Increased yield and enhanced steel quality by improved deslagging and slag conditioning (OptDeslag)

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Background

- RFSC Project “Increased yield and enhanced steel quality by improved deslagging and slag conditioning”
- Partners:
  - VDEh-Betriebsforschungsinstitut GmbH (BFI), Coordinator
  - Saarschmiede GmbH Freiformschmiede (SAARSCHMIEDE),
  - Swerea Mefos AB (MEFOS),
  - SSAB EMEA AB (SSAB
- This presentation shows MEFOS work in the project

Background

- The objective of the project was to improve deslagging processes during process steps of liquid steelmaking by applying image sensors and process models to control deslagging operations. The process step that were investigated is:
- after hot metal desulphurisation at SSAB EMEA AB, Sweden
- In the steelwork suitable sensors and cameras were installed - CCD and IR at SSAB

Objectives of the project

The main objectives of this project were

- to improve the monitoring and control of deslagging operations, for reproducible performance of the deslagging process and to minimise the remaining slag and the metallic losses

- to establish dynamic process models to monitor and control the slag condition throughout important steps of steelmaking, for improved quality of the steel by adapting subsequent steelmaking processes to the amount of slag that remains after deslagging

Description of activities

The project includes 7 work packages that can be summarised as

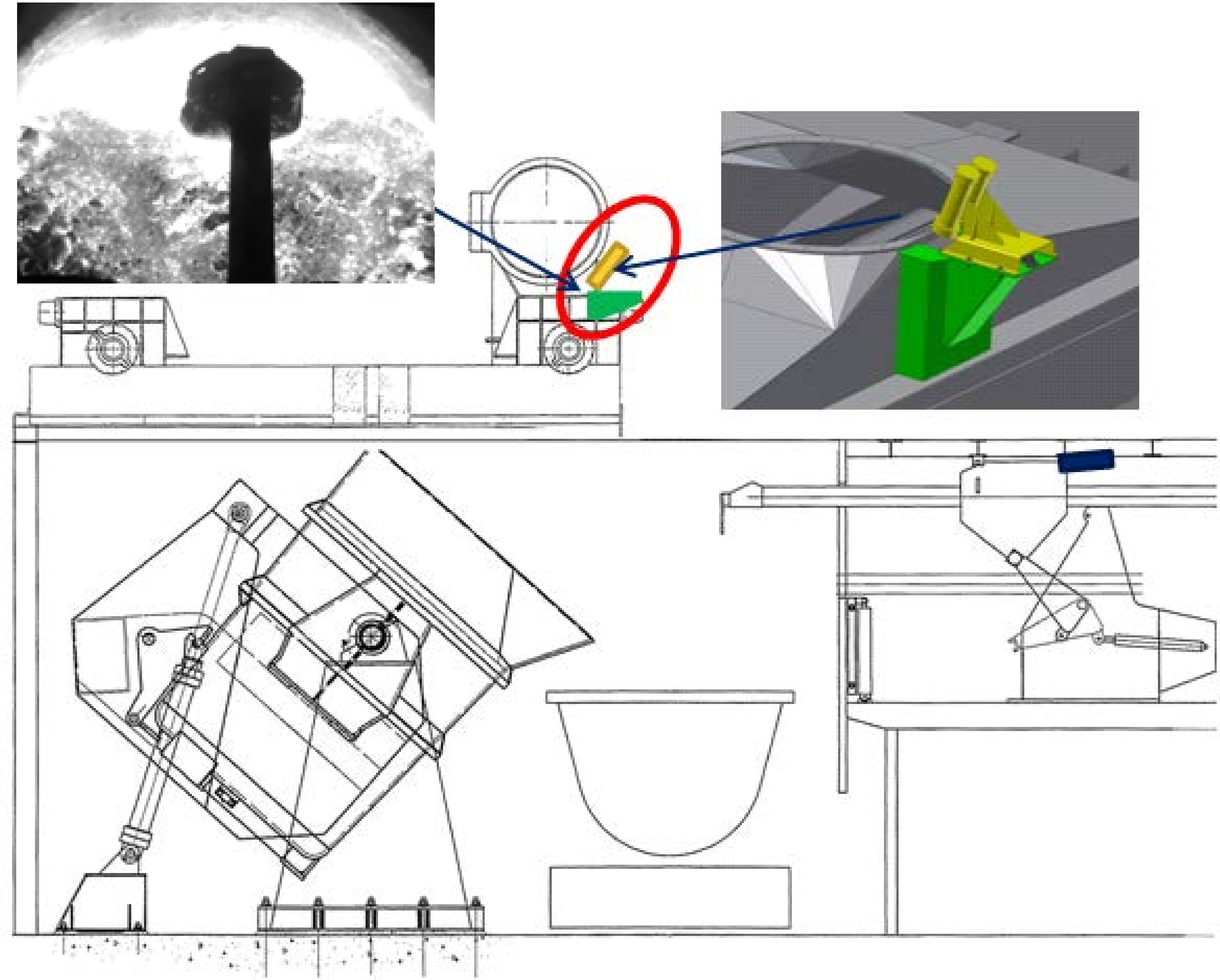
- Hardware and sensor implementation
- Software development, image analysis
- Test campaigns – data acquisition
- Modelling work
- Test campaigns – validation

All of these are partly presented in a non structured way!

Hardware and sensor implementation

- Initial tests at deslagging stations for selection of suitable cameras CCD and IR, in order to develop imaging systems were performed.
- The main objective of the tests was to find an appropriate place where the camera holder could be mounted and meet the demands of the image analysis system
- Also the **design** and **construction of camera housing** and **cooling** were carried out which was fundamental to get the project going
- Another fundamental part of the work at SSAB was the **installation of sensors for the deslagging machinery which moves the slag rake**. The sensors give the slag rake position in x, y and z direction, which means that the raking movement can be restricted in semiautomatic mode, or if actuators are installed it can be controlled
- **A sensor that gives the tilting angle of the ladle**

Placement of cameras on the off-gas hood



Hardware and sensor implementation

- CCD and an IR camera were to be selected due to operational experience and technical properties/performance by MEFOS.
- The CCD camera selected by MEFOS was a Basler Ace. The resolution is 1296 x 966 pixels and with some additional filters, the lenses is from Fujinon.
  - The camera gives a resolution of the working area or ladle surface area of 0.5 cm per pixel. In theory a 0,025 cm^2 accuracy of surface is achievable
- The IR camera selected is from FLIR and the model is SC655.
  - The resolution is 640x480 and the wavelength it operates in is 7,5-13µm.

Placement of cameras on the off-gas hood

Initial step was to find positions that matched these criteria:

- Possibility to see the complete hot metal bath when ladle is tilted,
- Getting cooling media and connections to the camera system and possibility to shield the camera during desulphurisation treatment,
- Easy maintenance of the camera system.

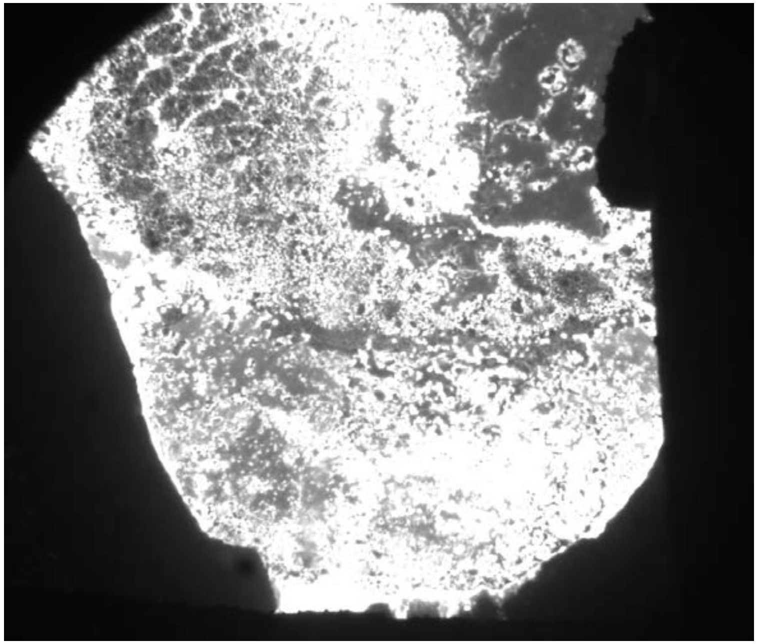
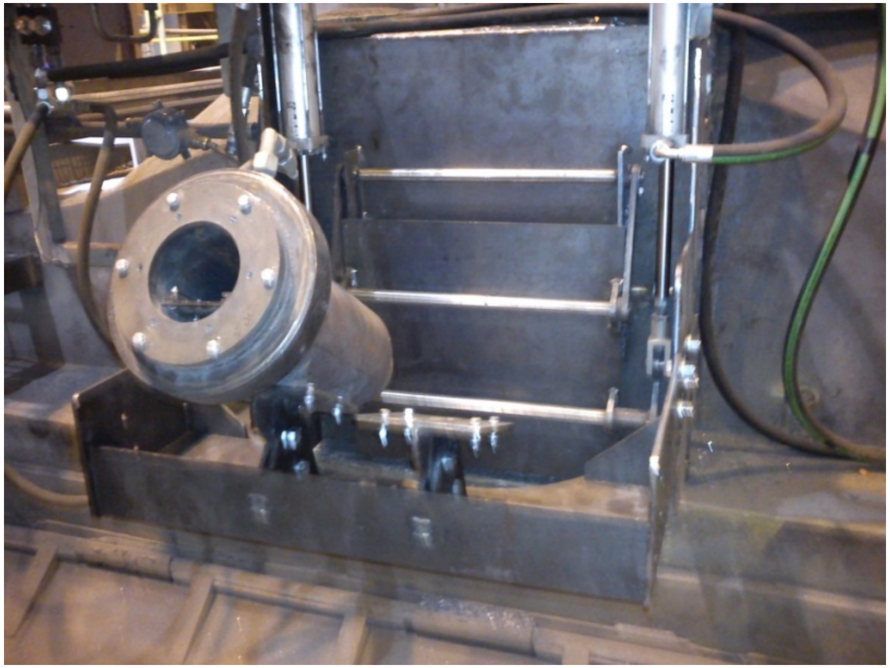


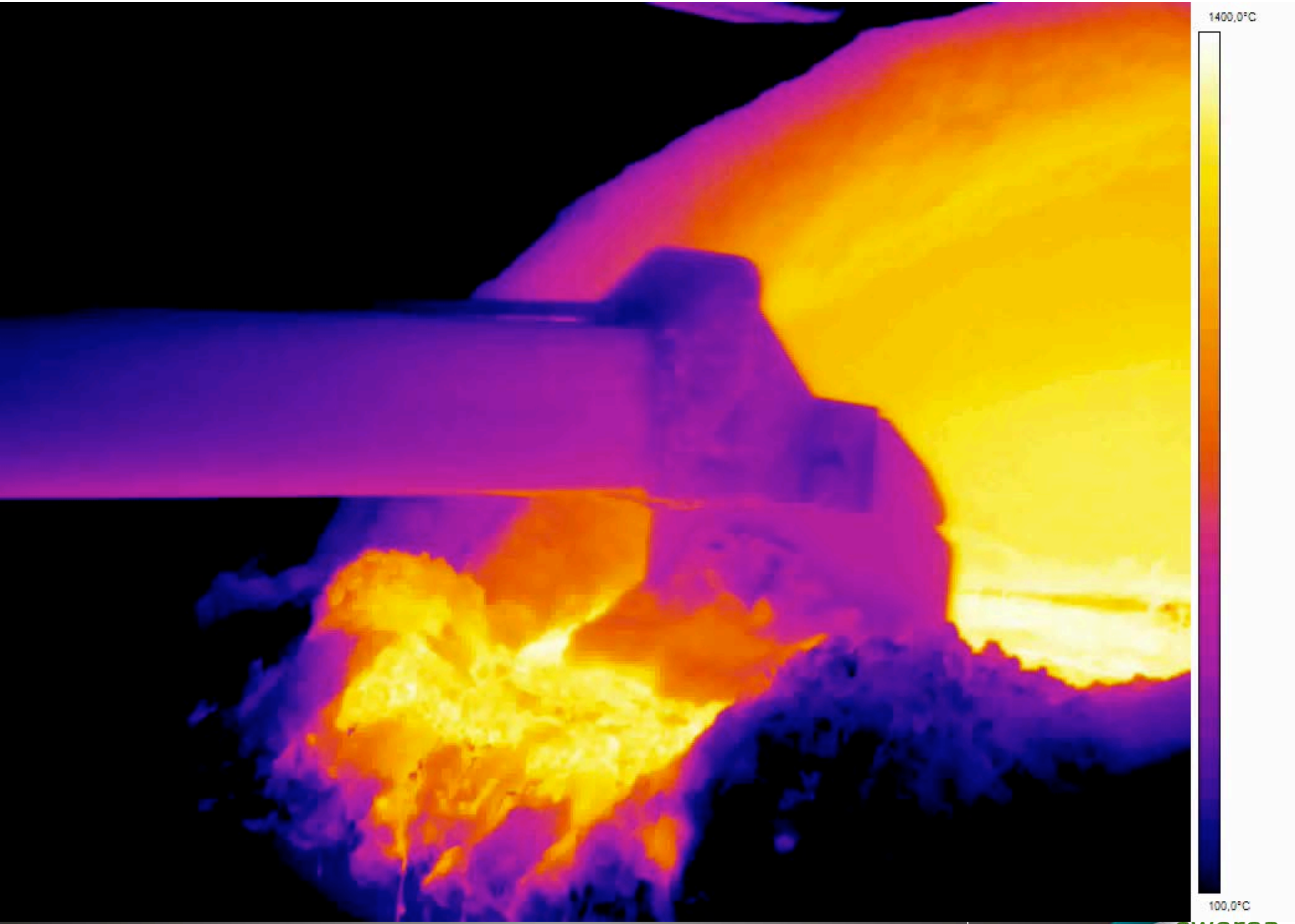
Image of ladle slag surface

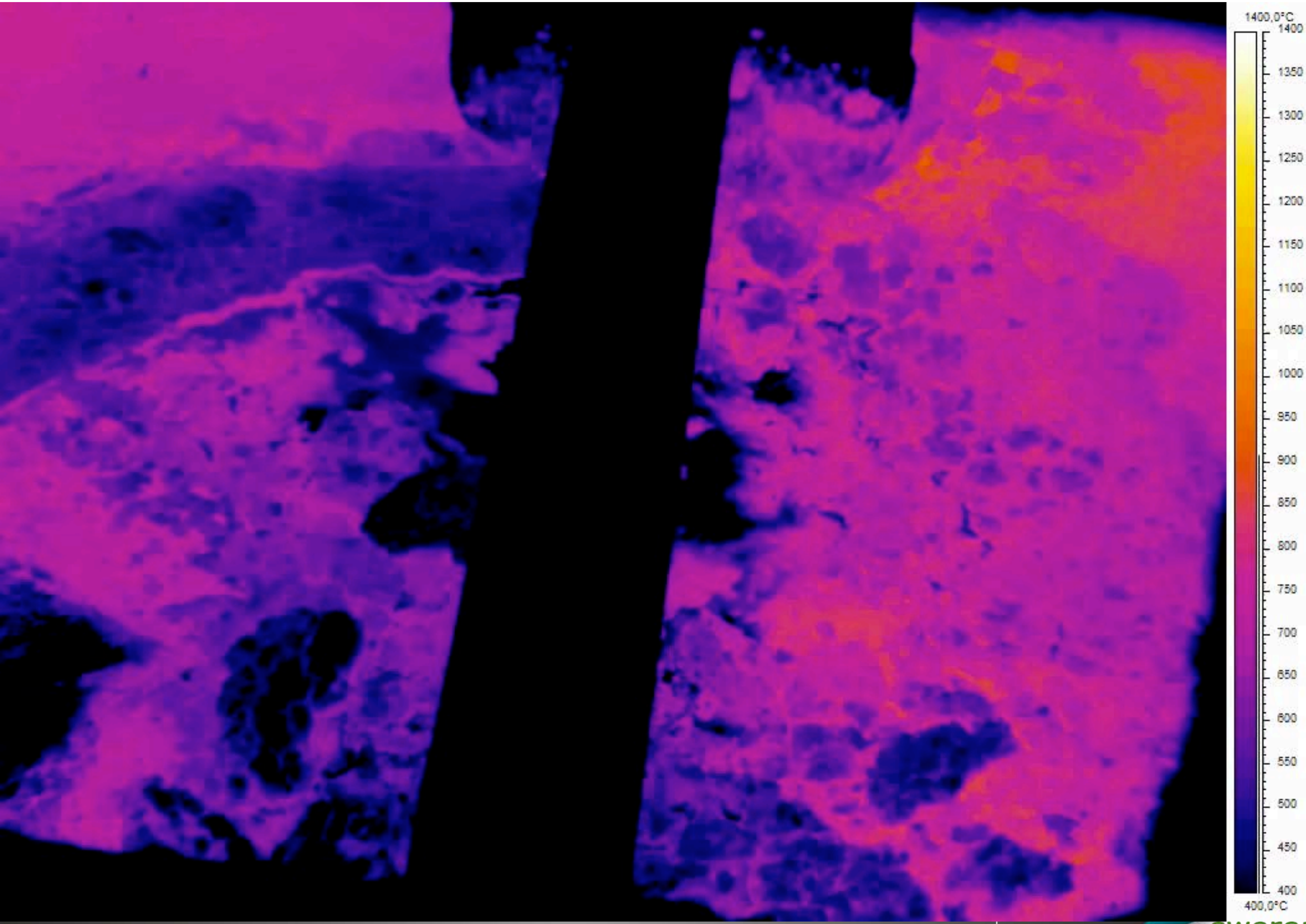
Placement of cameras on the off-gas hood



Camera housing mounted to the left, to the right the hatch opened, camera mounted on top as in left image

CCD picture of the ladle surface


1400,0°C
100,0°C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Software development, image analysis

The images from the CCD camera were acquired and processed in a standard computer. The operator/computer/camera interface was made in NI Labview environment.

This program can show the online image, save images or an avi-file.

It works as a stand-alone unit collecting image data.

The program also gives the remaining amount of slag based on the camera image as an area part of slag covered surface.

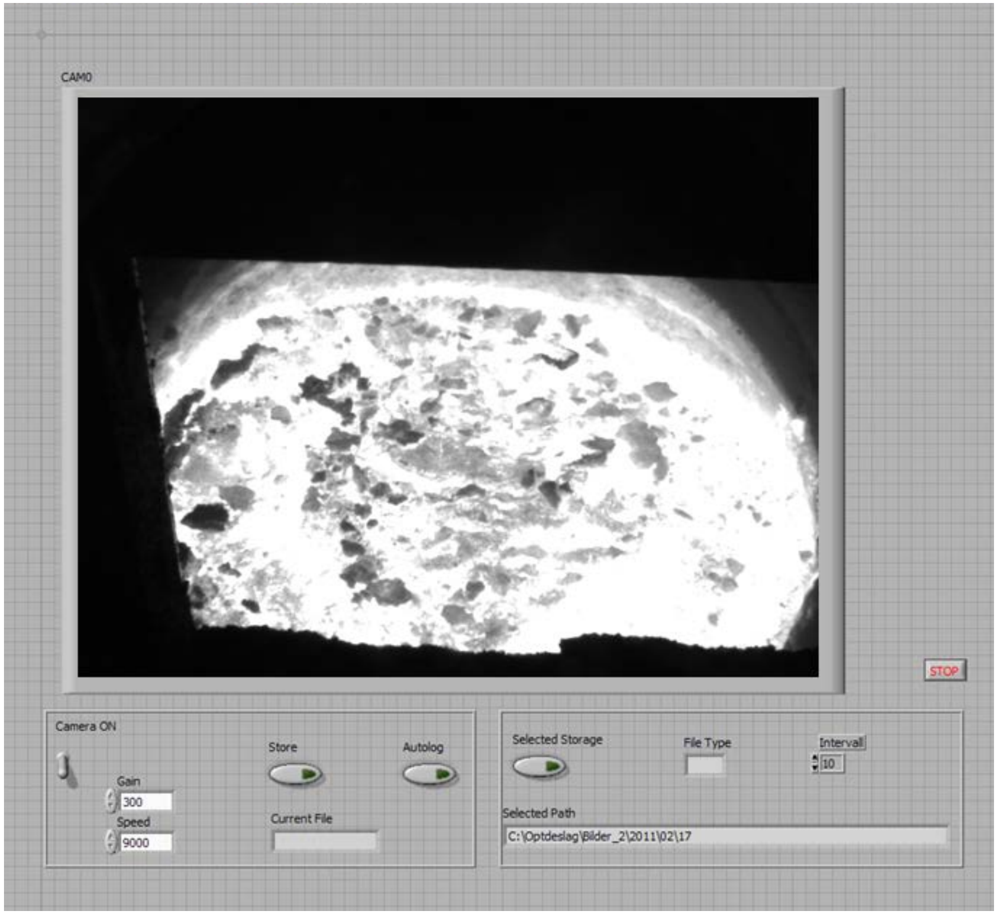
Depending on the thickness of the slag the amount can be calculated based upon this estimation.

Software development, image analysis

The information from the new imaging based sensor systems are used

- to control the deslagging process and optimise the deslagging schemes (control the movement of rake, stirring gas flow rate, tilting angle of the ladle etc) according to the ordered steel quality,
- to estimate the amount of remaining slag before secondary metallurgical operations,
- to aid/support the decision whether the deslagging operation is sufficient.

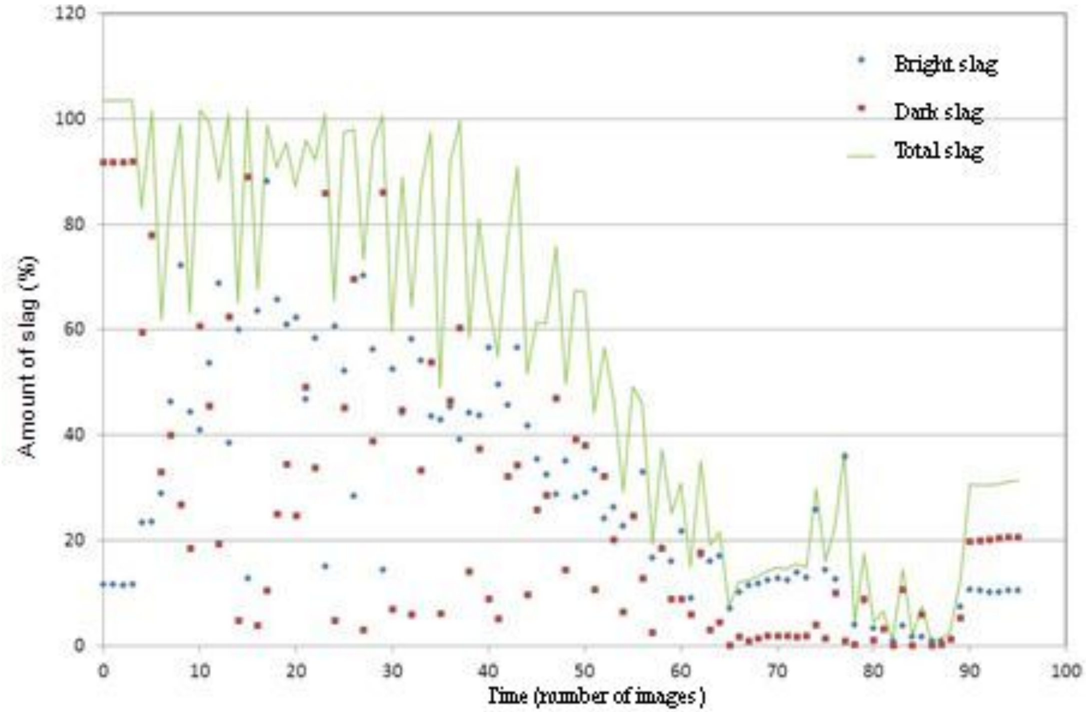
Software development, image analysis



Operator interface of image analysis system

Software development, image analysis

Outcome from the image analyse



The imaging system implemented controls the deslagging and estimates the amount of remaining slag. The mechanical deslagging is monitored by the image analysis system. Bright equals thin slag and dark equals thick slag

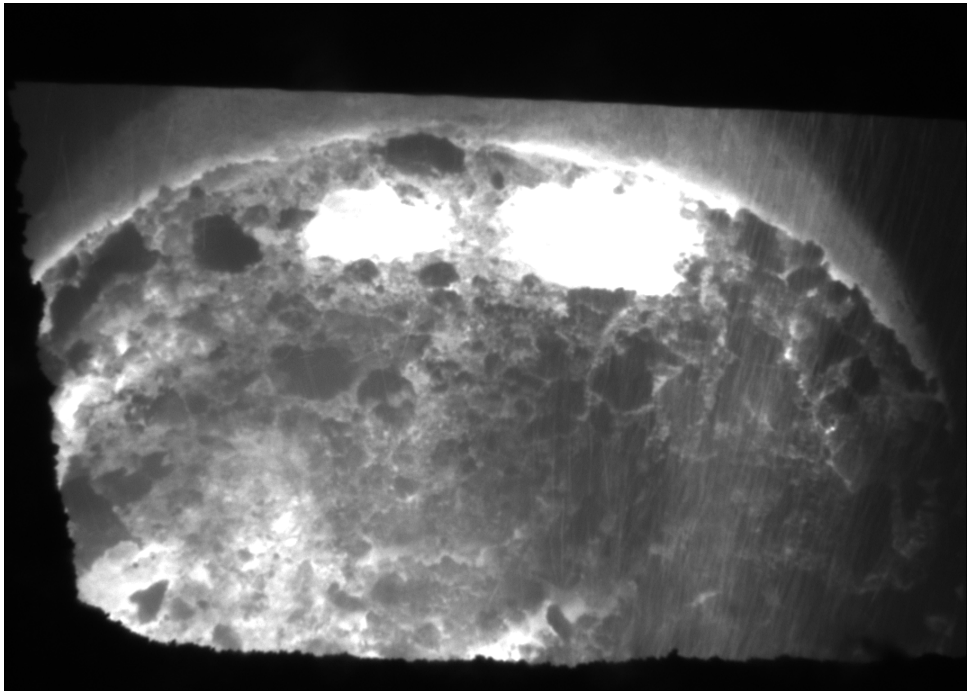
Test campaigns – data acquisition

Plant trials for monitoring and optimisation of deslagging

Objectives:

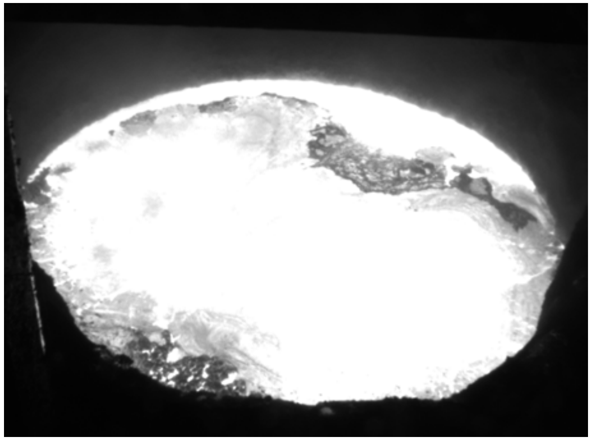
- Extensive image and process data acquisition (including sampling for slag analysis) during deslagging
- Enhancement of knowledge on the influence of process parameters on deslagging efficiency
- Improved deslagging schemes for optimum deslagging
- Input data to work with sulphur modelling

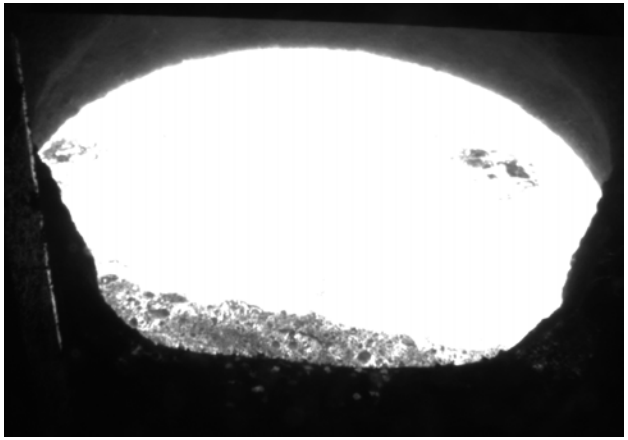
Test campaigns – data acquisition

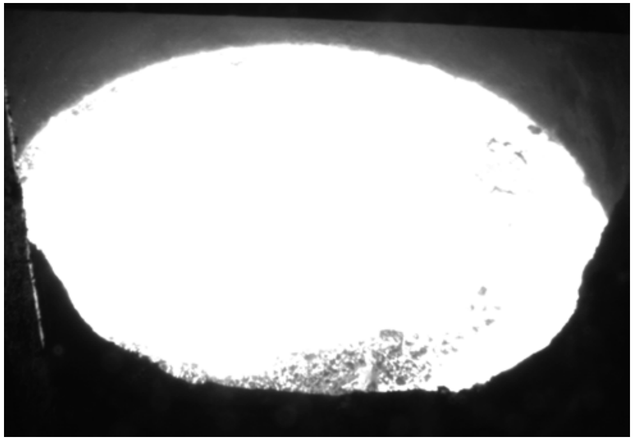


Bottom purging, two open eyes at the back side wall makes the slag move towards the lip of the ladle. Makes it easier to deslag after treatment.

Test campaigns – data acquisition







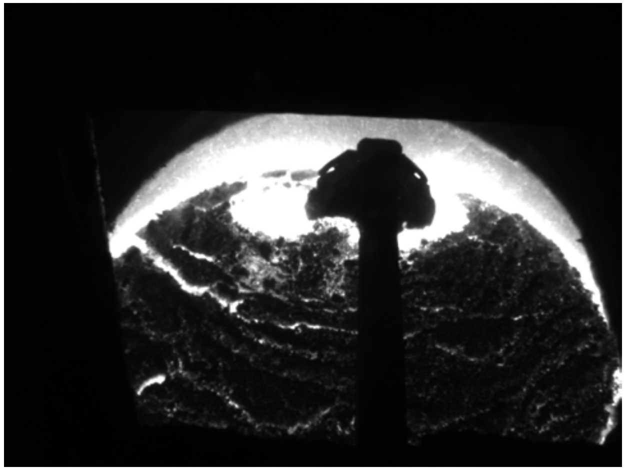
Slag area 17% of hot metal surface

Slag area 11% of hot metal surface

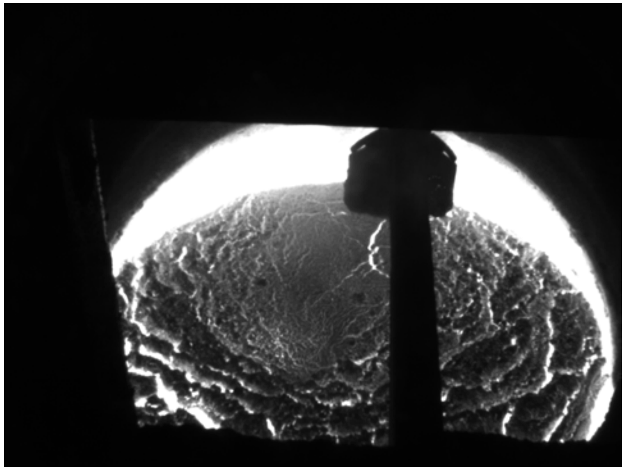
Slag area 8% of hot metal surface

Differences after deslagging

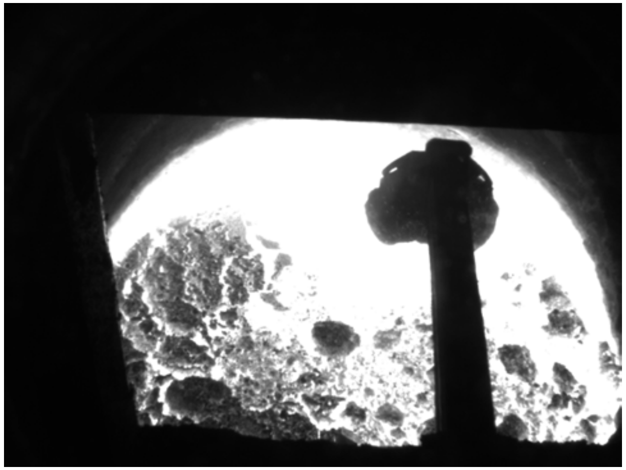
Test campaigns – data acquisition



Mono-injection of Calcium carbide



Co-injection of Calcium carbide and magnesium



Multi-injection of Calcium carbide, magnesium and soda

The images show differences in slag composition. The CaC2, mono-injection, processed hot metal has a very stiff, thick, dry, grainy, firm and heavy viscous slag .
The CaC2 and Mg, co- injection, processed hot metal are more liquid, lighter but still firm in slag composition.
The CaC2, Mg and soda, multi- injection, processed hot metal are even more liquid, still firm in slag composition, quite similar to the CaC2 and Mg treated melts. The condition of the slag (firm or loose) affects the deslagging time and the accuracy of deslagging.

Test campaigns – data acquisition

Average value of analyses of slag samples with different desulphurisation agents used

Average %	Fe	CaO	SiO2	MnO	P2O5	Al2O3	MgO	Na2O	K2O	V2O5	TiO2	Cr2O3	GLF	C_Leco	S_leco
Mono	59,235	23,993	3,239	0,466	0,075	1,476	0,161	0,009	0,043	0,595	1,346	0,059	16,271	10,492	1,601
Co	67,030	12,540	5,240	0,870	0,060	1,420	1,030	0,010	0,030	0,830	2,730	0,090	20,800	7,420	0,720
Multi	65,932	15,416	3,9	0,609	0,063	1,231	1,729	0,018	0,039	0,646	1,756	0,073	19,86	7,082	1,309

Test campaigns – data acquisition

Chemical composition of the slag samples taken after desulphurisation at SSAB

Heat	Inj. type	Fe	CaO	SiO_2	MnO	Al_2O_3	MgO	V_2O_5	TiO_2
1	Mono	72.9	15.3	3.0	0.52	0.71	0.11	0.67	1.68
2	Mono	72.5	16.3	2.6	0.52	0.51	0.08	0.69	1.76
3	Co	69.5	16.4	3.8	0.64	0.75	1.57	0.80	2.40
4	Co	75.6	12.5	3.0	0.50	0.45	0.63	0.70	1.39

Modelling work

The dynamic process models for slag balancing and conditioning are used

- **to estimate slag composition** (e.g. Sulphur content) prior to hot metal deslagging for optimisation of the hot metal desulphurisation operation (e.g. different co-injection schemes),
- **to estimate the slag amount prior to deslagging**, so that suitable deslagging schemes can be chosen depending on the slag amount, e.g. the deslagging scheme should be different for small amount and compact slag compared to large amount and voluminous slag,
- **to predict the impact of the remaining slag** on the metallurgical operations after deslagging and the metallurgical outcome,
- **to monitor online the evolution of the slag properties** throughout ladle treatment, and to calculate set-points for slag conditioning to adjust the slag properties so that the metallurgical operations that follow after deslagging are operated in an optimal way.

Deslagging scheme

An example of a typical deslagging scheme:

No 1: Start with the slag rake in the middle positioned about ¾ of the ladle diameter
No 2: The second stroke with the slag rake positioned ¾ of the ladle diameter to the right following the boundary of the refractory
No 3: The third stroke as the above but to the left
Repeat no 1 six times
Repeat no 2 and no 3 after amount
Repeat no 1 three times

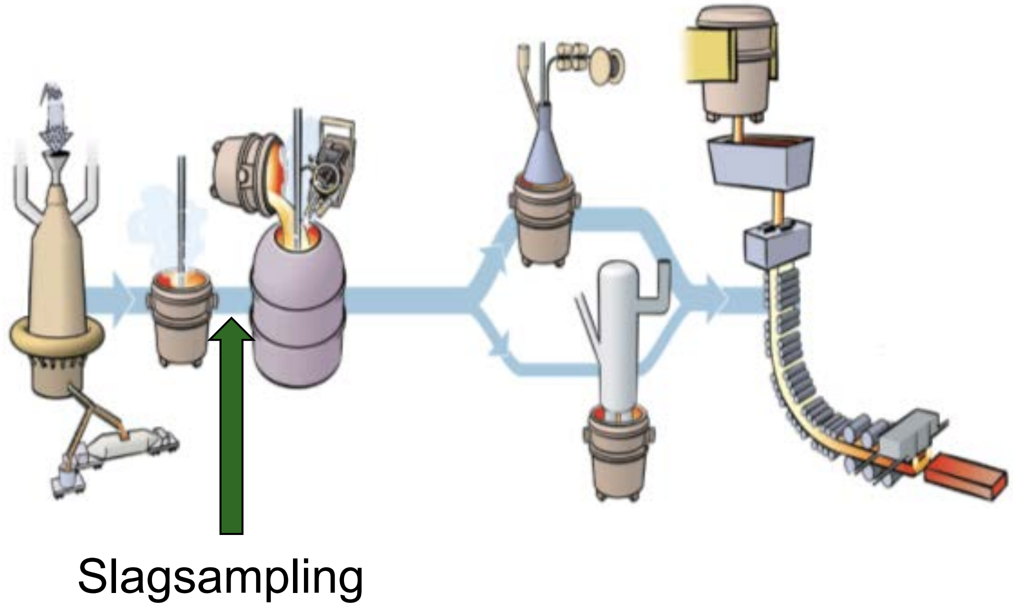
Modelling work

The slag balancing model at SSAB uses a multivariate tool where all significant data are used as input. All data are presented in a multidimensional coordinate system and the parameter/parameters of interest are fitted in the best possible way versus all input parameters.

The joint application of the new imaging based evaluation of deslagging processes and improved process models is used as input parameter for process control.

Overall, the software gives advice to the operator for slag area and remaining slag amount and slag rake movement

Modelling work



Slag sampling at SSAB after deslagging

Modelling work

Objectives:

Dynamic modelling of slag evolution during hot metal desulphurisation process

Development of set-point calculation for deslagging operation with regards to desulphurisation operation and steel quality conditions

Modelling work

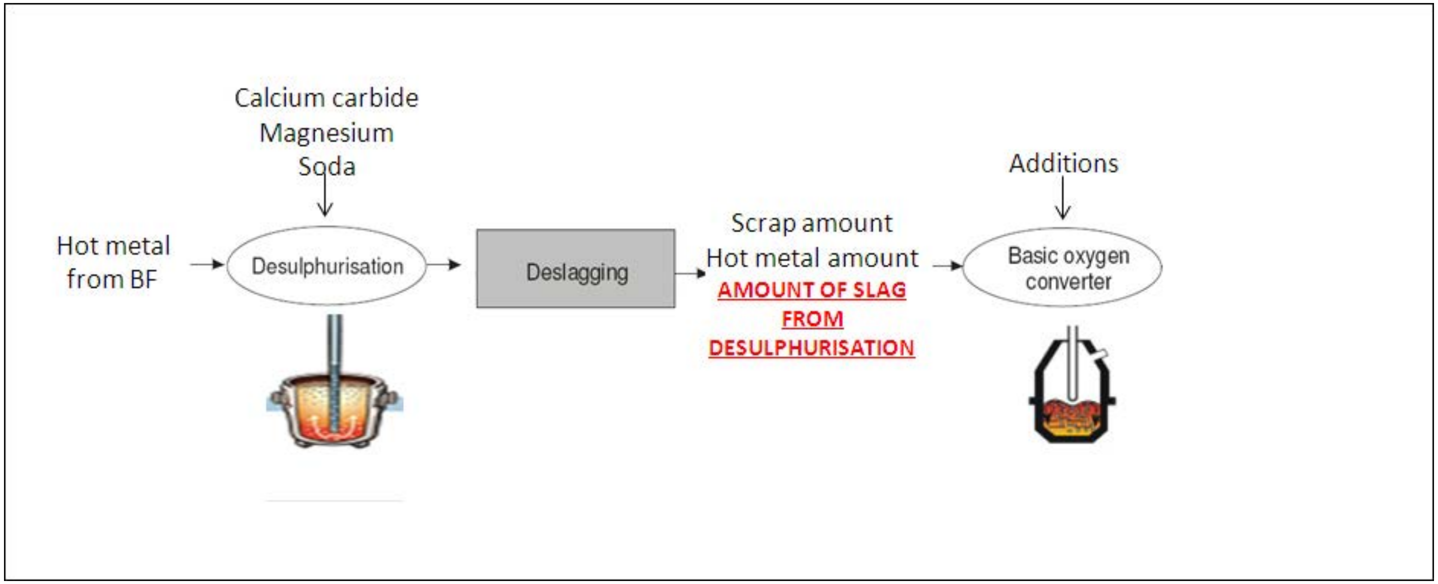
One part of the project was to **develop set-point calculations** to provide target values for permissible amount of remaining slag for deslagging to be used for selection of suitable deslagging schemes.

To decide the impact of remaining amount of slag on the steel quality and develop set-point calculations for deslagging, the sulphur amount in the produced steel has also been predicted.

The models to predict sulphur content/amount in the desulphurisation slag and the produced steel were developed by using multivariate data analysis and the models were built by samples and process data collected during campaign 1-3 conducted in this project.

To validate the models, results from campaigns 4-5 conducted in this project were used.

Modelling work



Schematic overview over the desulphurisation- and BOF process at SSAB

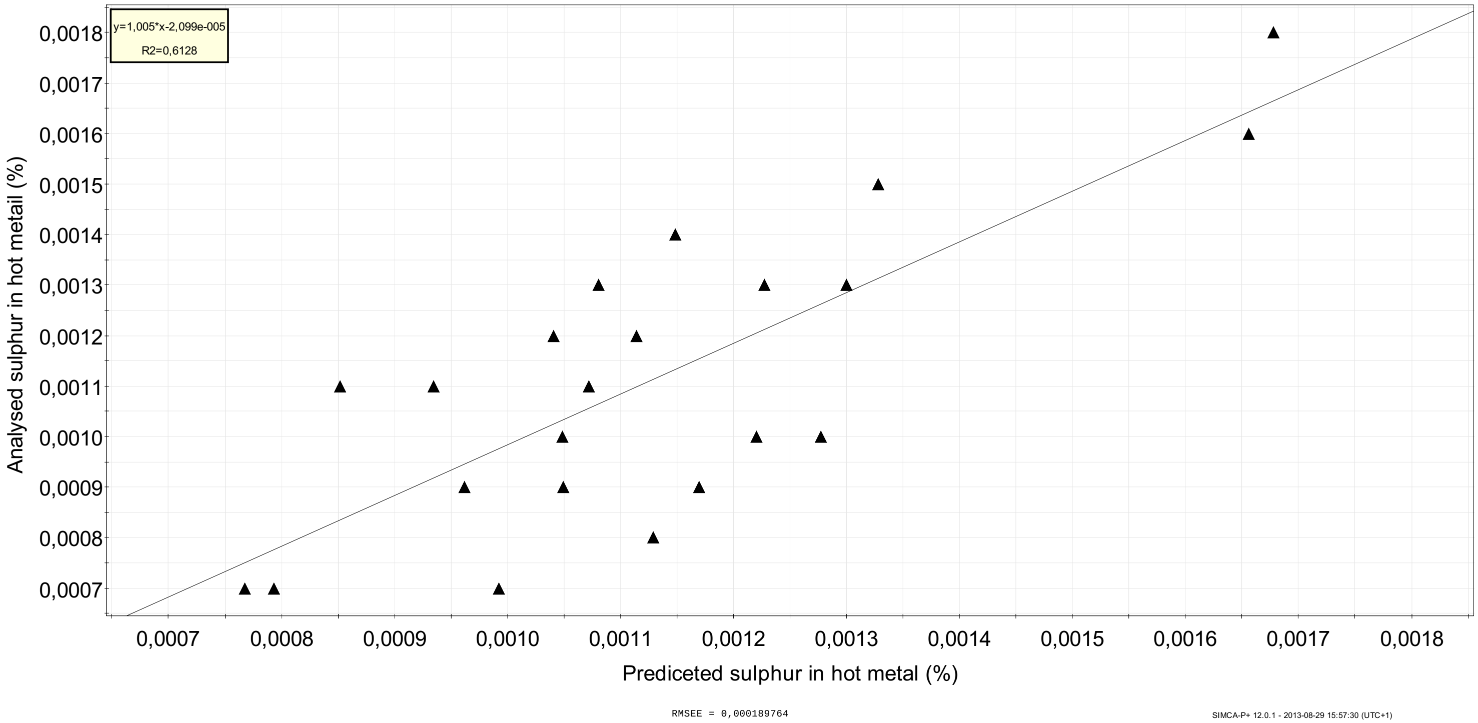
During the route of one heat the following samples are collected at SSAB:

Hot metal sample before the desulphurisation process starts

Steel sample in the end of BOF process

Modelling work

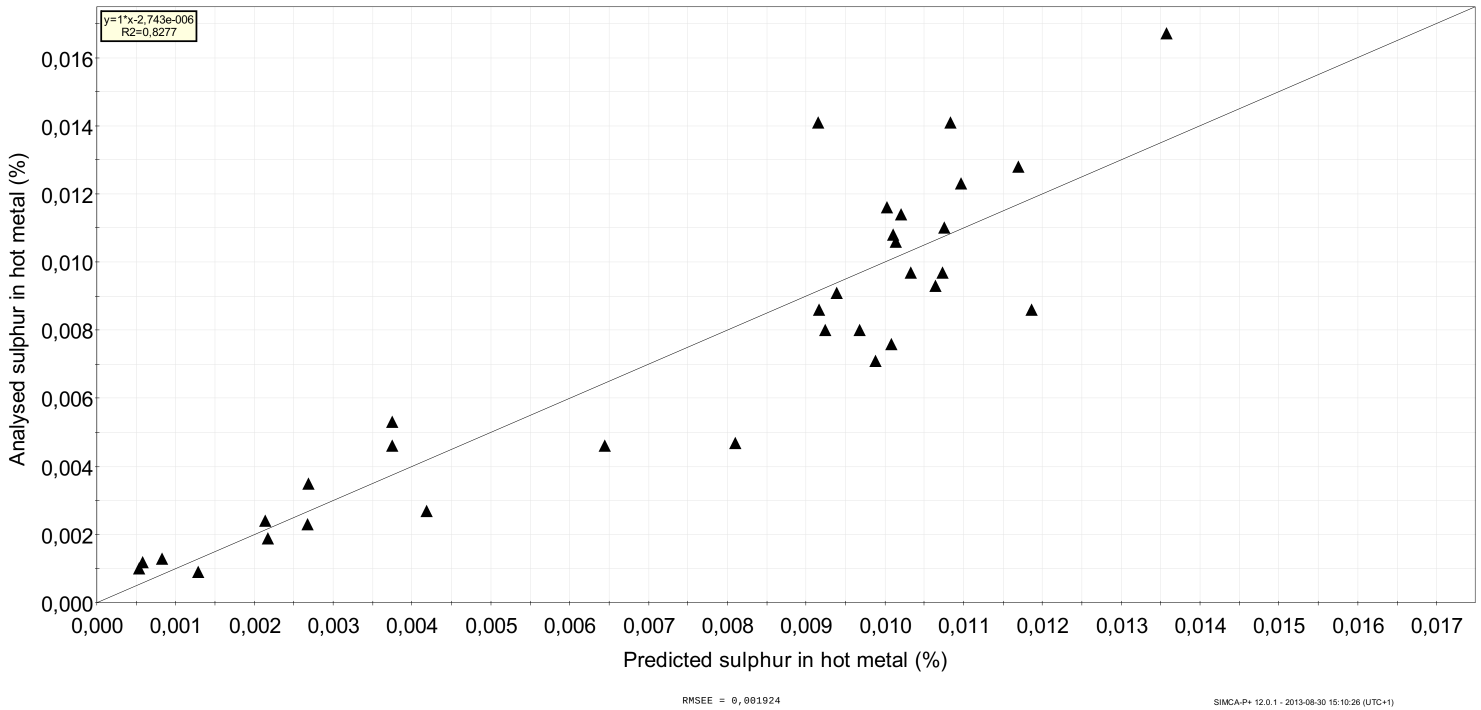
Low sulphur model, hot metal



Observed versus predicted value for sulphur content in hot metal low sulphur demand (S≤0.001%) 10ppm

Modelling work

High sulphur model, hot metal



Observed versus predicted value for sulphur content in hot metal, high sulphur demand (S>0.001%)

Test campaigns – validation

Error estimation of models

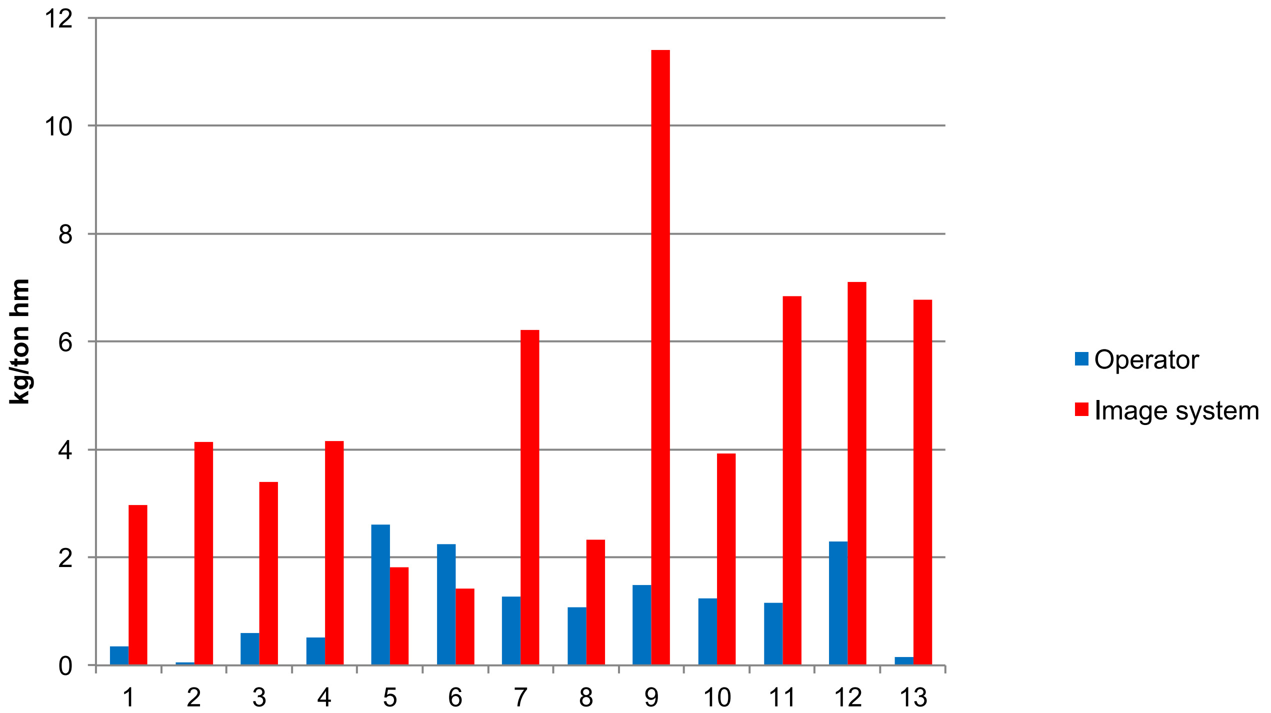
Low sulphur	
S in slag (%)	±2*0,24 %
S out (%)	±2*0,00019 %
S in steel (kg)	±2*0,26 kg

High sulphur	
S in slag (%)	±2*0,29 %
S out (%)	±2*0,0019 %
S in steel (kg)	±2*0,90 kg

Modelling work

- The predicted values of the sulphur amount in the produced steel are higher than the actual values and this together with the predicted sulphur content in the desulphurisation slag results in a lower permissible amount of slag that can be transferred into the BOF without any impact on the steel quality
- The optimum is to have a model that results in a permissible slag amount close to the actual slag amount that can be transferred into the BOF

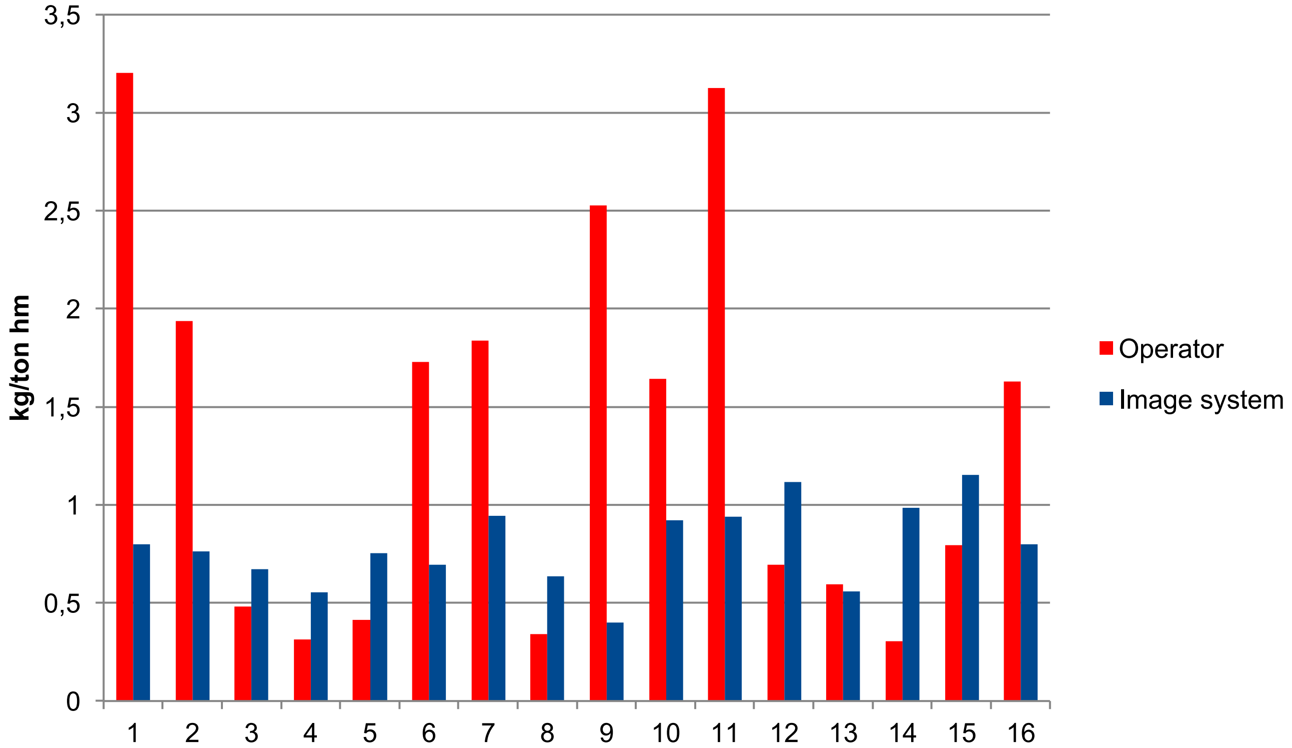
Test campaigns – validation



Recommended allowed slag amount by image system after deslagging (red) and remained amount of slag after deslagging by operator (blue). Max 0.01% S in steel > 0,0044%

Model work

Recommended allowed slag amount by image system after deslagging (red) and remained amount of slag after deslagging by operator (blue). Max 0.0044% S in steel



Overall project objectives - result

- The main objective at SSAB EMEA to have fully automatic control of the deslagging was not reached.
- The reason of this was the delay of delivering sensors, first one failed and as a consequence the actuators could not be delivered and installed within the time limit of the project.
- Without the fundamental parts it was not feasible to control the slag rake movements.
- Therefore SSAB and MEFOS investigate the possibility of using semi -automatic control of the deslagging. This was the new main objective which was reached.

Overall project objectives - results

- Overall the objectives were reached by development and installation of image based sensors and analysis tools to monitor the deslagging process, then investigating deslagging processes based on the new sensors.
- Based on the investigations, deslagging schemes for optimum deslagging were developed.
- Furthermore dynamic slag balancing models, and based on these online set-point calculations for slag conditioning were developed, to allow an online slag control within the steelmaking processes.
- Concurrently, online control systems for an optimal deslagging process based on the new sensors were established.
- Finally, deslagging schemes and model-based control systems were implemented and validated at two steelmaking plants.