# Scientific Exchange Day 2012

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# Session Research Area 1

**"Zero Waste Processing in Metallurgy"**

## a) Evaluation of technical separation processes of flue dusts in terms of their "selectivity"

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Abstract
In previous meetings, the potential separability of dusts has been described by means of fractionation and plotting the Henry-Reinhardt chart. In contrast, this presentation deals with the comparison of actual technical separation processes – be it the same unit with different settings or completely different methods of separation.

One way to refer to the quality of an instance of a two-product separation is by the characteristic figure of its "selectivity" which is calculated from the recovery of two different elements or phases. In the so-called Kappa chart values of selectivity are represented by a set of curves. Plotting the outcome of different tests in this chart gives a visual comparison of the separation quality and therefore aids in choosing proper settings respectively separation methods.

Selected results from previous tests on dust samples from integrated steel mills will be presented in this way.

**b) Flash Reactor: Further Development and outlook for 2012**

Lecturer
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Abstract

## c) Utilization of Export Gas in the Chemical Industry

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Abstract
Export gases from the alternative smelting reduction processes COREX® and FINEX® are typically used as an energy source for heat and power generation within the iron and steel industry. For the last 12 years, COREX® export gas has also been recycled as reducing gas in a MIDREX® direct reduction plant. The fact that COREX® and FINEX® smelting-reduction export gases typically consist of the major synthesis gas compounds CO and H2 and especially COREX® export gas is low in nitrogen makes them attractive for the utilization as synthesis gas (syngas) in chemical industry, with growing market especially in Asia and the Middle East.

State of the art technology can be applied for export gas treatment, which has been simulated for the generation of pure carbon monoxide, oxo gas, methanol, Fischer-Tropsch and ammonia syngas and for hydrogen. Next steps are the estimation of CAPEX and of consumption figures.

## d) Desulfurization with NaHCO3 in dry sinter plant off-gas cleaning - Results of residue leaching tests

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Abstract
The residue from dry sinter plant off-gas cleaning contains dust from the sinter plant and reacted and nonreacted sorbent. Due to the increased content of heavy metals and other toxic components the residue has to be safely disposed of. If NaHCO3 is used as a sorbent for desulfurization the reaction product is Na2SO4. Therefore, a substantial fraction of the residue is water soluble. For example, more than 80% of the residue from a European sinter plant is water soluble.

There is a request from sinter plants located close to the sea, to reduce the amount of residue for deposition by leaching the non-toxic water soluble salts (Na2SO4, KCl, ..) and to discharge the leachate with these salts into the sea.

In laboratory experiments leaching tests with subsequent process steps for cleaning of the leachate were performed in order to analyze the discharge water with respect to legally limited components (As; Cd; Hg; sum of Cr, Cu, Ni, Pb and Zn; fluoride; ammonium; COD and TOC). After optimization of the process for the cleaning of the leachate all values were below the permissible values except the limits for organic material (COD and TOC).

## Session Research Area 2

**"Development and Optimization of Refractories used in Metallurgical Processes"**

### a) Carbon burnout in magnesia-carbon refractories during ladle preheating

Lecturer
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Abstract
Magnesia-carbon refractories applied in the in slag bath area of steel ladles show high chemical, mechanical and thermal resistance, but one of their major disadvantages is the possibility of carbon burnout. This may occur during preheating of the steel ladle after refractory relining. To reduce the thermal shock of the refractories at the start up, the steel ladle is preheated up to 1100°C with natural or blast furnace gas with significant amount of excess air. The preheating conditions in the ladle favour the carbon burnout in magnesia-carbon refractories. The objective of the project is to quantify possible carbon burnout during preheating in dependence of the relevant parameters. The approach for this investigation is to define the reaction rate of carbon oxidation to carbon monoxide and to include this reaction in a CFD and thermal simulation.

The reaction kinetics depends on the mass transfer coefficient, which defines oxygen transport at the refractory hot face, diffusion coefficient, which defines oxygen transport in the open porosity of the refractory and a reaction rate coefficient, which defines the velocity of the chemical reaction.

The diffusion coefficients were determined experimentally using a thermogravimetric analysis. As the diffusion coefficients showed dependence on the temperature, the results of this investigation could be represented by an Arrhenius approach. The other influencing factor was the carbon content of the refractory.

Using commercial CFD code FLUENT to simulate gas and refractory temperature distribution as well as oxygen concentration in the ladle during its preheating will deliver the necessary data to define mass transfer coefficient and further the dynamics of carbon oxidation.

## b) Growth rate of mold slag crystallization – measurement, evaluation and interpretation of results

Lecturer
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Abstract
Single hot thermocouple technique (SHTT) has been applied for investigation of mold slag crystallization. First crystallization usually is nucleated at the slag/platinum wire interface, as the temperature is by far higher than that of the maximum of the homogeneous volume nucleation rate. This enables the determination of growth rates. An evaluation procedure has been setup for this purpose. It yields a polynomial fit of growth rates in dependence of the crystalized fraction (for TTT experiments) or the temperature (for CCT experiments). The question arises how these results may be interpreted. It is especially of great interest to link them to other mold slag properties. For this purpose fundamentals of incongruent crystallization have been revealed and applied for simulations. Results show how solid/liquid equilibria and viscosity may be used to at least qualitatively compare growth rates of different mold powders. They emphasize the necessity of a further thermochemical characterization of mold slags which is planned in Project 2.2. during the second funding period.

## Session Research Area 3

**"Modeling, Simulation and Automation of Metallurgical Processes"**

### a) Modeling of coal conversion and particle fragmentation inside the corex®-melter-gasifier

Lecturer
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Abstract
For the efficient and stable operation of the COREX®-Melter-Gasifier good gas-solid contact is essential. The charged particle size distribution and the particle fragmentation behavior inside the slowly moving fixed bed strongly influence the local counter current gas flow due to variations of the voidage and particle size inside the packed-bed. As a consequence the heat transfer between gas and coal, and subsequently the rates of drying, devolatilization and gasification depend on the local particle size distribution. A coarse mean particle size allows smooth tapping of liquid pig iron as well as slag.

In order to be able to describe and simulate the changes of the coal particle size distribution inside the slowly moving fixed bed a mathematical model has been developed. The afore mentioned processes - heat transfer, drying, pyrolysis, gasification and fragmentation – have been put into a mathematical context and solved for each particle size class of each coal brand charged into the Melter-Gasifier. The rate of coal particle fragmentation is assumed to be driven by solids pressure and shear stress in the slowly moving fixed bed, as well as the rates of heating, drying, pyrolysis and gasification. All of these processes except for gasification change the particle size distribution because of induced breakage of the particles. Gasification reduces the diameter of the particles according to a "shrinking particle" behavior.

The applicability of the developed model to the simulation of coal particle fragmentation has been tested by comparison of simulation results to experimental observations.

The fragmentation model has been included into a CFD-model of the slowly moving fixed bed of the COREX®-Melter-Gasifier. In a first attempt only gas, coal and inert iron particles have been considered in the model. In addition to this simplification the modeling domain contains only the slowly moving fixed bed above the Raceway zone.

In order to study the influence of coal particle fragmentation on the performance of the slowly moving fixed bed of a COREX®-Melter-Gasifier simulations have been performed with and

without particle fragmentation considered in the model. The results clearly show that neglecting particle fragmentation leads to large differences in the prediction of coal particle conversion behavior as well as temperature-, flow- and pressure-fields compared to cases with particle fragmentation. Thus, for reliable simulation results a model for the fragmentation behavior of coal particles has to be incorporated into CFD-models of slowly moving fixed bed gasifiers.b) Experimental and numerical investigation of sloshing resonance phenomena in a spring mounted rectangular tank

## b) Analytical, Numerical and Experimental Investigations in Continuous Casting Mould Flows

Lecturer
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Author
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Abstract
The analysis of the liquid steel flow inside a continuous casting machine is one of the main topics in project 3.2. It is known that the liquid steel flow influences the product quality and the process stability. Therefore it is important to investigate the flow situation. All three basic modelling techniques (analytical, numerical and experimental) are applied. Flow measurements are performed on a 1:1 scaled laboratory water model of the voestalpine continuous casting machine. Water has similar flow properties like liquid steel and is transparent, which is necessary for the applied PIV flow measurement technique. The turbulent flow is also simulated by numerical models. The resolution of turbulent vortices in the mould flow becomes more and more necessary in order to be able to model the relevant flow effects. Despite of the constant increase of computational power, the required computational resources are still a serious limitation. Thus, a new hybrid turbulence model was developed which is able to perform high resolution simulations for regions covering only the interesting part of the coarser resolved entire domain in a very fast and efficient way. Previous research showed an influence of the liquid steel flow and geometrical caster parameters on the inclusion concentration in the solidified steel. Numerical flow simulations can model these effects, but do not give insight in the relation between result and parameter variation. Thus, an analytical model was developed which allows to better understand the relations between the parameters and the resulting inclusion concentration.

## c) Correlation between micro-alloying precipitation and the high-temperature part of the second ductility minimum

Lecturer
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Abstract
The formation of small precipitates in the cooling process of slabs is a well known mechanism leading to a loss of ductility, where the small particles interact with recrystallization at deformation temperatures. Better knowledge of the mechanisms involved in the continuous casting process at these temperatures is of great importance, since the choice of optimum process parameters is highly dependent on the temperature-dependent ductility changes. The present investigation is focused on both, the laboratory as well as computer simulation, of formation and growth of AlN, TiN and NbC precipitates in different steels. In the analysis, samples are heated up to an austenitization and grain coarsening temperature of 1320°C. After cooling at different rates, they are tensile-tested to fracture using the thermo-mechanical simulator Gleeble1500. Changes of size and distribution of precipitates are obtained from carbon extraction replicas by TEM-investigations and compared to computer simulations performed with the software MatCalc. The simulation results are closed to experimental findings. The increasing density of fine dispersed precipitates with decreasing temperature clearly correlates with the ductility loss observed in the mechanical testing.

## d) Continuous Casting of Round Bloom Strands with Mould-Electromagnetic Stirring; Numerical Simulations with A Full Coupling Method

Lecturer
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Abstract
In the continuous casting of round bloom strands electromagnetic mould–stirrers (M EMS) are often employed to enhance the flow inside the strand. It is well known, that the flow in the liquid core of the strand strongly influences the quality of the end product. With M EMS optimal velocities at the solidification front can be achieved. These velocities further the transition from columnar to equiaxed solidification as well as reducing the number of surface and sub-surface defects among other benefits. Therefore M-EMS is used at the steel plant of voestalpine Stahl Donawitz GmbH & Co KG for the majority of products.

In the present work the electromagnetic stirring is studied by means of numerical simulations. Due to the harsh environment at the steel plant measurements are difficult to perform. Physical 1:1 scaled models of the casting process can not be used because the conductivity of water is too low. If liquid metals are used, measurements are getting rather complicated due to the opacity or the required treatment of the metals. Thus numerical simulations are very important to gain a better understanding of the whole process.

The presented numerical model considers the full coupling between the flow field and the magnetic field. Each part of this multiphysic problem is simulated with an optimal solver. While the flow field is calculated with FLUENT, a commercial finite volume CFD code, the electromagnetic field is calculated with ANSYS EMAG, a commercial finite element solver. This approach enables the study of various parameters and their influence on the flow field and solidification structure. It will be shown how variations of the stirring frequency and stirring strength affect the flow inside the liquid core. With the help of numerical simulations the knowledge about the continuous casting process with electromagnetic stirring can be deepened and optimizations of the process found.

## Session Research Area 4

**"Valuation and Optimization of Metallurgical Raw Materials"**

### a) Injection of heavy fuel oil and waste plastics into a blast furnace raceway

Lecturer
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Abstract
The production of raw iron is conventionally done by reducing iron oxides using coke as reducing agent. As this process is very capital and energy intensive, the iron and steel producing industry attempts to reduce the demands by introducing alternative carbon carriers into the blast furnace. voestalpine Stahl Linz GmbH utilizes a wide variety of alternative reducing agents at blast furnace A including oil, crude tar, natural gas and waste plastics.

In this work, the blast furnace process is investigated using Computational Fluid Dynamics (CFD), aiming at the optimization of the operating conditions, in order to decrease the coke rate. It is of special interest to predict the behavior of injected material into a blast furnace raceway. Therefore the original model setup includes functions to predict not only the raceway shape, but also allows for calculating the progress of the reaction of a heavy fuel oil spray or plastic particles injected via the tuyeres. Simplified mechanisms for gasification and subsequent gas phase reactions within the void zone are in use. The reactions of the gaseous mixture with the coke bed are also considered.

To provide suitable boundary conditions and to validate the predictions of the simulation, lab scale measurements were carried out at Vienna University of Technology: A downscaled cold model of a blast furnace section was used to predict the droplet size distribution of the heavy fuel oil spray, since internal measurements within the blast furnace are hardly possible. Data on droplet sizes and velocities were collected by high-speed imaging and particle image velocimetry (PIV).

To characterize the behavior of the injected plastic particles, experiments were undertaken at RWTH Aachen University. The mass change of the particles inserted into a high temperature atmosphere was recorded using a Tammann Furnace. In addition to that short time exposure experiments were done: the plastic particles were injected into a pressurized and inductively heated tubular reactor at raceway conditions, the reaction products are collected and analyzed. The experimental results were used for validation of the particle reaction model in CFD.

The concept of the advanced model is based on the description of the solid-phase properties using a porous medium approach, avoiding computationally expensive full Eulerian multiphase simulations. The newly implemented method accounts for the flow of solids as well as gaseous fluids in the furnace by solving separate sets of conservation equations. Heterogeneous reactions as well as heat transfer effects are modelled by implementing source terms based on correlations describing the underlying physics. This model setup has been validated using a number of heat transfer problems as well as setups including heterogeneous and homogeneous chemical reactions. Model predictions compare well with experimental data from literature. In the next step, the model will be applied to the lower part of the real blast furnace geometry to examine the conditions in the raceway and the coke bed.

**b) Characterization of the reducibility / disintegration of lumpy iron carriers**

Lecturer
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Author
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Abstract
In addition to the development of new industrial processes and techniques one major aspect of research work is the continuous improvement and optimization of existing processes in terms of both, economical and environmental aspects. Within this project lumpy iron carriers namely lump ores, pellets and sinters as feed material for blast furnace-, COREX® and/or MIDREX® iron making route are investigated for their applicability in each process. Therefore beside the characterization of the named materials regarding their reducibility and mechanical properties in conventional reduction lab testing facilities the material will be characterized in terms of morphology with microscopic investigations.

The reduction tests are performed at the Chair of Metallurgy (CoM) at the Montanuniversitaet Leoben. The new installed vertical tubular furnace enables tests according to different ISO standards as well as the testing of the burden material under conditions closer to the industrial processes, especially regarding temperature and gas composition profiles. In addition to the work at the CoM there are efforts of combining these results with “VisuMet”, an automated image analysing software. Previous research work at the Chair of Geology and Economic Geology proved that reducibility of different iron ore fines can be evaluated at polished sections by fully automated image analysis of the mineralogy and petrography of the raw materials. For iron ore fines and to some extent for lumpy iron ores the results are in good accordance to the measurements of conventional reduction tests but nevertheless there is a lack of knowledge concerning the effects of more complicated morphological structures, glass phases and pore distribution for example, on the reduction properties. In a first step, within the assembling and implementing of the lab facility at the CoM, numerous different kinds of raw materials had been tested analogous to the ISO 4695 test to ensure the correct operation of all facility parts. These results have been compared to other laboratory´s results and additionally serve as input data for evaluating and improving the VisuMet Software for its possible application to pellets and sinters in the near future. Another objective is the investigation of the behaviour of the iron carrying material at conditions of the indirect reduction zone of the blast furnace or the COREX®- and MIDREX® shaft furnace respectively. The approach to these process conditions is realized by more sophisticated testing procedures, e.g. variation of gas composition in dependence of temperature and testing time. But nevertheless the testing parameters are defined in a systematic way in order to ensure the comparability of these results.

The objective of this work is to ease the characterization of lumpy iron carriers regarding their reduction and mechanical properties and coinstantaneous, with a better understanding of the coherency of raw material characteristics and behaviour under industrial scale ironmaking processes. By these means a more selective and purposive assortment of lumpy iron carriers should be provided for different reduction processes.

## Session Research Area 5

**"Optimization and Development of Processes and Key Components of Metallurgical Plants".**

### a) Effect of an improved material distribution in the blast furnace process

Lecturer
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Abstract
The objectives of the project are the investigation of alternative, new developed distribution system for blast furnace operation. Cold tests and simulation are carried out to gain information regarding distribution pattern which are relevant for real installation. The fully developed distribution system was installed on an industrial blast furnace.

The evaluation of operation results for material flow, segregation materials pattern for the burden material and coke is ongoing. First results are promising: lower consumption of reducing agents, increased gas utilisation and lower top gas temperature.

## b) Modification of Oxide Inclusions due to Steel-Slag Interactions with Special Focus on the Electroslag Remelting Process

Lecturer
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Abstract
Through Electroslag Remelting (ESR) a significant improvement of steel cleanness can be achieved. Due to the contact of the liquid metal with the reactive slag bath at the three steel/slag interfaces not only the number and size but also the chemical composition of non-metallic inclusions changes significantly between the electrode and the remelted ingot.

Within a K1-MET project between Böhler Edelstahl GmbH & Co KG and the Chair of Metallurgy at the Montanuniversitaet Leoben, the modification of oxides in the steel X38CrMoV5-1 through remelting is studied in detail from the viewpoints of experiments, thermodynamics and kinetics, especially focusing on the spinel inclusion type MgOAl2O3.

The presentation concentrates on the performed laboratory tests in a Tammann Furnace simulating the influence of slag composition and dwell time of inclusions in the liquid pool on inclusion modification. Additionally, results of investigations with a Laser Scanning Confocal Microscope are shown which enables the in-situ observation of the dissolution behavior of oxides in steel and slags. These findings are then compared to industrial observations. Special attention is paid on the changes in inclusion morphology. Finally, the most decisive factors primarily influencing inclusion size and composition in the remelted ingot are summarized.

## c) Thermodynamic and kinetic model of the BOF process

Lecturer
Yuri Lytvynyuk, Montanuniversität Leoben

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Abstract
A model was developed which considers the chemical reactions between each component in heterogeneous thermodynamic system, the dissolution and melting of the charge materials, as well as mass and heat balances. The thermodynamic parameters of this model are: equilibrium constants of the oxidation reactions, the activity coefficients of hot metal and the activity coefficients of slag components. The kinetic parameters are the mass transfer coefficients in the metal and slag phases, which are defined by the technological parameters of the process and the specific geometry of the converter. Models for charge materials dissolution and melting include the separate calculations for the heating and melting of each charge material portion. The technological parameters considered are the lance design, the lance height, the oxygen blow rate, the flow rate of inert gas, the time and amount of charge material addition.