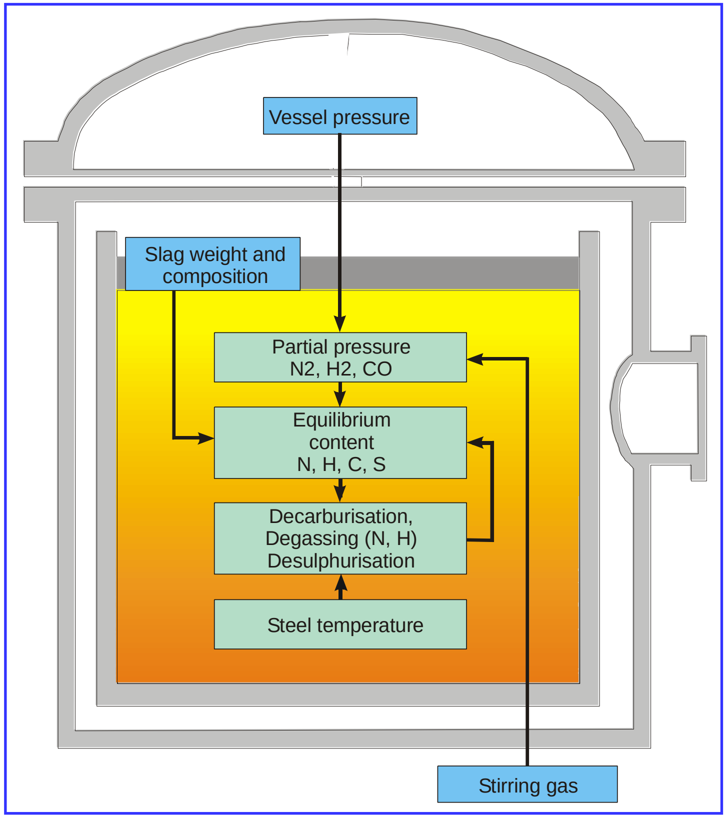
Dynamic model of the Ladle Tank Degassing (VD) process

Functions of the process model

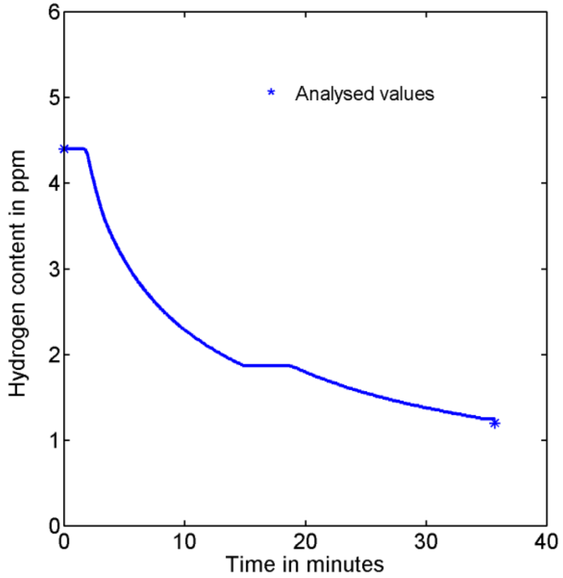
- On-line observation of decarburisation, denitrogenation / nitrogen pick-up, dehydrogenation, desulphurisation and steel temperature
- Dynamic prediction of remaining degassing time and corresponding temperature losses

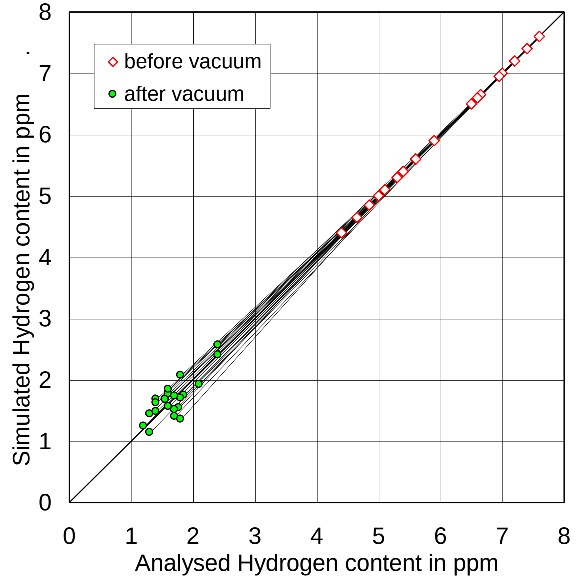
Required input data

- Vessel pressure
- Bottom stirring gas flow rate
- Cooling water flow rate and temperature difference for water-cooled roof
- Heat state at start of treatment
- Weights and types of all charged materials



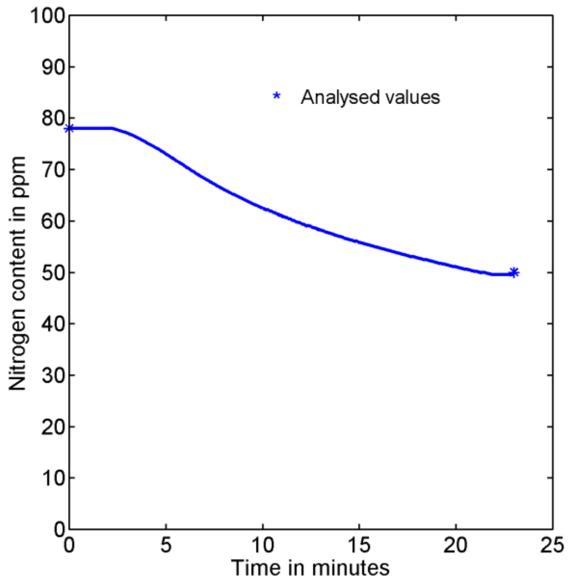
Model results: dehydrogenation and denitrogenation

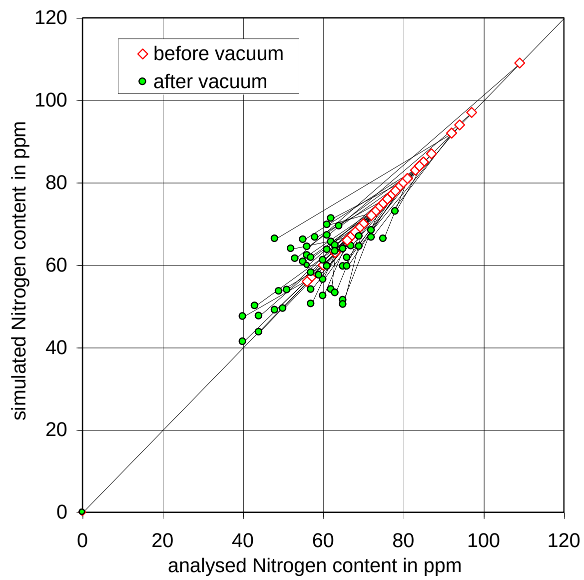




Model error of final H content:

mean value	=	0.01	ppm
standard deviation	=	0.2	ppm

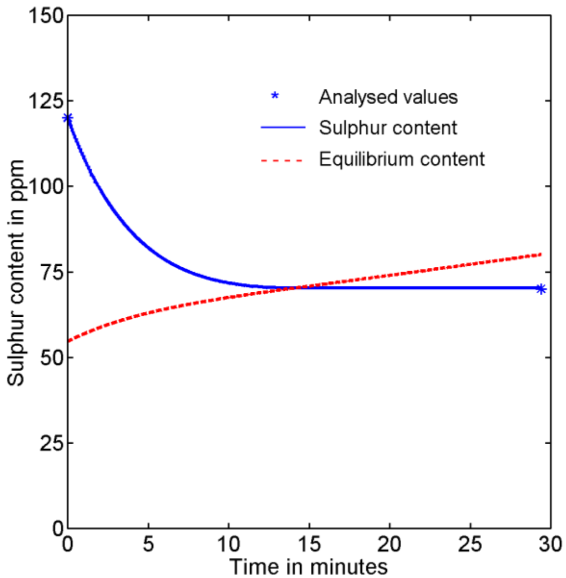


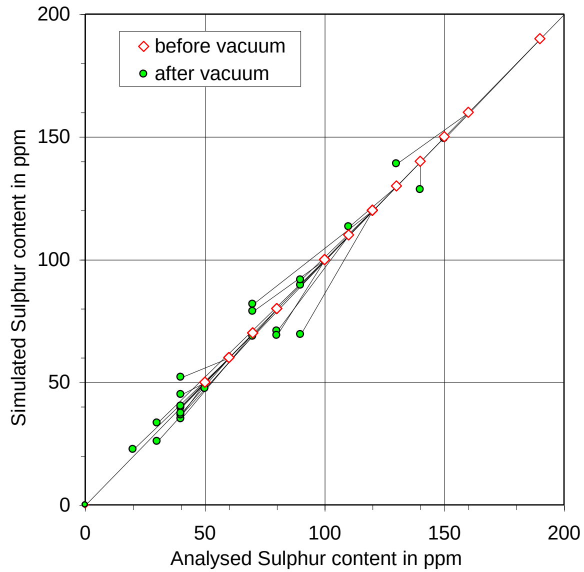


Model error of final N content:

mean value	=	0.7	ppm
standard deviation	=	6.6	ppm

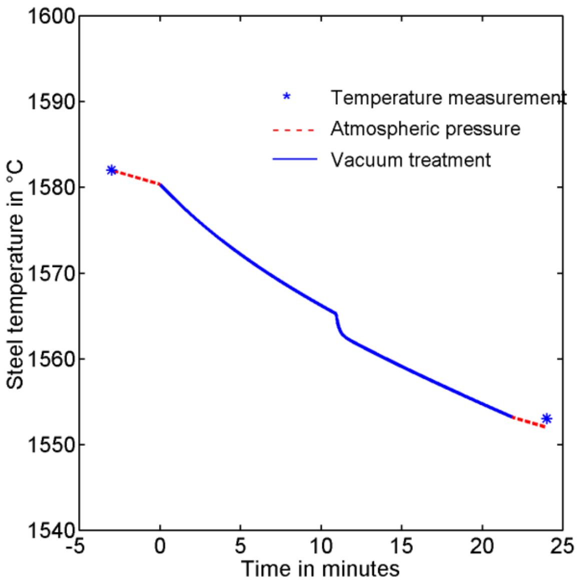
Model results: desulphurisation and steel temperature

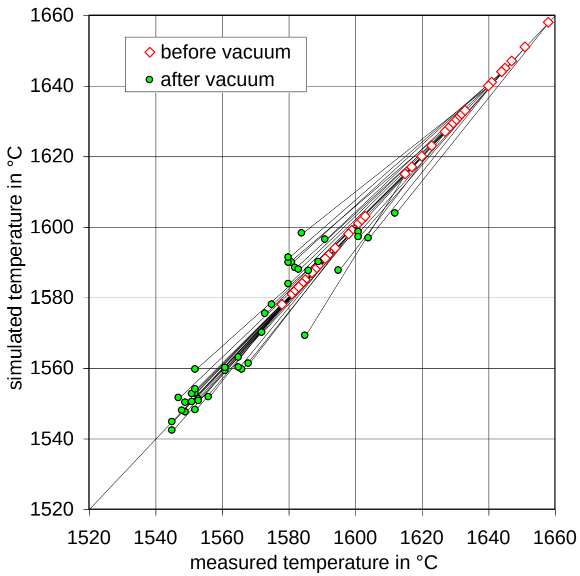




Model error of final S content:

mean value = -0.6 ppm
standard deviation = 7.7 ppm





Model error of steel temperature:

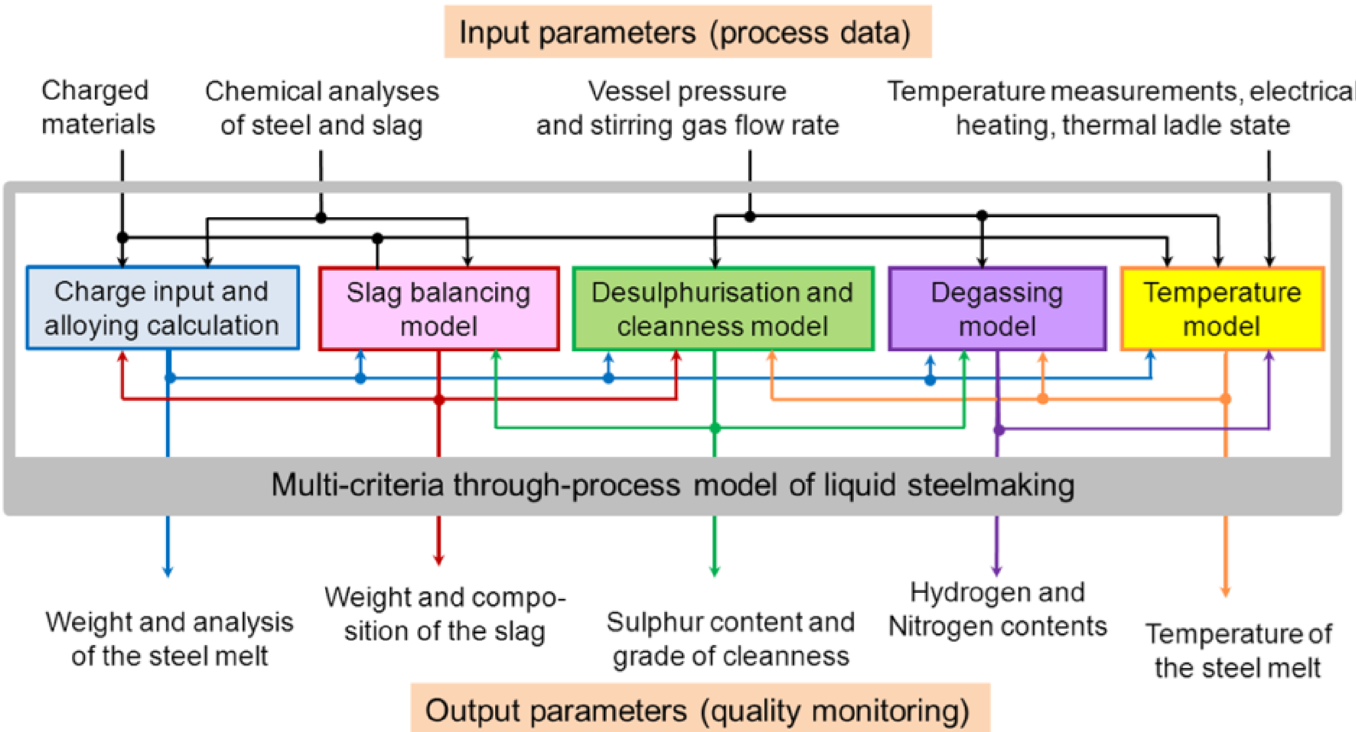
mean value = 0.1 K
standard deviation = 5.9 K

Through process modelling and control of liquid steel temperature and composition

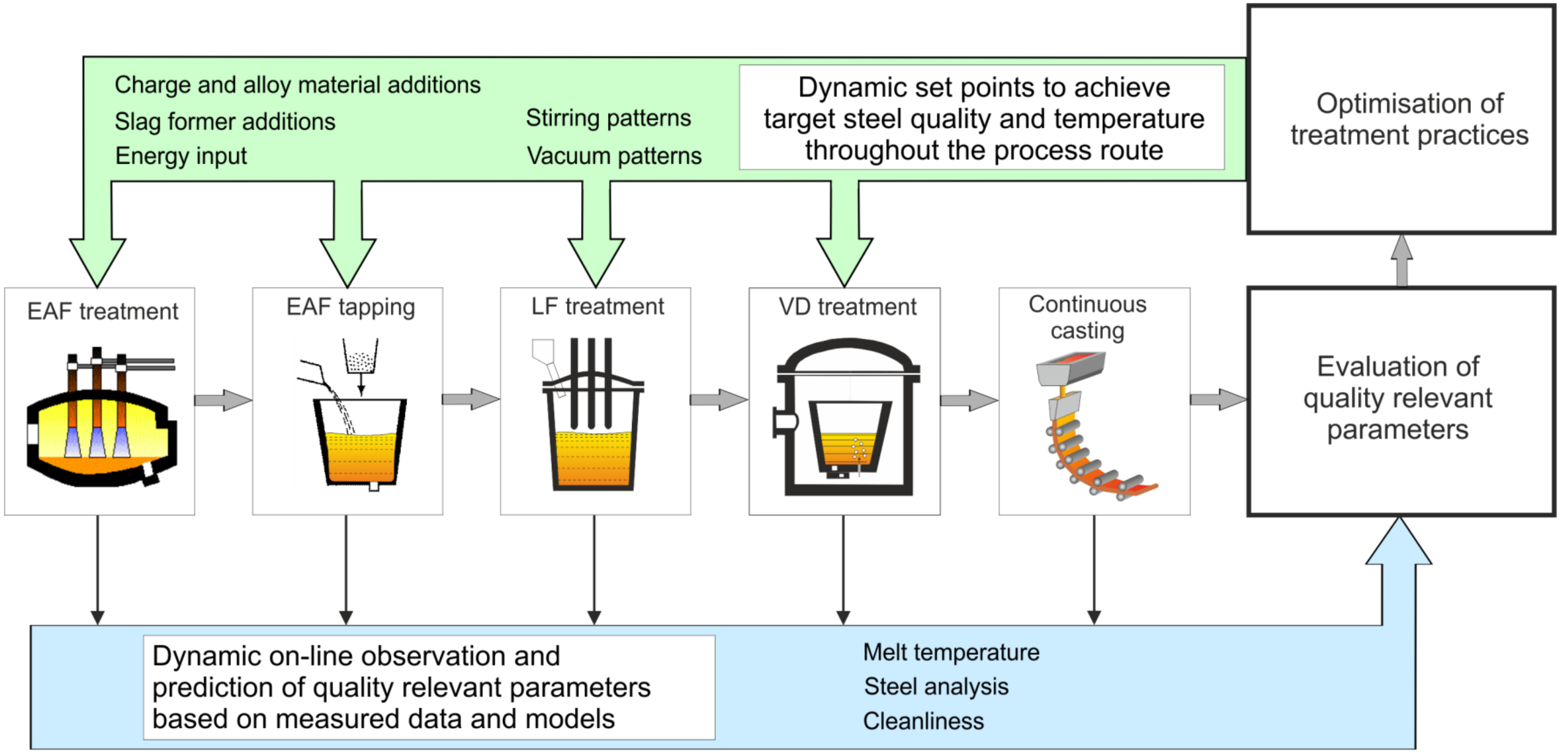
Integration of dynamic models for

- slag balancing and desulphurisation
- vacuum degassing
- through-process temperature evolution

for online monitoring, end-point control and calculation of optimal control set-points



Through-process temperature and quality control along the electric steelmaking route

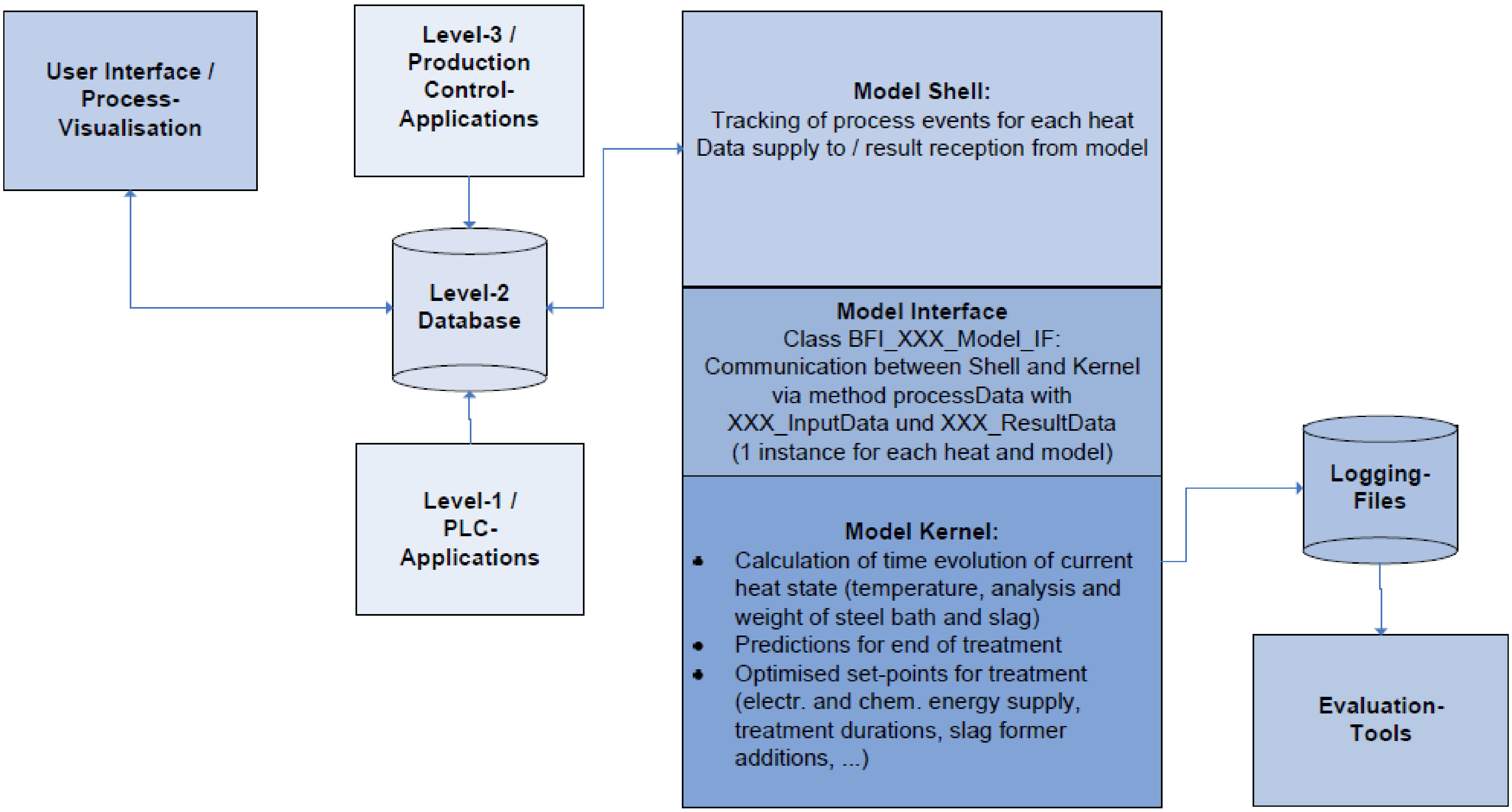


- Integration of dynamic process models to monitor and control the heat state evolution throughout the complete process route
- On-line control along the process route by combination of predictive model calculations with optimisation tools for adaption of defined set-points of given treatment practices

↳ Temperature and quality targets can be achieved under minimum material, energy and production costs with maximum productivity

↳ Improved steel quality, less downgrading due to violation of limits for C, N, H or S targets

Integration of BFI process models into on-line automation systems

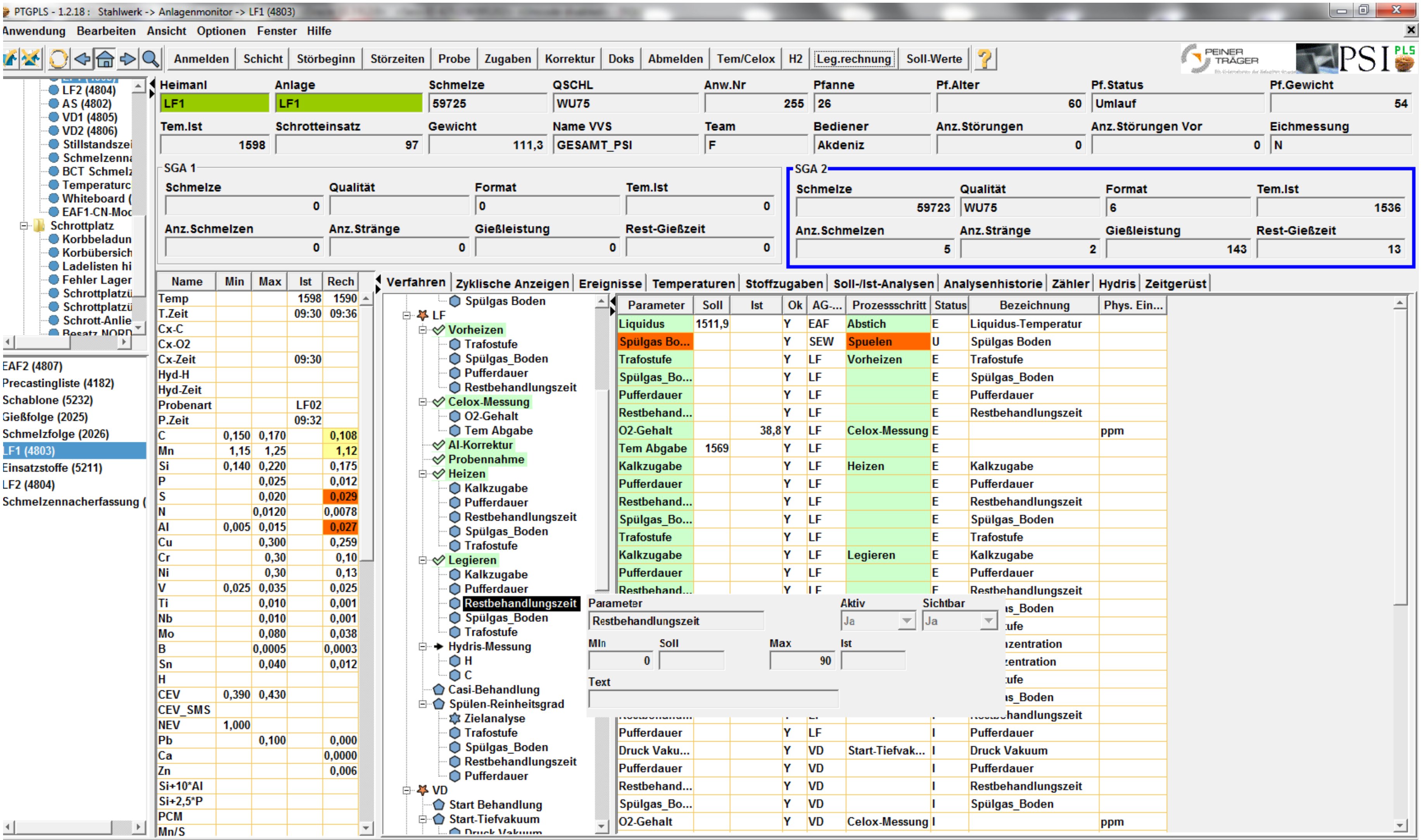


Operating instructions

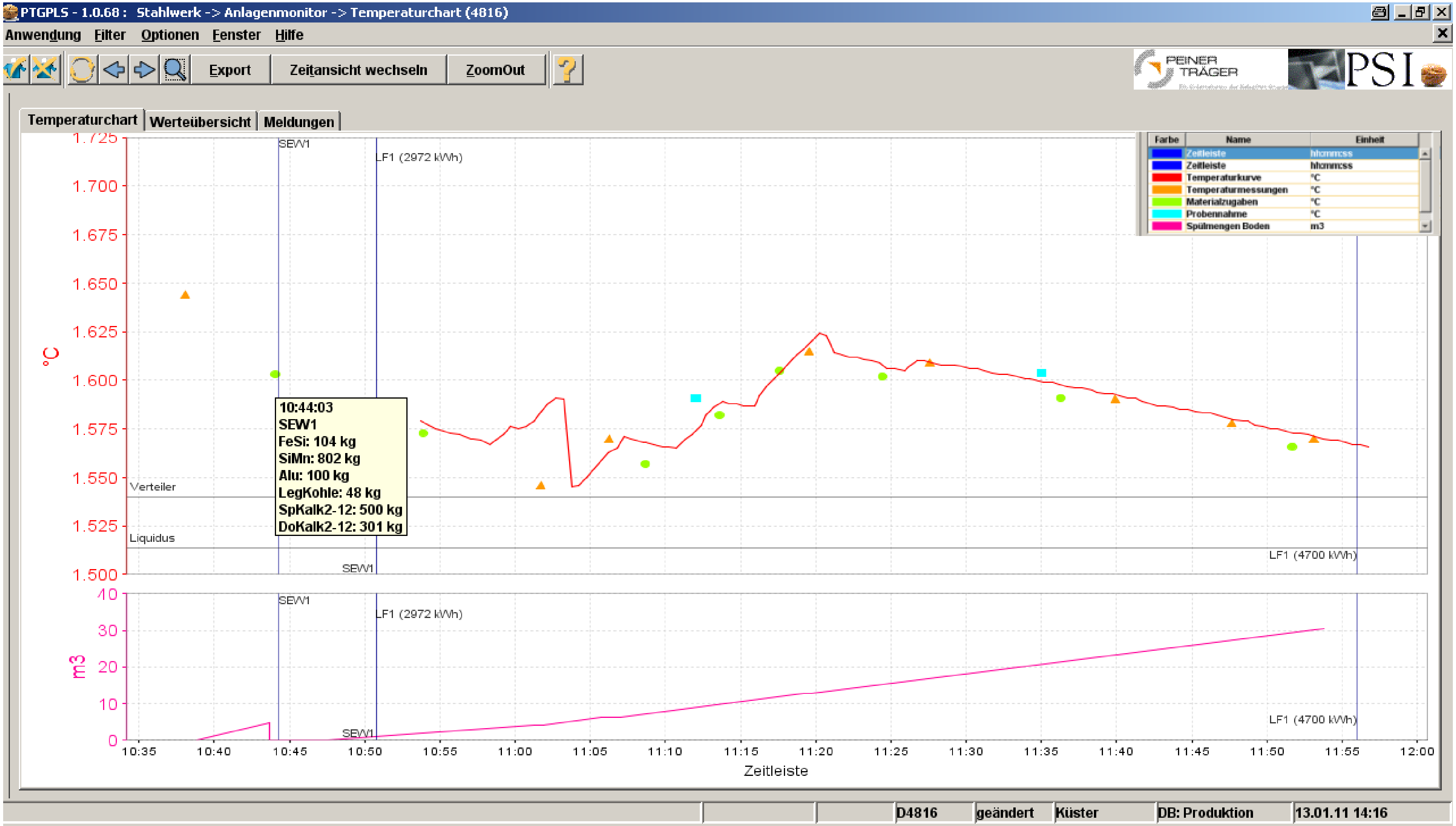
Definition of operating instructions by treatment practice data and rules within quality module of the PSI*metals* PMS

- for quality dependent treatment steps like
  - LF first heating (with slag formation), second heating (after alloying)
  - Vacuum degassing
  - Final stirring (with cleanness treatment)
- with min, max and target values regarding the relevant operational parameters like
  - duration of treatment
  - transformer tap (for electrical power input in LF)
  - vacuum pump control and vessel pressure (for VD)
  - argon stirring
  - scrap and alloy additions (based on charge input and alloy calculations)
  - slag former additions
  - deoxidation material and calcium additions (for cleanness control)

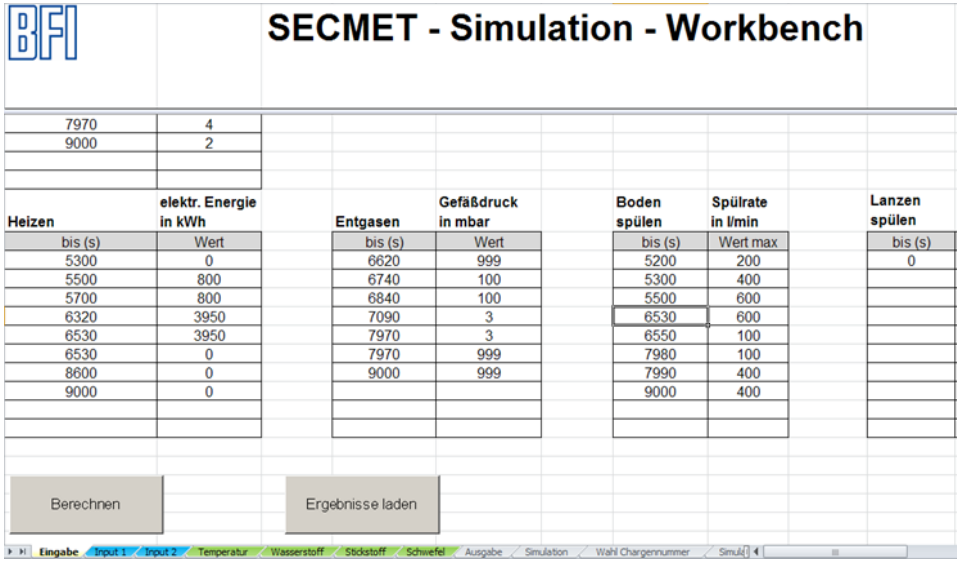
Configuration and monitoring of treatment steps within PSI*metals* PMS



Monitoring and control of temperature evolution within PSI*metals* PMS

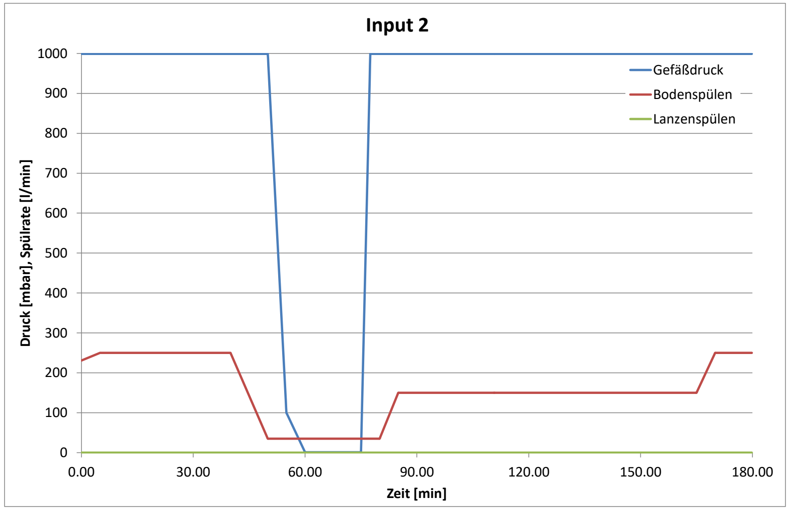


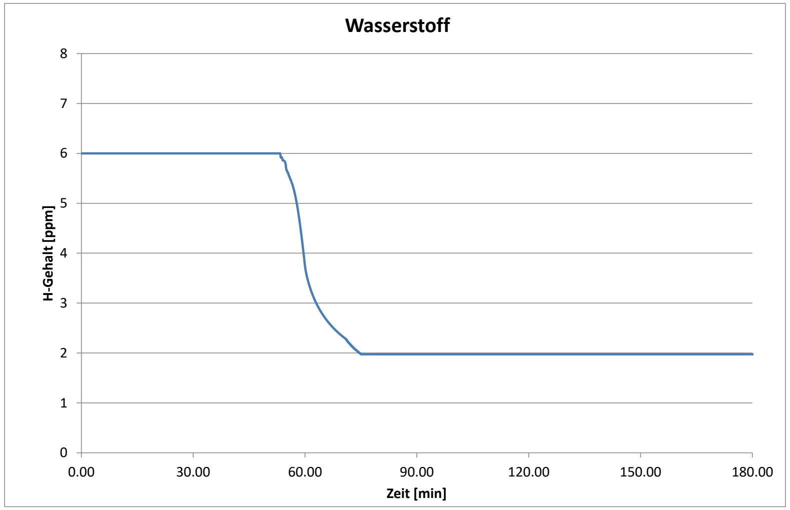
Offline Simulation Workbench



7970	4
9000	2

Heizen bis (s)	elektr. Energie in kWh Wert	Entgasen bis (s)	Gefäßdruck in mbar Wert	Boden spülen bis (s)	Spülrate in l/min Wert max	Lanzen spülen bis (s)
5300	0	6620	999	5200	200	0
5500	800	6740	100	5300	400	
5700	800	6840	100	5500	600	
6320	3950	7090	3	6530	600	
6530	3950	7970	3	6550	100	
6530	0	7970	999	7980	100	
8600	0	9000	999	7990	400	
9000	0			9000	400	





Use of dynamic through-process models for ladle treatment within offline simulation environment

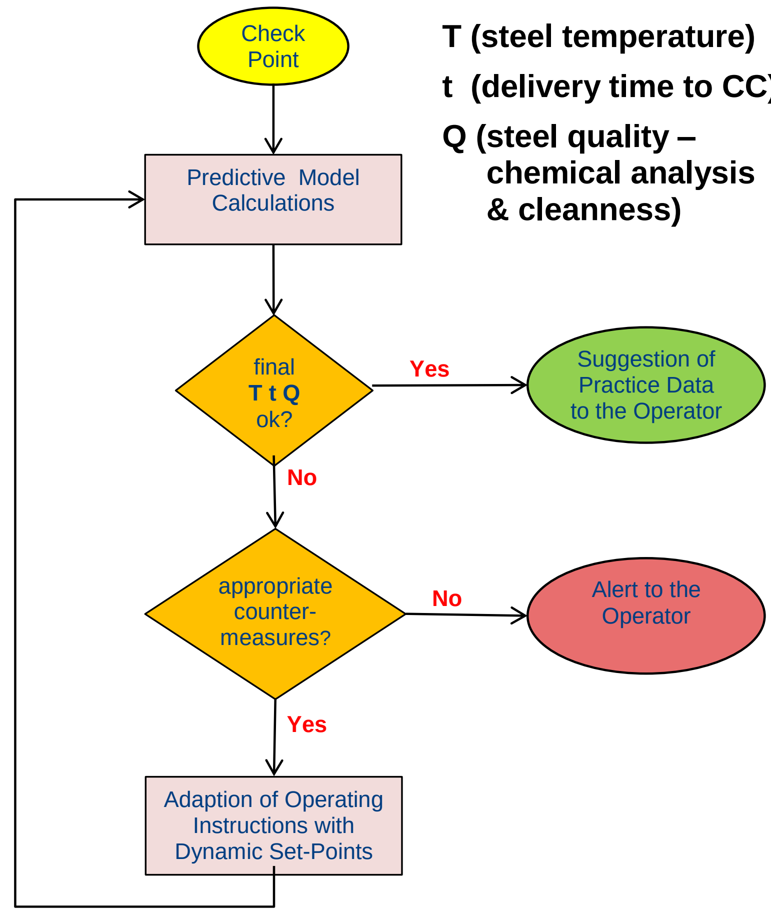
- Case studies for detailed analysis of effects of varied metallurgical process operations on evolution of steel temperature and quality parameters
- Fine tuning of treatment practices

Dynamic optimisation of treatment practices

- Model based through-process prediction calculations start with actual heat status and use process conditions as defined by practice data for remaining treatment steps
- For variable practice data, optimal set-points are calculated within given limits by iterative applications of prediction functions, using heuristic rules and regula-falsi algorithms to adjust treatment aims with minimal energy and material consumption
- In case of conflicts between different production aims regarding heat delivery time, steel temperature and quality, rules adjust

  1. treatment durations
     according to target heat delivery time
  2. target steel quality in terms of H, N, S contents and cleanness requirements
  3. target steel temperature

  Remaining conflicts are displayed to the operator in order to solve them manually



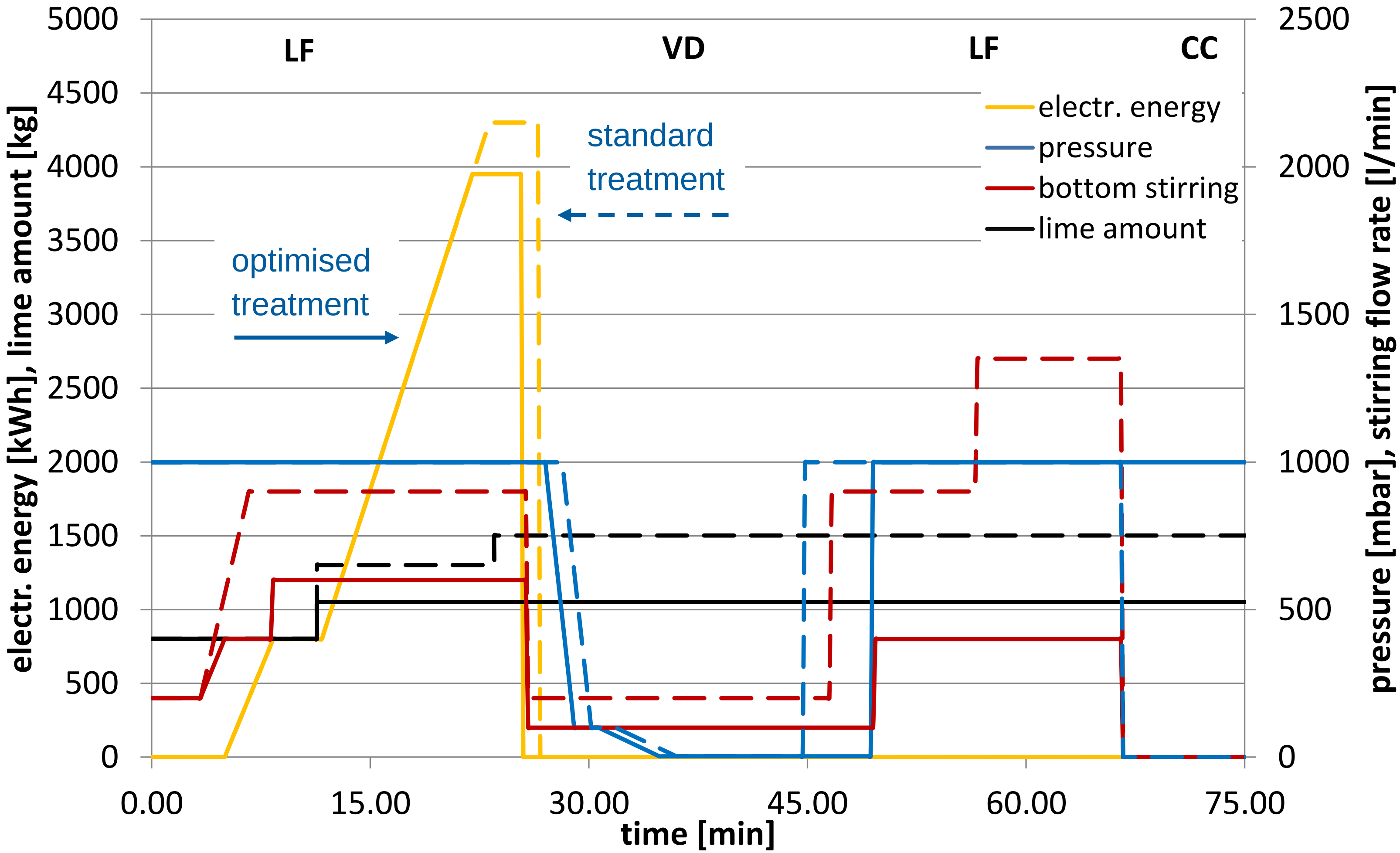
T (steel temperature)

t (delivery time to CC)

Q (steel quality – chemical analysis & cleanness)

Dynamic optimisation of treatment practices

Comparison of ladle treatments based on dynamically optimised and standard practice data



Dynamic optimisation of treatment practices

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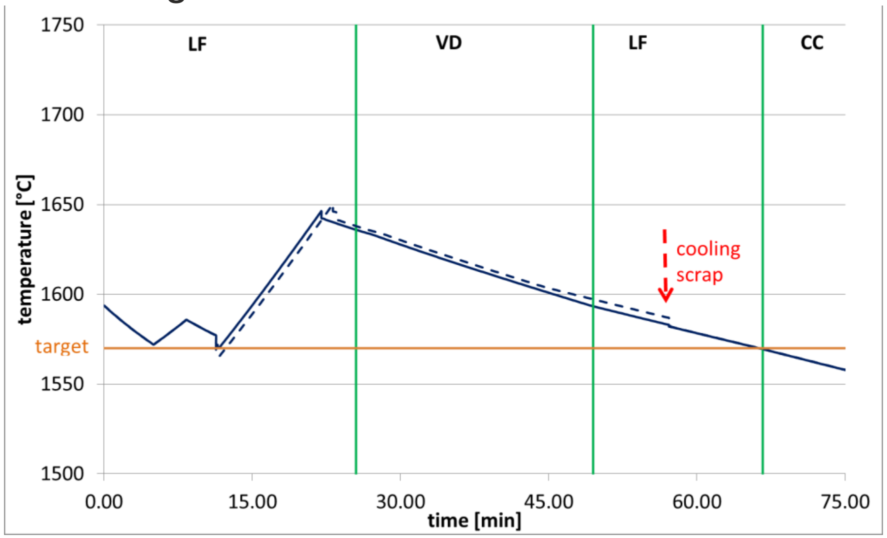
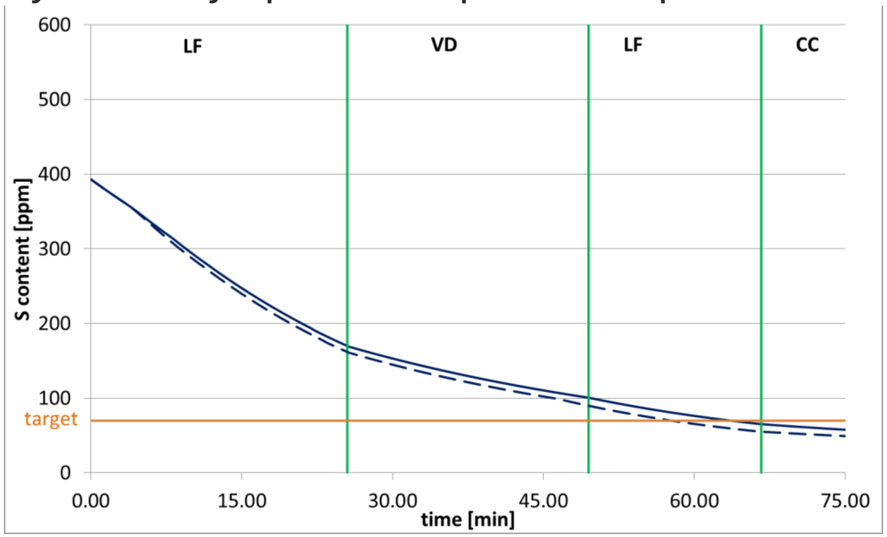
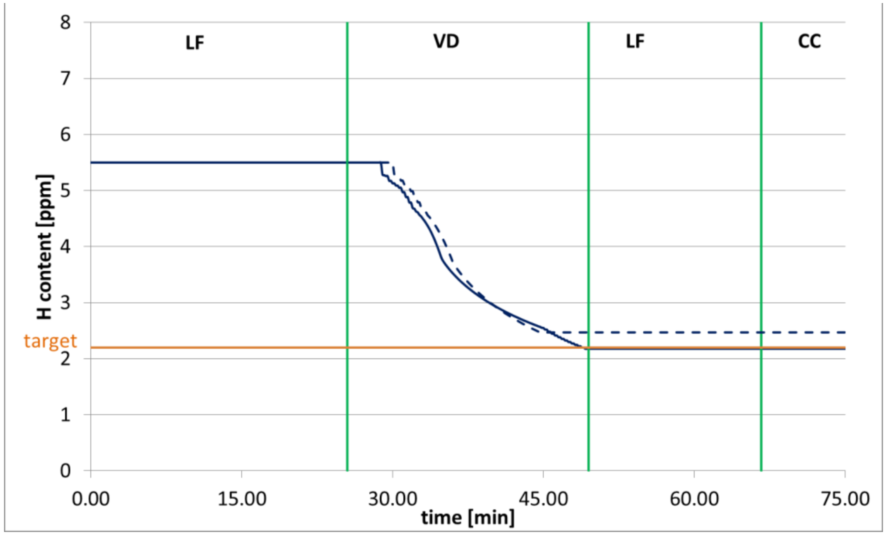
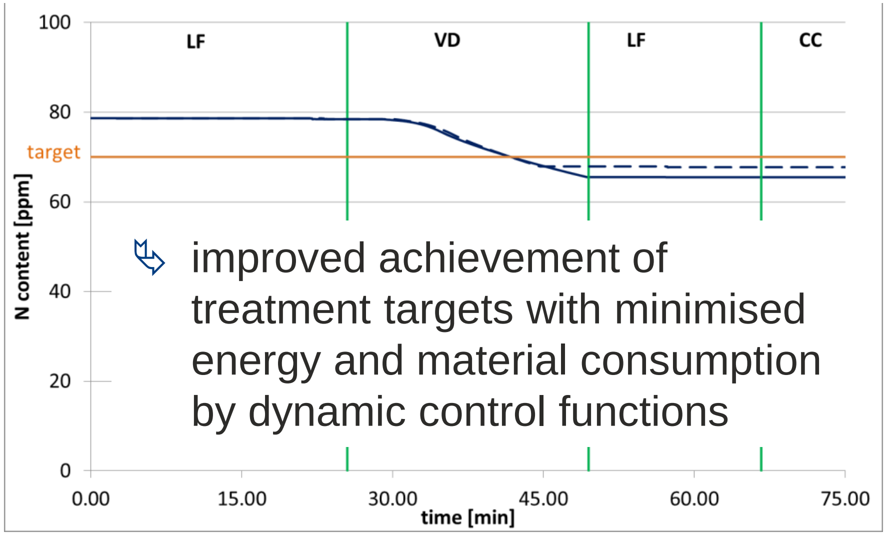
Resulting heat state evolution with and without dynamically optimised operational parameters









➯ improved achievement of treatment targets with minimised energy and material consumption by dynamic control functions

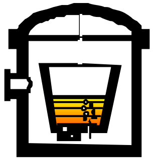
Conclusions and achieved industrial benefits

- Integration of dynamic process models into production management system to monitor and control the heat state evolution throughout the complete process route
- On-line control along the process route by combination of predictive model calculations with optimisation tools for dynamic adaption of defined set-points of given treatment practices

- ↳ Temperature and quality targets can be achieved under minimum material, energy and production costs with maximum productivity
- ↳ Improved steel quality, less downgrading due to violation of limits for C, N, H or S targets
- ↳ Savings of electrical energy of about 2.4 kWh / ton and material additions of abut 10 € / ton compared to standard operational practice are achievable

References of recent on-line applications of BFI models in secondary metalurgical steelmaking processes (1)

■ Saarschmiede, Völklingen, Germany (with PSI Metals)	(2009)
■ Peiner Träger, Peine, Germany (with PSI Metals)	(2009)
■ Benteler, Lingen, Germany (with PSI Metals)	(2010)
■ Elektrostahlwerke Gröditz, Germany	(2012)
■ Ascometal, Hagondange, France (with PSI Metals)	(2014)
■ Buderus Edelstahl, Wetzlar, Germany (with PSI Metals)	(2016)



■ Edelstahlwerke Buderus, Wetzlar, Germany (with PSI Metals)	(1999, 2016)
■ Stahlwerk Bous, Germany	(2002)
■ SZ Acroni, Slowenia (with SMS Mevac)	(2004)
■ Hyundai Steel, South Korea (with SMS Mevac)	(2007)
■ Saarschmiede, Völklingen, Germany (with PSI Metals)	(2009)
■ Peiner Träger, Peine, Germany (with PSI Metals)	(2011)
■ PNTZ, Russia (with SMS Mevac)	(2011)
■ Elektrostahlwerke Gröditz, Germany	(2012)
■ Ascometal, Hagondange, France (with PSI Metals)	(2014)

References of recent on-line applications of BFI models in secondary metalurgical steelmaking processes (2)

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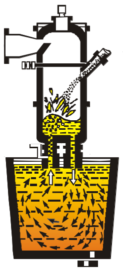
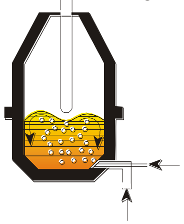
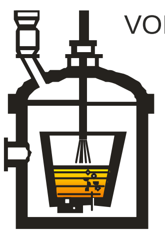

RH

- LTV Steel Indiana Harbor, USA (1988)
- Bethlehem Steel Burns Harbor, USA (RH-OB) (1990)
- LTV Steel (AM) Cleveland, USA (1991, 2005)
- voestalpine Linz, Austria (1999)
  (RH / 1 with oxygen lance, RH / 2)
- JFE, Fukuyama works, Japan (2016)


AOD

- ThyssenKrupp Nirosta, Bochum, Germany (2004)
- ThyssenKrupp Nirosta Krefeld, Germany (2006)


VOD

- SZ Acroni, Slowenien (2009)
- Dörrenberg Edelstahl (2011)
- DEW Siegen-Geisweid (2003, 2014)
- Buderus Edelstahl, Wetzlar (with PSI Metals) (2016)

Thank you very much for your attention!

Do you have questions?

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