7TH EUROPEAN COKE AND IRONMAKING CONGRESS - ECIC 2016

Monday 12 September 2016 - Wednesday 14 September 2016

Design Center Linz

Book of Abstracts
[INNOVATIVE TOOLS FOR PROCESS OPTIMIZATION – BURDEN SURFACE SCANNING VIA BEAMFORMING RADAR AND MEASUREMENT OF THE TOP GAS TEMPERATURE DISTRIBUTION] ........................................... 7

CHARACTERISATION OF STEELPLANT BY-PRODUCTS TO REALISE THE VALUE OF FE AND ZN ................................................................. 8

FLOW SHEET MODELLING OF STEEL MAKING ROUTES IN A PROCESS INTEGRATION PLATFORM ......................................................... 8

PHYSICAL MODELLING BASED ANALYSIS OF DRY SLAG GRANULATION ................................................................. 9

ANALYSIS OF NONSTATIONARY TRANSIENT PROCESSES IN BLAST FURNACE ................................................................. 9

KINETIC ANALYSIS AND EFFECT OF BIOMASS ASH ON COMBUSTION CHARACTERISTIC OF PULVERIZED COAL ................................................................. 9

RESEARCH AND APPLICATION OF SINTERING HIGH-TEMPERATURE CHARACTERISTICS OF IRON ORE ................................................................. 10

EFFECTS OF MGO ON THE SINTERING LIQUID, THE PROPERTIES AND MINERALOGICAL MORPHOLOGY OF THE HIGH-BASICITY SINTER ................................................................. 10

THE INFLUENCE OF ZINC VAPOR ON COMPOSITION AND PROPERTIES OF COKE ................................................................................ 10

STUDY THE INFLUENCE MECHANISM OF POTASSIUM VAPOUR ON SINTER REDUCTION ................................................................. 11

CHARACTERISTICS OF LITHIUM SILICATE PREPARED BY SOLID STATE REACTION AND THERMOGRAVIMETRIC ANALYSIS ................................................................. 11

STUDY ON THE MECHANISM OF CEO2 AS COMBUSTION IMPROVER IN PCI ................................................................. 12

DRY BLAST FURNACE SLAG GRANULATION WITH WASTE HEAT RECOVERY ................................................................. 12

EFFICIENT SINTER COOLING WITH OPTIMIZED ENERGY RECOVERY, ENERGY SAVING AND EMISSION REDUCTION ................................................................. 12

LOW CO2 IRONMAKING IN THE BLAST FURNACE ................................................................. 13

DIRECT REDUCTION TECHNOLOGY AS A FLEXIBLE TOOL TO REDUCE THE CO2 INTENSITY OF IRON AND STEELMAKING ................................................................. 13

COMPARING THE CO2 EMISSIONS OF DIFFERENT IRONMAKING ROUTES ................................................................. 14

LATEST DEVELOPMENT IN DRY AND WET BLAST FURNACE GAS CLEANING TECHNOLOGY ................................................................. 14

INSTALLATION, COMMISSIONING AND RAMP-UP OF THE NEW PULVERIZED COAL INJECTION SYSTEM AT ARCELORMITTAL KRYVYI RIH BLAST FURNACE NO. 9 ................................................................................ 14

NEW BLAST FURNACE OPERATION PROSPECTS WITH THE G3 CHUTE TRANSMISSION GEARBOX ................................................................. 15

BLAST FURNACE RELINE IMPLEMENTATION STRATEGY ................................................................. 15
DRIPAX – THE NEW GENERATION OF DR PLANT PROCESS OPTIMIZATION

HIGH-CARBON DRI THE FEEDING MATERIAL TO IMPROVE PERFORMANCES AND DECREASE CO2 EMISSIONS IN BOTH BF AND EAF

APPLICATION OF MIDREX TECHNOLOGIES IN INTEGRATED STEEL PLANTS: POSSIBLE REDUCTION OF ENVIRONMENTAL IMPACT AND OPEX

SELECTION AND IMPLEMENTATION OF IRONMAKING TECHNOLOGY – EXPERIENCE, PRINCIPLES AND RISKS

EFFECT OF HEATING RATE ON THE PROPERTIES OF TWO NONCOKING COALS USED IN TUNNEL KILN DIRECT REDUCTION OF IRON PROCESS

EFFECT OF VOLATILE MATTER OF COAL ON VOLUME CHANGE AND REDUCTION OF IRON ORE/COAL COMPOSITE PELLETS

EXAMINATION OF COKE REACTIVITY USING MICRO-CT ANALYSIS

TOWARDS PREDICTION OF COAL CONVERSION BEHAVIOUR IN THE BLAST FURNACE

EFFECT OF SILICA ON THE REDUCTION KINETICS OF CaO-Fe2O3-SiO2 SYSTEM

COMMISSIONING OF 60 KG MOVABLE WALL OVEN AT THYSSENKRUPP STEEL EUROPE AG

THE NEW GERMAN PAH-REGULATIVE INFLUENCING COKE MAKING AT SCHWELGERN PLANT

OPTIMIZATION OF COAL PREPARATION PLANT IN LINZ

CHANGING BULK DENSITY IN CARBONISATION BLENDS

CAREFUL CONTROL OF REFRACTORY LINING CONDITIONS ENSURES PROLONGED CAMPAIGN OF BLAST FURNACE

ENERGY EFFICIENT TECHNOLOGY TO PRODUCE HOT METAL FROM TITANIA-MAGNETITE ORE

OPTIMAL DISTRIBUTION OF SUPPLEMENTAL FUEL AND OXYGEN AMONGST FURNACES IN BLAST FURNACE SHOP

ADVANCED SIGNAL PROCESSING OF TUYERE PRESSURE DATA TO DETECT REDUCED HOT WIND THROUGHPUT AND RACEWAY BLOCKAGES

THE LONG WAY TO PCI IN LINZ – FIRST OPERATION EXPERIENCE

UPDATES ON THE FINEX®️, A COMMERCIAL PROVEN ALTERNATIVE IRONMAKING PROCESS

FINEX®️ - AN INNOVATIVE AND ENVIRONMENT FRIENDLY IRONMAKING PROCESS

COREX®️ - AN ALTERNATIVE FOR HOT METAL PRODUCTION IN A CHALLENGING ENVIRONMENT
<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>THE STUDY OF CORE-BORED TAPHOLE CLAY USED IN FINEX</td>
<td>40</td>
</tr>
<tr>
<td>THE EFFECT OF BINARY AND TERNARY MINERAL COMBINATIONS ON THE</td>
<td></td>
</tr>
<tr>
<td>REACTIVITY OF A COKE ANALOGUE</td>
<td>40</td>
</tr>
<tr>
<td>NEW THEORY OF COAL BLENDING BASED ON NOVEL THERMOPLASTICITY</td>
<td></td>
</tr>
<tr>
<td>MEASUREMENT; PERMEATION DISTANCE</td>
<td>41</td>
</tr>
<tr>
<td>EFFECTS OF BRIQUETTE BLEND ON PACKING STRUCTURE OF FINE COAL PART</td>
<td>41</td>
</tr>
<tr>
<td>THE EFFECT OF BROWNCOAL ADDITION ON COKE STRENGTH</td>
<td>42</td>
</tr>
<tr>
<td>APPLICATION OF SMALL ANGLE NEUTRON SCATTERING TO UNDERSTAND</td>
<td></td>
</tr>
<tr>
<td>NANOPOROSITY OF COKES</td>
<td>42</td>
</tr>
<tr>
<td>THE USE OF PLASMA TORCHES IN BLAST FURNACE IRONMAKING</td>
<td>43</td>
</tr>
<tr>
<td>KÜTTNER'S PULVERIZED COAL INJECTION TECHNOLOGY – LATEST DEVELOPMENTS</td>
<td>43</td>
</tr>
<tr>
<td>LONG LIFE COPPER STAVE FOR BLAST FURNACE OF NIPPON STEEL &amp; SUMIKIN</td>
<td>43</td>
</tr>
<tr>
<td>ENGINEERING</td>
<td></td>
</tr>
<tr>
<td>BLAST FURNACE MODERN DESIGN – MODULAR CONSTRUCTION</td>
<td>44</td>
</tr>
<tr>
<td>EQUIPMENT FOR THE INJECTION OF TI-CONTAINING POWDERS INTO THE</td>
<td></td>
</tr>
<tr>
<td>BLAST FURNACE TUYERES</td>
<td>44</td>
</tr>
<tr>
<td>BLAST FURNACE COOLING STAVE DESIGN</td>
<td>44</td>
</tr>
<tr>
<td>DEVELOPMENT OF REACTION BONDED SiC BRICK WHICH HAVE HIGH THERMO-</td>
<td></td>
</tr>
<tr>
<td>MECHANICAL CONDUCTIVITY FOR BLAST FURNACE</td>
<td>45</td>
</tr>
<tr>
<td>DEVELOPMENT OF A VERTICAL CHAMBER COKING OVEN FOR UPGRADING</td>
<td></td>
</tr>
<tr>
<td>LIGNITES OR SUB-BITUMINOUS COAL</td>
<td>45</td>
</tr>
<tr>
<td>STUDIES ON MINERALOGICAL AND THERMO-MECHANICAL PROPERTIES OF</td>
<td></td>
</tr>
<tr>
<td>DENSE SILICA BRICKS FOR COKE OVEN SOLE AND WALL LINING</td>
<td>45</td>
</tr>
<tr>
<td>REFRACTORIES FOR COKE OVEN WALL - OPERATOR'S PERSPECTIVE</td>
<td>46</td>
</tr>
</tbody>
</table>
THE BLAST FURNACE - FIT FOR THE FUTURE?
Prof. SCHMÖLE, PETER¹

¹ ThyssenKrupp Steel Europe

The blast furnace process is worldwide the dominant technology for producing metallic pre-products for steelmaking. Today, blast furnaces are operated close to thermodynamic equilibria. The carbon-based iron ore reduction process inevitably causes CO₂ emissions. With regard to reducing CO₂ emissions, the coke/pulverized coal injection operation is compared with various process alternatives: Use of pre-reduced material (HBI: Hot Briquetted Iron) and injection of natural gas or hydrogen, and the respective CO₂ abatement costs are calculated. Another way of reducing CO₂ emissions is to use the by-product gases arising in an integrated iron and steel mill for the production of valuable chemical raw materials which is to be examined in a “cross-industrial“ project jointly carried out between steel and chemical industries and energy suppliers.

COMBINED INJECTION TECHNOLOGY OF GAS FUEL AND OXYGEN IN IRON ORE SINTERING PROCESS

Author(s): HIROSAWA, TOSHIYUKI¹
Co-author(s): IWAMI, YUJI ¹; YAMAMOTO, TETSUYA ¹; NOBUYUKI, OOYAMA ¹; MATSUNO, HIDETOSHI ¹

¹ JFE Steel Corporation

JFE Steel Corporation developed a technology for injection of hydrogen-based gas fuel in sintering machines, “Super-SINTERTM (Secondary-fuel Injection Technology for Energy Reduction)”, which makes it possible to greatly reduce CO₂ emissions in the sintering process, and successfully applied this technology to a commercial sinter plant for the first time in the world. In ordinary sintering process, after coke breeze is mixed with iron ore and limestone, raw materials are charged and sintered in sintering machine. To produce high strength and high reducibility sintered ore, it is necessary to keep the sintering temperature between 1,200 °C and 1,400 °C during sintering. In the temperature zone below 1,200 °C, the strength of sintered ore decreases because raw materials don’t melt enough. In the temperature zone over 1,400 °C, the strength and reducibility decrease by increasing glassy silicate. With “Super-SINTERTM” technology, it is possible to extend the period in the optimum temperature by injecting a hydrogen-based gas fuel from the upper side of the charged raw materials as a partial substitute for coke breeze. As the result, the energy efficiency of the sintering process is greatly improved, and it has been achieved to reduce CO₂ emissions. Moreover, combined injection technology of hydrogen-based gas fuel and oxygen is developing as the improvement technology of Super-SINTERTM. This technology can extend the period in the optimum temperature extends longer than Super-SINTERTM and increase sintering speed by increase of combustion rate of hydrogen-based gas and coke breeze by oxygen enrichment. As the results, sinter productivity was improved greatly.

AUTOMATIC SAMPLING AND ANALYSIS OF GRANULATED SINTER FEED

Author(s): REIDETSCHLAEGER, JOHANN¹
Co-author(s): BETTINGER, DIETER ¹; SEILER, ANDREAS ²; MUNKE, STEFAN ²; SCHADLER, SONJA ³; SCHUSTER, ELMAR ³; ZIRNGAST, JOHANN ³

¹ PRIMETALS Technology GmbH
² Maschinenfabrik Gustav Eirich GmbH &Co KG
³ voestalpine Stahl Donawitz GmbH
In today’s competitive iron making environment the optimization and continuous supervision of the sintering process is of major importance. Today, the quality control of mixes mainly relies on the experience and expertise gained by one or several operators working at the production facility. Standardized and representative sample taking and preparation is an unfulfilled wish of the operating personnel. The benefits of sampling, sample preparation and analysis are even more important when they are combined with process models and expert systems. Only a comprehensive and detailed knowledge of the process parameters together with measurement of process variables enables corrective actions and an optimized operation of the plant. This paper describes the development of a fully automated sampling device which takes several representative samples directly during material discharge from conveyor and a sample preparation system via utilisation of robotic systems and measurement of permeability, bulk density and other material properties. Direct action is taken via level2/expert system to change process parameters (e.g. moisture) according to the measurements. Continuous adjustments and design modifications result in a stable and robust measuring system including peripheral devices and a sophisticated control unit.

Sintering, Operation and Control - Board: 88 / 39

RECENT ADVANCES IN UNDERSTANDING SINTERING EMISSIONS AND THEIR MITIGATION TECHNOLOGIES
LU, LIMING

CISRO MINERAL RESOURCES

Iron ore sintering is a material preparation process used world-wide in the production of iron and steel. Because of the very large quantities of iron ore processed and the large volume throughout of air involved, sintering is a major point source of toxic emissions and also CO2 into the atmosphere. Waste gases from sintering also contain varying quantities of acidic species, dust and dioxin pollutants. As legislated limits become increasingly more stringent, sinter plants are under scrutiny by local authorities to further decrease emission levels. Extensive efforts have been made in mitigating CO2 and toxic emissions from sinter plants since 1980-90 and a number of different technologies are now available. However, most of these technologies are secondary measures which take affect only after emissions are formed, adding to the complexity of the operations. This paper will first examine the emission characteristics of CO2 and various toxic species, including SOX, NOX, dioxins and particulate matter, and then review the mitigation technologies available for preventing and reducing the formation of these toxic species in the sintering bed.

Ironmaking Fundamentals - Board: 96 / 74

MINERAL4/RECOGNITION4: A UNIVERSAL OPTICAL IMAGE ANALYSIS PACKAGE FOR IRON ORE, SINTER AND COKE CHARACTERIZATION
Author(s): DONSKOI, EUGENE
Co-author(s): POLIAKOV, ANDREI; VINING, KEITH; HAPUGODA, SARATH

CSIRO Mineral Resources

Understanding the characteristics of iron ore is paramount for predicting the performance of downstream processes. Whilst chemical assay and mineralogical assessments are routinely undertaken, the effects of textural information are often overlooked. For an industry striving to optimise productivity, an understanding of the impact of the textural characteristics of feed materials on process performance is critical. Rapid data collection and meaningful data sets can only be gathered effectively by an automated method. Optical image analysis (OIA) has traditionally been used for reliable identification of different iron oxides and oxyhydroxides in iron ore. The automated CSIRO optical image analysis system Mineral4/Recognition4 was created for rapid mineral and textural characterisation of iron ore providing identification of different
minerals, as well as different morphologies of the same mineral. The technique has further
been applied to processed iron ore products such as iron ore sinter to determine key parameters
such as porosity, different morphologies of hematite (primary and secondary), and different
morphologies of SFCA (silicoferrite of calcium and aluminium), the key bonding phase in sinter.
Application of textural identification has recently been extended to coke characterisation where
the Mineral4/Recognition4 software effectively distinguishes between IMDC (inert maceral derived
components) and RMDC (reactive maceral derived components). Furthermore, the software gives
comprehensive characterisation of porosity, IMDC, RMDC and the boundaries between IMDC
and RMDC which includes parameters such as size distributions, wall thickness, roundness, ferret
ratio, and abundances. Together with comprehensive image analysis, textural identification and
improvement of mineral maps, the software has many unique features needed for iron ore research
including characterisation of large objects like pellets and ore lumps; automated gangue and
quartz identification; automated particle separation; multiple block imaging; multiple image set
processing and on-line measurements. All these features make the Mineral4/Recognition4 OIA
system a unique, reliable, industry/research focused tool for ore, sinter and coke characterisation.

Ironmaking Fundamentals - Board: 102 / 75

A STUDY ON THE METALLIZING SINTERING OF PEL-
LETS OF IN-PLANT IRON-BEARING DUST AND MUD

Author(s): ZHU, DEQING
Co-author(s): ZHANG, QIANG; GUO, ZHENGQI; LI, QIHOU

School of Mineral processing and Bioengineering, Central South University

It is of significant importance to utilize the in-plant iron-bearing dust and mud of steel mills
which are characterized by high iron and carbon content, and some toxic metals such as lead
and zinc etc. In this paper the conditions of new process of metallizing sintering of pellets were
optimized to manufacture pre-reduced sinter. Under the conditions of C/Fe ratio of 0.5 (50%
coal blended in the pellet feed), 18% moisture of green ball, bed height of 400mm and air speed
of 0.4 m/s, the pre-reduced sinter product, assaying 60.53% Fe and the iron metallization degree
of 45.23%, was produced, and the removal rate of Zn, Pb and As was obtained at 92.78%, 96.37%
and 62.45%, respectively. The sintering index of unit productivity of 0.471 t·m⁻²·h⁻¹, tumble
index of 81.31%, and solid fuel consumption of 309.67 kg·t⁻¹, were achieved respectively. The
reducibility index and reduction disintegration index (RDI+3.15) of pre-reduced product are
80.69% and 96.45%. All of which prove that the pre-reduced sinter product is the high quality
burden for blast furnace. The toxic metals were precipitated in the dust of sintering flue gas,
containing 51.49% ZnO, 3.15% PbO and 1.45% As₂O₅.

Ironmaking Fundamentals - Board: 140 / 76

ADSORPTION CHARACTER OF SINTER ORE ON POTAS-
SIUM VAPOR

Author(s): YAN, ZHIWU
Co-author(s): ZHANG, JIANLIANG; LIU, ZHENGJIAN; YUAN, XIANG; GAO, BIN; ZHANG, HESHUN

University of Science and Technology Beijing
Shougang Jingtang United Iron & Steel Co. Ltd

The cycle and enrichment of potassium (K) exist in the blast furnace. Under laboratory conditions,
a kind of vapor adsorption test between the K and sinter was design to research the adsorption
character of sinter ore on K vapor, and adsorption mechanism was analyzed by some microscopic
observation. Elemental K and K₂CO₃ was chosen as potassium source to provide K vapor. Sinter
ore had the adsorption capacity for K vapor. After adsorption, existence forms of the K in the
sinter ore were potassium oxide, potassium aluminum oxide and potassium iron oxide. The crack
appeared in the enrichment area and stretched to the nearby micro hole. Inward diffusion of K
happened, which mainly depend on the interaction between the K and sinter ore and the crack.
The model of adsorption process was presented. The adsorption was the mixture of physical
absorption and chemical absorption, and chemical adsorption was the main adsorption manner.
A STUDY OF THE GASEOUS REDUCTION OF MAGNETITE ORE IN A FIXED-BED REACTOR AND USING IN-SITU HIGH-TEMPER

Author(s): KAPELYUSHIN, YURY
Co-author(s): SASAKI, YASUSHI; ZHANG, JIANQIANG; JEONG, SUNKWANG; OSTROVSKI, OLEG

Depletion of high-quality hematite ore stimulates an increase in the utilization of magnetite ore in ironmaking. Reduction of magnetite ore pellets was studied in a fixed-bed reactor at different temperatures and gas compositions. The effect of temperature on the magnetite ore reduction was studied at 700 – 900 °C by CO/CO2 gas mixture with 80 vol pct CO. The effect of gas composition was examined at 750 °C using CO/CO2/H2 gas mixture with H2 content 5 – 25 vol pct and fixed CO/CO2 ratio of 80/20. Phase development in the process of the ore reduction was studied in-situ using High-Temperature XRD (HT-XRD) analysis. In the HTXRD reactor, magnetite ore was reduced by CO/CO2 gas mixture (80 vol pct CO) at 750 °C with measurements of XRD patterns along the reduction course. Phase development in the process of reduction was derived using Rietveld refinement of the HT-XRD spectra. Carbon concentration in iron was found from the lattice parameters of γ-Fe formed during reduction. Swelling of magnetite ore was observed in the process of reduction by CO/CO2 and CO/CO2/H2 gas mixtures, which was attributed to carbon dissolution in γ-Fe and bubbles’ formation. Swelling index increased with increasing CO/CO2 ratio and decreased with temperature. In the reduction of magnetite ore by CO/CO2/H2 gas mixtures, swelling decreased with H2 addition.

EXPERIMENTAL SIMULATION OF THE INTERACTION OF SLAG AND HOT METAL WITH COKE AT THE BOSH REGION OF BLAST FURNACE

Author(s): BHATTACHARYYA, ANRIN
Co-author(s): SCHENK, JOHANNES; JÄGER, MICHAEL; STOCKER, HUGO; THALER, CHRISTOPH

Coke is the only raw material which remains solid even at the lowest zone of blast furnace. The bed-permeability in the bosh zone of the blast furnace is maintained by the solid coke structure. The wetting behaviour of slags in the coke bed of the bosh region in a blast furnace plays a very important role on the process efficiency by directly influencing the free movement of the burden and furnace gas and thereby affecting the fuel consumption. Cokes of unsuitable quality will lead to lower permeability in the bosh zone and hinder the furnace operation. In this work, various industrial coke samples are treated with slags of different basicities in a drop-shape analysis facility at high temperature similar to process conditions. The coke samples have been treated under standard CRI (Coke Reactivity Index) test conditions beforehand in order to impart a closer process simulation. The results display the variations in wetting angle, temperature and time for different coke and slag combinations as a function of coke properties and slag compositions. The wetting behaviour at the coke/hot metal interface has also been investigated. The results provide a better understanding of the solid-liquid interaction which takes place at the bosh region of the blast furnace.
QUANTIFICATION OF SINTER MINERAL PHASES WITH IMAGE PROCESSING

**Author(s):** KAIN-BÜCKNER, BIRGIT

**Co-author(s):** MALI, HEINRICH; SCHADLER, SONJA; SCHUSTER, ELMAR

1. **K1-Met GmbH**
2. **Montanuniversität Leoben**
3. **voestalpine Stahl Donawitz GmbH**

The micro-image processing software package VisuMet identifies the main mineral phases in sinter. Magnetite, hematite, calcium ferrite, siliceous glass as well as pores will be distinguished by their different grey levels. VisuMet calculates the area in pixel of the phases and the pores. Each phase is available as a binary image for further analysis.

Ironmaking Fundamentals - Board: 14 / 17

ANALYSIS OF THE ALKALI DISTRIBUTION IN IRONMAKING REACTORS BY THERMOCHEMICAL MODELLING

**Author(s):** PICHLER, ANTON

**Co-author(s):** SCHENK, JOHANNES; HAUZENBERGER, FRANZ; STOCKER, HUGO; THALER, CHRISTOPH

1. **Chair of Ferrous Metallurgy, Montanuniversitaet Leoben**
2. **Primetals Technologies Austria GmbH**
3. **Voestalpine Stahl Donawitz GmbH**
4. **Voestalpine Stahl Linz GmbH, Linz**

Due to their physical and thermochemical properties, alkali metals as potassium and sodium show a specific behavior in ironmaking processes. The reduction and oxidation of alkali compounds as well as their evaporation and condensing behavior lead to the formation of an alkali cycle. Furthermore, an enrichment of harmful K- and Na-compositions takes place. This affects refractory material, fuel rate, dust & cyanide emissions and the formation of scaffolds. To predict the influence of different process parameters on the creation of this alkali cycle, a multi stage model was developed for ironmaking processes. A special slag model and thermochemical calculations connected with the pressure, temperature and gas composition leads to a prediction of the alkali distribution. Main findings of the calculations are the influences of process parameters on the alkali flow inside different reactors. A comparison between the conditions in the blast furnace and the melter-gasifier (Finex®/Corex®-process) confirms the influence of temperature, pressure and gas composition on the formation of cyanides and carbonates. The model enables an evaluation of mass balances based on industrial data and contributes new information and ideas about the fundamental reactions in ironmaking reactors.

Blast Furnace, Operation and Control - Board: 11 / 21

ENHANCING THE PRODUCTIVITY OF LARGE BLAST FURNACES AT HIGH SLAG RATES

**Author(s):** SINGH, NAVEEN

**Co-author(s):** SINGH, LR; SINGH, AVTAR; ANAND, RAJESH; M, UBAYADULLAH

1. **JSW steel Ltd**

JSW Steel Ltd. Vijayanagar works is an integrated steel plant with installed crude steel production capacity of 12 MTPA. Blast furnace III & IV are two large furnaces with annual production capacity of 3 MTPA each. JSW has been successfully operating these large furnaces at productivity > 2.80 t/m3/day at slag rate of 400 kg/thm. This paper focuses on the process improvements and technological innovations adopted to achieve ‘Global bench mark productivity level at high slag rate’. Paper also includes two case studies of recent operational challenges.
BLAST FURNACE OPERATION IN ROUGH TIMES

Author(s): VAN OPBERGEN, ROB
Co-author(s): ENGEL, EDO; VAN STRAATEN, VICTOR

Over the past years, several factors such as weak demand, high raw material costs and global overcapacity have exerted unprecedented pressure on steel producers around the world. The liquid section of the steel plant, and the blast furnace in particular, covers a substantial part of the overall production cost. This article discusses a scenario for sustainable hot metal production under these conditions based on assessment of risks related to operations and maintenance condition of the plant. It addresses the question of whether or not our industry is prepared for the operational conditions that are the result of the conditions under which we have had to operate in recent years.

EFFECT OF SMALL COKE RATE ON CONSUMPTION BEHAVIOR OF SMALL COKE IN BLAST FURNACE

Author(s): KASHIHARA, YUSUKE
Co-author(s): IWAI, YUKI; MURAO, AKINORI; FUKADA, KIYOSHI; MATSUNO, HIDETOSHI

Utilization of small coke (nut coke) in the blast furnace was carried out to improve the permeability in the lower part of the blast furnace. However, at high small coke rates, it was thought that some small coke continues to exist in the lower part of the blast furnace because the small coke charging rate is larger than the gasification reaction rate of the small coke in the blast furnace. Therefore, the reaction behavior of the small coke in the blast furnace was investigated by a mathematical model of the blast furnace. The gasification reaction rate of the small coke and the lump coke were respectively considered for the simulation, and the reaction behavior of each coke was calculated. At high small coke rate, some small coke with a reduced particle size continues to exist in the lower part of the blast furnace, and a coke packed bed mixed with the unconsumed small coke was formed in the lower part of the blast furnace. As a result, the increase in pressure drop in the lower part of the blast furnace was predicted by the decrease in average particle size and void fraction of the coke packed bed in the lower part of the blast furnace.

CHARACTERISATION OF FRACTURE MECHANISMS IN A BLAST FURNACE COKE

Author(s): ROEST, RICHARD
Co-author(s): LOMAS, HANNAH; GUPTA, SUSHIL; KANNIALA, RIKU; MAHONEY, MERRICK R.

Metallurgical coke samples were retrieved from the tuyere drilling of an operating blast furnace. These were analysed using a novel fractographic approach to identify and quantify the various coke failure mechanisms. This allowed for quantification of the factors contributing to the strength of the coke through analysis of coke fracture faces. Tuyere level cokes were found to display different failure mechanisms compared to the feed coke, implying an influence of the blast furnace reaction environment. Feed coke breakage behaviour was strongly influenced by existing fissures, while the breakage of the deadman coke lumps was dominated by pore wall collapse through intergranular
crack growth as well as erosive wear. This fractographic study demonstrates that despite the inherent heterogeneity of coke, the fracture faces generated by the evolution of the external fissures in the large coke lumps show evidence of several failure mechanisms, in addition to the erosive wear resulting from the blast furnace exposure. The main factors contributing to coke strength from our fractographic analysis were quantified using a standard scale and summarized using a radar diagram. Understanding the differences in the microstructural weaknesses/fracture properties of the coke may have implications for the selection of coal blends and processing during cokemaking that would result in improved coke performance in the blast furnace.

Blast Furnace, Operation and Control - Board: 51 / 25

MODULAR UPGRADES FOR EXISTING BLAST FURNACE AUTOMATION SYSTEMS

Author(s): MIJNEN, ROB ¹
Co-author(s): WEEGENAAR, FERRY ¹; WARREN, PETER ¹

¹ Danieli Corus BV

Modern Blast Furnace Ironmaking units are usually equipped with a high level of process automation, process control and operator advisory. The advantages of such systems have been widely discussed and confirmed by operators from around the world. Where Level I and possibly Level II automation systems were implemented early when such systems were available, upgrading these systems to more recent types may be an attractive option. This article presents possibilities for implementing modern blast furnace automation systems while leaving existing instrumentation and Level I systems in place. The approach presented is based on the installation of a modern computer server for the Level II system and the addition of several modules for process control, process automation and operator advisory based on whether or not modifications to the existing systems are required for the operation of these modules. In addition, the scope of full implementation of the modern system is presented, along with the theoretical background of the modules.

Blast Furnace, Operation and Control - Board: 136 / 36

CHARGING PRACTICE OF BLAST FURNACE OPERATED WITH 100% ACID PELLETS

Author(s): SHEPETOVSKY, IGOR ¹
Co-author(s): SHALYGIN, ANDREW ¹; MYASNIKOV, KONSTANTIN ¹; NURIEV, RUSTAM ¹; BERMES, PHILIPP ²; HAUSEMER, LIONEL ²

¹ KOSAYA GORA IRON WORKS
² PAUL WURTH S.A.

This paper describes optimization of the charging process of blast furnace No.1 at Kosaya Gora Iron Works (Tula, Russia) producing nodular pig iron with many restrictions on impurities. Focus is on the unconventional operation with 100% acid pellets and various methods for lining protection against the aggressive action of Wüstite-rich primary slag by means of top charging control. Along with this, the paper explains how burden distribution was adapted to make maximum use of the MINI Bell Less Top (BLT) capabilities, taking into account technological and organizational restrictions of non-integrated iron works.

Blast Furnace, Operation and Control - Board: 100 / 148

INNOVATIVE TOOLS FOR PROCESS OPTIMIZATION – BURDEN SURFACE SCANNING VIA BEAMFORMING RADAR AND MEASUREMENT OF THE TOP GAS TEMPERATURE DISTRIBUTION

Author(s): FEILMAYR, CHRISTOPH ¹
Novel measurement systems for gauging the full three-dimensional burden surface and the two-dimensional top gas temperature distribution in a blast furnace in real time with an update period of a few seconds are presented in this paper. An introduction to the radar imaging principle for burden surface measurement and the fast acoustic tomography system for temperature distribution measurement are provided. Measurement results obtained at a test stand, during blast furnace relining, and during standard operation of multiple active voestalpine blast furnaces over a long period of several years are shown and validate the outstanding performance of the sensor systems. The possibility to monitor the blast furnace condition and improve the charging processing both offline and even in real time is discussed.

**Recycling of In-Plant Residues** - Board: 2 / 61

**CHARACTERISATION OF STEELPLANT BY-PRODUCTS TO REALISE THE VALUE OF FE AND ZN**

**Author(s):** LONGBOTTOM, RAYMOND J.  
**Co-author(s):** MONAGHAN, BRIAN J. 1; ZHANG, GUANGQING 1; CHEW, SHENG J. 2; PINSON, DAVID J. 2

1. University of Wollongong  
2. BlueScope Iron & Steelmaking Technology

Recycling of steel plant by-products is a critical area that needs careful assessment and development if the integrated steel plant is to remain environmentally and economically sustainable into the future. A research program is being embarked upon in the Australian Steel Research Hub with aims to realise the value of the by-products to the Australian Steel industry and minimise volumes being stockpiled. As a first step, key by-product streams (such as blast furnace, BOS and sinter dusts) are being evaluated and characterised so that their potential uses in-plant or elsewhere can be assessed/evaluated. These streams contain components including iron and zinc units which have value on plant and elsewhere. Realising the value in these streams by recycling or other processing will help to minimise emissions and reduce costs by replacement of raw materials and reducing the amount going to stockpile. In this paper, microscopy (SEM and EDS analysis), X-ray diffraction (XRD), thermo-gravimetric analysis (TGA) and differential scanning calorimetry (DSC) of a by-product material are presented and discussed with a view of understanding the behaviour of the material in use and on plant and its limits for further processing.

**Recycling of In-Plant Residues** - Board: 74 / 62

**FLOW SHEET MODELLING OF STEEL MAKING ROUTES IN A PROCESS INTEGRATION PLATFORM**

**Author(s):** WEISS, BERND  
**Co-author(s):** SPANLANG, ANDREAS 2; WUKOVITS, WALTER 3

1. Primetals Technologies GmbH  
2. K1-MET GmbH  
3. TU Wien, Institute of Chemical Engineering

An increasing demand in flexible process variations, raw material utilisation, internal by-product and waste material recycling in iron and steel production together with the needs for standardisation to partners and interfaces with equipment suppliers requires new and intelligent platforms for mass and energy balancing based on a flow sheeting approach. Following an evaluation on state of the art process simulation programs, Primetals decided to develop a comprehensive metallurgical flow sheet model library for simulation of integrated steel plants. Intensive development efforts
were taken in order to migrate existing well established calculation and engineering routines as well as integrate newly developed models. The generated model library enables the setup of mass and energy balances for integrated steel plants, development and evaluation of new process concepts as well as investigations on impacts of raw material changes and trace material distributions. By using this process integration platform, it is possible to compare different iron and steelmaking routes within one standardized environment. Additional benefits from the use of a modern flow sheeting tool are flexible adaption of process routes, clearly represented plant depictions as well as robust and well defined calculation routines.

Welcome Drink & Postersession - Board: 47 / 118

PHYSICAL MODELLING BASED ANALYSIS OF DRY SLAG GRANULATION

Author(s): KALI, PRASAD
Co-author(s): RAVINDRA, DHIRHI ; AJAY, KUMAR SHUKLA ; PUSHPAVANAM, S

1 Indian Institute of Technology Madras

A physical model of blast furnace slag granulation using rotating disk method is developed, based upon similarity criteria namely solidification similarity, geometric similarity and dynamic similarity. For dynamic similarity ratio of inertial, viscous and surface tension forces between the model and prototype are considered. Based upon dynamic similarity, equality of Ohnesorge number, Reynolds number and Weber numbers are determined by proper selection of liquid metal for cold model experiments as well as design and operating parameters. Cold model experiments using rosin and paraffin wax in the ratio of 4:1 were used. A strategy has been developed for predicting appropriate operating parameters for actual pilot plant experiments in a reasonable way to achieve the desired size of slag granules. The mass accumulation on the disk decreases with increase in the temperature however, the decrease was found much in case of smaller diameter disc. Higher temperature and rotating speed led to formation of finer particles.

Welcome Drink & Postersession - Board: 62 / 119

ANALYSIS OF NONSTATIONARY TRANSIENT PROCESSES IN BLAST FURNACE

Author(s): BOKOVIKOV, BORIS
Co-author(s): GORDON, YAKOV ; LAVROV, VLADISLAV ; MOIKIN, VITALIY ; SPIRIN, NIKOLAI ; SHVIDKIY, VLADIMIR ; YAROSHENKO, YURIY

1 Torex
2 Hatch Ltd.
3 Ural Federal University

Understanding and managing the risks associated with the introduction of a new technology in the highly capital-intensive, large volume and low-margin iron and steel industry, is a key to effectively implementing a lasting change. Hatch has developed a robust methodology for process technology selection for the iron and steel industry to address the risks. The methodology is based on a two-stage approach in which the first stage includes short-listing of the best technologies based on results of mass and energy balance modelling, and a simple financial evaluation as well as risk analysis. The second stage involves a detailed analysis using refined input data, mass and energy balance modelling, capital and operating cost estimation, as well as a detailed financial analysis of the best technologies selected. To illustrate the critical elements of this methodology and the analysis required for the successful selection of ironmaking process technology, a Case Study covering the evaluation and selection of the best (most-suitable) ironmaking technologies for an Iron and Steel Company located in the European part of the Russian Federation, is presented in this paper.
KINETIC ANALYSIS AND EFFECT OF BIOMASS ASH ON COMBUSTION CHARACTERISTIC OF PULVERIZED COAL

Author(s): LIU, SIYUAN
Co-author(s): ZHANG, JIANLIANG ; XU, RUNSHENG ; SONG, TENGFEI ; WANG, HAIYANG ; LIN, HAO

1 University of Science and Technology Beijing

Biomass is a kind of renewable, clean resource and reducing agent, and has become the focus. In recent years, several papers deal with the combustion and gasification of the biomass, however, the research of biomass ash catalytic reaction process is not elaborated completely. Biomass ash itself usually contains a certain amount of K, Na and other mineral elements, these elements will have a catalytic on gasification process of pulverized coal. In this paper, ash content and ash melting point catalytic to pulverized coal gasification are researched by tube furnace, thermo-gravimetric balance. It is found that there is an obvious catalytic effect of K, Na on the gasification reaction. And the activation energy of the gasification reaction decreased gradually with the increasing of K, Na content.

RESEARCH AND APPLICATION OF SINTERING HIGH-TEMPERATURE CHARACTERISTICS OF IRON ORE

Author(s): Mr. ZHANG, JIAN-LIANG
Co-author(s): LIU, DONG-HUI ; LIU, ZHENG-JIAN ; WANG, YAO-ZU ; KANG, QING-FENG ; WANG, GUANG-WEI ; YAN, JIE ; FENG, SHUAI

1 University of Science and Technology Beijing
2 Hebei Iron & Steel Group

Effects of MgO on the sintering liquid, the properties and mineralogical morphology of the high-basicity sinter were investigated in this paper. The results show that the assimilability and the infiltration area index of original liquid (IAO) decreases with increasing MgO content. The tumbler index (T), the low temperature break-down (RDI+3.15) and softening start temperature (T10%) of the sinter increases first and then decreases with increasing MgO content, whereas the reduction degree (RI) and softening interval (ΔT) of the sinter exhibit the opposite behavior. With increasing MgO content, the content of the SFCA and hematite in sinter decrease, but magnetite content increase, the mineral distribution becomes uneven, the cracks and the pores in bonding phase increase; The metallic phase composed of hematite, SFCA and silicate calcium and the metallic phase composed of magnetite and glassiness transforms to the phase of interlaced corrosion structure composed by magnetite, SFCA and merwinite. To improve the high-basicity sinter properties and decrease the fuel consumption, the MgO content should be kept within 3.30wt% in ore proportioning.

THE INFLUENCE OF ZINC VAPOR ON COMPOSITION AND PROPERTIES OF COKE

Author(s): ZHONG, JIANBO
The composition and thermal performance of coke affected by zinc vapor was investigated in this work. Two different kinds of experiments were employed in this paper. The first experiment was that coke absorbed zinc vapor in a muffle furnace at 1300 °C. From SEM/EDS analysis of the treated coke samples and thermodynamic calculation (used by the FactSage software), it was found that zinc was not able to react with minerals in coke, suggesting that zinc vapor could hardly be absorbed into coke when the temperature is higher than its boiling point. The second experiment was further to simulate the practical situation in blast furnace where coke was exposed to zinc vapor at high temperature region, so CRI test at the atmosphere of zinc vapor was conducted. Results presented that no changes in thermal performance of coke happened, proving no catalytic effect of zinc vapor on the coke gasification reaction. Therefore, it was concluded that zinc, in the form of vapor, did not affect coke in blast furnace.

Welcome Drink & Postersession - Board: 132 / 125

STUDY THE INFLUENCE MECHANISM OF POTASSIUM VAPOUR ON SINTER REDUCTION

Author(s): YAN, ZHIWU
Co-author(s): ZHANG, JIANLIANG ; YUAN, XIANG ; GAO, BIN ; ZHANG, HESHUN

1 University of Science and Technology Beijing
2 Shougang Jingtang United Iron & Steel Co. Ltd.

The actual situation of cycle and enrichment for potassium in the BF was simulated, in order to complete the adsorption of sinters on potassium (K) vapor, the method of vapor adsorption was chosen to conduct sample preparation test in a horizontal tube furnace. With the increase of the enrichment times of K, enrichment rate of K increased and the absorption capacity of sinter on K vapor decreased. To determine the effect of the K on the reduction of sinters, the mass loss due to oxygen removal was continuously recorded, from which reduction curves were obtained. The K was found to promote the sinter reduction, but the effect of promotion declined and even played a converse function with the increase of K content. The apparent activation energy (E) value of sinter 1#-4# was 70.993, 47.881, 51.175 and 61.063 kJ/mol, respectively. The fitting results and compare of the microstructure showed the kinetic behavior was controlled almost by interfacial chemical reaction in the whole reduction process. Microstructure analysis of different sinters with different reduction degree showed the K made the micro holes of sinter edge more during the reduction process, which appeared to improve the reduction condition.

Welcome Drink & Postersession - Board: 134 / 126

CHARACTERISTICS OF LITHIUM SILICATE PREPARED BY SOLID STATE REACTION AND THERMOGRAVIMETRIC ANALYSIS

Author(s): WANG, HAIYANG
Co-author(s): ZHANG, JIANLIANG ; WANG, GUANGWEI ; ZHONG, JIANBO ; SONG, TENGFEI

1 School of Metallurgical and Ecological Engineering

Lithium silicate(Li4SiO4) was prepared by solid state reaction using leached residue(LR) from blast furnace slag as silicon source, and pure silica was chosen for comparison. Chemical analysis, scanning electron microscope(SEM) and X-ray diffraction(XRD) were used to characterize the Li4SiO4 prepared in the present study. Thermogravimetric analysis was carried out to obtained the absorbed curves for Li4SiO4 with different silicon source. The results indicated that silicon in blast furnace slag can be used as silicon source to prepare Li4SiO4, and silica in leached residue of blast furnace slag is indeed all amorphous. The Li4SiO4 prepared by LR showed dense
polygonal particles with particle size between 16 and 47\(\mu m\). However, the Li4SiO4 prepared by pure silicon showed dense polyhedral particles with particle size between 55 and 90\(\mu m\), and formed agglomerates. The initial absorbed temperature and final absorbed temperature are 760.62K and 982.94K, respectively. Coats-Redfern method was used to calculated the kinetic parameters in absorption process, and the activation energy for absorption process of PS-Li4SiO4 and LR-Li4SiO4 are 146.11kJ/mol and 99.61kJ/mol, respectively.

**STUDY ON THE MECHANISM OF CEO2 AS COMBUSTION IMPROVER IN PCI**

Author(s): LIU, SONG
Co-author(s): SUN, YAN-QIN; LI, JIAN-PENG; QIE, YA-NA; LV, QING; LIU, XIAO-JIE; SUN, LI-YUAN

1 North China University of Science and Technology

CeO2 is a kind of pulverized coal combustion improver which is suited for the Blast Furnace. Combustion mechanism of CeO2 is that Ce4+(CO-)4 weakens bridge adhesion of carbon structural units and alters the lattice structures to lower the activation energy of pulverized coal and accelerate the combustion. Collecting unburned powdered coal by simulating combustion conditions of blast furnace, the result of XRD and SEM pictures is that with the addition of the CeO2, microcrystalline parameters of unburned pulverized coal increases, height and diameter of aromatic slices increase 0.0067nm and 0.0467nm respectively, particle size of unburned pulverized coal reduces 3.48\(\mu m\), morphological appearance becomes irregular.

**DRY BLAST FURNACE SLAG GRANULATION WITH WASTE HEAT RECOVERY**

Author(s): WERNER, ANDREA
Co-author(s): MCDONALD, IAN; FLEISCHANDERL, ALEXANDER

1 Primetals Technologies, Austria GmbH
2 Primetals Technologies UK

Each year, approx. 400 million tons of blast furnace slag is produced worldwide with a tapping temperature of around 1,500\(^\circ\)C. Currently, the slag is granulated in wet granulation plants using large volumes of water and to date it has not been possible to utilize the remnant heat energy of the molten slag, with approx. 1.8 GJ of energy per ton. However, in an R&D project currently underway by a consortium of companies led by Primetals Technologies and comprising voestalpine Stahl (Austria), FEhS Building Materials Institute (Germany) and the University of Leoben (Austria), a new dry atomising technology is being investigated to use air to cool molten slag and recover the lost heat energy. Phase 1 of the project has been completed where a technical plant was set up in 2012. The research results have shown the process suitability as an industrial application and the decision was taken to escalate the project to a semi-industrial scale prototype plant. The Phase 2 development of this plant is now underway and is scheduled for installation at the site of voestalpine Stahl in Linz in mid-2017. This paper will show the development path taken to date and the planned route to our goal in 2017 of being the first to industrialise the ‘game changing’ process.

**EFFICIENT SINTER COOLING WITH OPTIMIZED ENERGY RECOVERY, ENERGY SAVING AND EMISSION REDUCTION**

Author(s): BOEBERL, MICHAELA
Primetals Technologies has developed a new sinter shaft cooler which allows utilizing nearly the total heat capacity of the hot sinter charged to the cooler. By application of the counter flow principle to the cooling process the temperature of the cooling air exiting the shaft can be maximized. Compared to conventional sinter cooler systems the maximized hot cooler off air temperature of the shaft cooler allows in a first utilization step an efficient generation of steam and electricity. The air exiting the heat recovery boiler system, still having remarkable thermal energy content, can be utilized in a second step in the sinter process. This means the exit air from the boiler is directed via duct system to a hood installed directly above the sinter strand. The sensible heat of this air then contributes to the sinter process by giving the possibility for solid fuel reduction. By using the total amount of cooling air for the sinter process no dedusting unit for the cooling air is required and no emissions are transferred into the environment. In case of excess blast furnace gas in a steel plant the hot cooler off air from the shaft cooler can be heated up to even higher temperatures for a further increase of efficiency of the waste heat recovery system.

CO2 Reduction and Energy Saving - Board: 109 / 89

LOW CO2 IRONMAKING IN THE BLAST FURNACE

Author(s): MORCEL, ADELINE 1
Co-author(s): ÖKVIST, LENA SUNDQVIST 1; ORRE, JOEL 1; BJÖRKMAN, BO 2; LAGERWALL, PER 3

1 Swerea MEFOS AB
2 Luleå University of Technology
3 SSAB Europe, Luleå Sweden

The steel industry contributes to the global emissions of fossil carbon dioxide (CO2) by around seven percent, mainly caused by the usage of coal and coke as reductants in the blast furnace (BF). In the same time the BF is, and will be in a foreseeable future, the most energy efficient method to produce ore based liquid hot metal. A number of concepts to minimise the emission of CO2 have been proposed by different R&D teams, as the ULCOS TGRBF (top gas recycling BF), or high injection of hydrogen (H2) in combination with CCS (Carbon Capture and Storage). Other options investigated, not requiring extensive modification of the BF plants, are the use of bio based reductants, charging of activated coke or carbon composite agglomerates including such involving biomass products. In this paper these latter are analysed relative the BF conditions, including impact on slag formation, temperature and gas profiles etc. Moreover the possible impact on energy consumption and CO2 emission is compared. The analyses are based on research results deduced from laboratory tests and trials in the LKAB Experimental BF (EBF).

CO2 Reduction and Energy Saving - Board: 80 / 145

DIRECT REDUCTION TECHNOLOGY AS A FLEXIBLE TOOL TO REDUCE THE CO2 INTENSITY OF IRON AND STEELMAKING

Author(s): BUERGLER, THOMAS 1
Co-author(s): KOFLER, IRMELA 2

1 voestalpine Stahl GmbH
2 K1-MET GmbH

The transfer of our fast growing society from a carbon based to a low carbon based economy/production within the next decades is the global megatrend which is discussed now for 15 years. The minus 80 % target can only be achieved by a transfer of the global energy system. We have today a portfolio of technologies available to reduce the CO2 intensity further, but without consideration of the two limitations plant lifetime and carbon lean energy a successful
transfer will not possible and every company and country has it’s own timeline for this process. The forced use of natural gas can act as a bridge technology for the transfer between the energy systems. HBI and DRI allow a broad flexibility for the EAF steel production route as well for the integrated BF/BOF steel production. The start-up of the voestalpine DR plant in the US is an important step to meet the challenges of the next decades.

**CO2 Reduction and Energy Saving** - Board: 143 / 131

**COMPARING THE CO2 EMISSIONS OF DIFFERENT IRONMAKING ROUTES**

**Author(s):** RAMMER, BARBARA

**Co-author(s):** MILLNER, ROBERT; BOEHM, CHRISTIAN

1 Primetals Technologies Austria GmbH

Steps to reduce greenhouse emission gases (CO2) are increasingly becoming a matter of priority for the industry, particularly for the iron & steel industry, which is the largest consumer of the world’s generated energy on a global basis. This paper outlines the principal factors necessary for evaluating CO2 emission rates as the basis for comparing the net CO2 emission figures for different iron & steel production routes from cradle to grave. Calculations show that CO2 emissions considerably depend on the assumptions for the system borders and some external factors e.g. the specific emission values for grid electricity. Based on the calculations carried out, it also was shown that already today the COREX/DR/EAF combination can shows CO2 emissions that are by far lower compared to any other coal based steelmaking configuration. The topics presented in this paper in relationship to the concerns of the iron & steelmaking industry are rarely dealt with in metallurgical journals, however, are becoming increasingly important because of environmental, political and especially economic reasons.

**Blast Furnace, Design and Equipment** - Board: 53 / 41

**LATEST DEVELOPMENT IN DRY AND WET BLAST FURNACE GAS CLEANING TECHNOLOGY**

**Author(s):** KLUT, PETER

**Co-author(s):** EWALTS, WOUTER; HINK, ROBIN; ENGEL, EDO

1 Danieli Corus BV

Most of the recent developments in blast furnace gas cleaning technology have been based on dry gas cleaning systems. Danieli Corus has developed a new system, applying proven technology available within the Danieli group for dry cleaning of e.g. EAF, DRI, BOF and aluminium smelter gases. This new system consists of a gas conditioning tower, reagent injection system and (pressurized) filter modules with low pressure pulse cleaning. The system was designed for a residual dust content below 5 mg/Nm$^3$ and for increased TRT output and calorific value of the blast furnace gas. For wet blast furnace gas cleaning systems, Danieli Corus introduces a new type demister to replace existing demisters. This type of demister is more compact and has a smaller footprint while offering a higher removal efficiency. This new demister requires lower investment while offering a higher calorific value of the blast furnace gas.

**Blast Furnace, Design and Equipment** - Board: 57 / 42

**INSTALLATION, COMMISSIONING AND RAMP-UP OF THE NEW PULVERIZED COAL INJECTION SYSTEM AT ARCELORMITTAL KRYVYI RYH BLAST FURNACE NO. 9**

**Author(s):** ADRICHEM, PETER

**Co-author(s):** HUBBELING, PAUL; ENGEL, EDO; DELIAMURE, SVETLANA

1 Danieli Corus BV
In 1995, Krivorozhstal (now ArcelorMittal Kryvyi Rih) awarded a contract for the supply of a Pulverized Coal Injection System to Hoogovens Technical Services (now Danieli Corus). Due to economic conditions, the project could not be completed at the time. In 2015, the project was revitalized by ArcelorMittal Kryvyi Rih and the system was completed by Danieli Corus. This article discusses the installation, commissioning and ramp-up of the PCI system for Ukraine’s largest Blast Furnace (5000 m³). It covers the refurbishment of the equipment, which had been kept in storage locally for nearly 20 years. The process and its changes with the introduction of coal injection is discussed in depth. The article briefly presents the chosen injection technology, which is based on the basic physical principle of equal pressure drop across all injection lines.

Blast Furnace, Design and Equipment - Board: 63 / 43

NEW BLAST FURNACE OPERATION PROSPECTS WITH THE G3 CHUTE TRANSMISSION GEARBOX

Author(s): TOCKERT, PAUL
Co-author(s): BRINCKMANN, JÖRG; HOLLMAN, JOSEPH

In 2010 Paul Wurth introduced the G3 chute transmission gearbox for Bell Less Top blast furnace charging systems. With a maximal flow rate of 1.1m³/s, a rotation speed of 12RPM while withstanding harshest operating conditions, the G3 chute transmission gearbox offers unprecedented operation possibilities. Finer charging patterns (i.e. more chute rotations) are possible due to the higher rotation speed. Furthermore the impact energy on the stockline is reduced minimizing amongst others the coke push effect. The high flow rate offers the possibility for charging a series of dedicated batches such as centre coke or sinter fines and will cope with today’s and tomorrow’s highest production capacity requirements. High quality raw materials are getting scarce and increased usage of lesser material grades is making the blast furnace operation more challenging; unstable intermittent periods are common. The attention to be dedicated to the gearbox is minimal as it is impervious to high blast furnace top temperatures, requires even less maintenance and features an increased component lifetime. Not spending thoughts on the equipment comes in handy to focus on what is at stake: the blast furnace process. The paper gives insight into the G3 features which were spun-off to the standard and reinforced gearboxes and will highlight the differences and fields of application.

Blast Furnace, Design and Equipment - Board: 76 / 45

BLAST FURNACE RELINE IMPLEMENTATION STRATEGY

Author(s): BUSER, JOHN
Co-author(s): HYDE, BARRY; GORDON, YAKOV; CAMERON, IAN

Recent blast furnace reline scope assessment studies performed by Hatch concluded that Blast Furnace Reline Implementation Strategy must be developed on a case-by-case basis as many different factors can affect choices with regard to scope, schedule and the implementation of new technologies. Important considerations include planned blast furnace campaign life, reline outage duration, environmental performance, capital costs, and future operating costs. Considering today’s economic environment, justification for additional spending on upgrades requires scrutiny. Case examples shall be presented with respect to variations in scope and schedule to demonstrate the summary level reporting that can be provided for management decision making.

Blast Furnace, Design and Equipment - Board: 135 / 53

ILTEC - METTOP’S REVOLUTIONARY COOLING SOLUTION FOR THE STEEL INDUSTRY

Author(s): HANEL, MARTINA
Co-author(s): FILZWIESER, ANDREAS 1 ; FILZWIESER, IRIS 1 ; RUHS, STEFAN 1

1 Mettop GmbH

It is the increasing demand for an economic and cost saving operation mode that requires effective cooling in order to achieve low refractory wear and good furnace lifetime, which is making cooling technology an important aspect of furnace operation. In addition, safety awareness is becoming more and more a focal point of the operating philosophy. However, the use of water - today’s standard cooling medium - has major drawbacks as it can cause problems during furnace start up and operation, namely hydration problems, corrosion, and explosion. Not to forget the severe personal as well as economical damage in case of a malfunctioning water cooling system. With the new patented cooling technology ILTEC it is possible to overcome the disadvantages of water by using an alternative cooling medium, namely the ionic liquid IL-B2001. The main characteristics, which makes IL-B2001 so favourable, are a neglectable vapour pressure, the absence of explosion, the wide liquidus range and the operation temperature from 50-200°C and the not flammable, non-corrosive and atoxic behaviour. All those properties lead to many areas of applications, which can contribute to accomplishing a water-free production route for the entire metal processing industry.

Ironmaking Fundamentals - Board: 20 / 63

DISINTEGRATION MECHANISM OF CALCIUM FERRITE IN SINTER BY REDUCTION

Author(s): MURAKAMI, TAICHI 1
Co-author(s): MARUOKA, DAISUKE 1 ; KASAI, EIKI 1

1 Tohoku University

Reduction disintegration of sinter at low temperature is one of important factors to maintain the stable operation of the blast furnace. The main factor of the disintegration is volumetric expansion of the iron oxide phase due to the reduction from hematite to magnetite at the temperature from 673 to 873 K. Furthermore, it is reported that the disintegration of sinter by CO reduction is caused by hematite reduction at temperatures from 773 to 873 K and by calcium ferrite reduction at temperatures from 923 to 1073 K. In this study, disintegration mechanism of calcium ferrite in sinter was studied at the temperature from 773 to 973 K. The reduction of acicular calcium ferrite proceeds at 773 K for 5.4 ks, while columnar calcium ferrite is not reduced. At higher temperature, reduction of acicular calcium ferrite begins for a shorter time and accelerate disintegration of sinter. At the same time, fine acicular particles with sizes of a dozen micrometers form, but the direct effect of this powder formation on the RDI value is small. However, cracks form due to the connection of pores caused by this falling, and the sinter becomes weak. At 973 K, on the other hand, disintegration is inhibited because the volume expansion of skeletal hematite becomes small and the cracks formed in the sinter seem to be mended.

Ironmaking Fundamentals - Board: 23 / 64

EFFECT OF COKE GASIFICATION WITH CO2 AND H2O ON THE POROSITY AND STRENGTH IN 1100-1500°C

Author(s): SHIN, SOON-MO 1
Co-author(s): JUNG, SUNG-MO 1

1 GIFT/POSTECH

The gasification of metallurgical cokes with CO2 and H2O on their porosity and macro-strength were investigated in the current study. Cokes were reacted with CO2 or H2O in the temperature range of 1100 to 1500°C. During the reaction, the compositional change of product gases were measured by Quadruple Mass Spectrometry (QMS) for evaluating the gasification rate. Image analysis was carried out to measure the porosity according to the distance from coke surface. The porosity at the surface of coke gasified with CO2 indicated low values due to its low reactivity, which resulted in the intraparticle reaction to diffuse into the pores at low temperatures while the
coking with H2O showed the tendency to react the coke at the surface. This difference in the reaction behavior can be explained by Thiele modulus. Furthermore, fine powder formation and tensile strength were measured to evaluate macro strength of cokes. According to the results, the different reaction mode caused obvious difference in the tendency of macro strength of the cokes of the same reaction degree. Tensile strength of cokes was strongly affected by their porosity distribution.

Ironmaking Fundamentals - Board: 26 / 113

DEVELOPMENT OF SLAG FLUIDITY PREDICTION SYSTEM AND ITS APPLICATION FOR BLAST FURNACE

Author(s): JIA-SHYAN, SHIAU
Co-author(s): SHIH-HSIEN, LIU ; CHUNG-KEN, HO

1 China Steel Corporation

According to the metallurgical conditions of CSC, the influences of MgO content, Al2O3 content and C/S (=CaO/SiO2) on slag fluidity are studied for blast furnace operation. The liquidus temperature and viscosity of a semi-synthetic slag are measured using an optical softening temperature device and a viscometer, respectively. Based on these measured data, equations of liquidus temperature and viscosity of semi-synthetic slags (SiO2-Al2O3-CaO-MgO-TiO2) are developed in the multiple-regression formula. In CSC, the index of slag liquidus temperature is often used to adjust the ratio of burden materials and to remedy the abnormal conditions in BF operation. To ensure a normal and stable BF operation with low production cost, the research results indicated that the tolerable Al2O3 content is ranged 15-17 mass% for the slag with 6-8 mass% MgO and C/S < 1.15 to obtain an acceptable viscosity (< 10 poise) at the hot metal temperature above 1495°C. Basically, the slag fluidity is mainly determined by both viscosity and liquidus temperature. A combined slag fluidity index, including viscosity and liquidus temperature, has been designed in this research to indicate appropriate slag fluidity. The combined slag fluidity index has been incorporated into the tapping system of CSC BFs. The system is able to predict the difficulty of slag flow based on real-time data of liquidus temperature and viscosity for the coming tapping. It can immediately provide BF staffs some information to control the variation of slag fluidity via the effective operating adjustment, such as enforcing management of thermal state or varying the chemical composition of final slag by adjusting BF burdens.

Ironmaking Fundamentals - Board: 111 / 59

A MECHANISTIC MODEL OF THE SAPOZHKINOV PLASTOMETER

Author(s): JENKINS, DAVID R.
Co-author(s): MAHONEY, MERRICK R

1 CSIRO
2 University of Newcastle, NSW

The Sapozhnikov plastometer is an integral part of the classification system for coking coal in China. While there have been many studies of the Sapozhnikov plastometer over a long period of time, the interpretation of the results of the procedure remain heuristic. We have developed a detailed model of the Sapozhnikov plastometer, based upon the mechanistic effects occurring during the carbonisation process. These include gas evolution in coal particles, bubble growth, bubble coalescence and bursting, gas transport through softened particles, and in the spaces between particles. During operation of the plastometer, all the different phases of carbonisation can exist at the same time – semicoke, plastic phase and the original coal. We present comparisons of our mechanistic model with plastometer results measured for coking coals across a range of rank. We show that the model can reasonably replicate the experimental results over the whole range of coals studied. Also, we provide a plausible mechanism for the oscillations that are observed in the results, particularly for higher fluidity coals. These results point to an important issue with interpretation of the plastometer results, which must be taken into account when using them for evaluation of coking coal.
FORMATION OF IRON-ORE SINTER MINERALOGY AND MICROSTRUCTURE: TOWARDS A COMPREHENSIVE CONCEPTUAL MODEL OF THE FLAME FRONT

Author(s): SMALL, JAMES
Co-author(s): ZINNGREBE, ENNO; MELZER, STEFAN; VAN HINSBERG, VINCENT

1 Tata Steel
2 McGill University, Montreal

Here we present a model of the formation mechanism of sinter mineralogy and microstructure in highly fluxed sinter (CaO/SiO2 ≈ 2.8-3.8), obtained by detailed investigation of quenched flame front and final sinter product samples. Contrary to the suggestion of several other studies, the observations here indicate only negligible solid-solid reaction and formation of low temperature Ca-ferrites prior to melting. Flash melting of adhering fines layers in the presence of solid carbon is the norm. Moreover, the formation of typical binding matrix dominated by acicular SFCA-I does not pass through a lower temperature, oxidised precursor stage, and instead can form by progressive oxidation of a reduced precursor stage comprising Fe2+-dominated melt + magnetite-rimmed ore-relicts via peritectic reactions during oxidation and cooling.

EFFECT OF FLUXING AGENTS ON THE QUALITY AND MICROSTRUCTURE OF HEMATITE PELLETS

Author(s): DWARAPUDI, SRINIVAS
Co-author(s): SEKHAR, CHANDRA; PAUL, INDRAJIT; MODI, KAPIL; CHAKRABORTY, UJJAL

1 R&D TATA STEEL JAMSHEDPUR INDIA
2 PELLET PLANT TATA STEEL JAMSHEDPUR

Indian iron ore fines with high alumina content (~2.5% Al2O3) resulted in poor quality pellets and a study was under taken to establish suitable pellet chemistry through proper fluxing agents. Limestone fluxed pellets were prepared at varying basicity (0 to 0.8) and pyroxenite fluxed pellets at varying MgO contents (0 to 3%) to study their effect on the metallurgical properties. Fired pellets were tested for their strength, RDI, reducibility and swelling. Microstructural studies were carried out to quantify different phases and their chemistry. Acid pellets exhibited poor quality whereas limestone pellets at 0.8 basicity and pyroxenite pellets at 1.5% MgO exhibited optimum metallurgical quality. Formation of widely distributed silicate melt in limestone pellets and high melting point slag & magnesioferrite in pyroxenite pellets found to improve their quality. However, commercially produced pyroxenite fluxed MgO rich pellets exhibited better high temperature properties but inferior low temperature properties; whereas limestone fluxed CaO rich pellets exhibited the quality vice versa. To yield the benefits of both CaO (for good strength and RDI) and MgO (for low swelling and high softening), a dual flux combination was established, using both the fluxes, that resulted in optimum metallurgical properties.

INNOFREIGHT CONTAINER SYSTEMS - A NEW STANDARD IN RAILWAY TRANSPORT FOR VOESTALPINE

Author(s): ZENI, LUKAS
Co-author(s): WANEK-PUSSET, PETER; ZIRNGAST, JOHANN; SCHUSTER, ELMAR; HERZMAIER, JOSEF

1 Innofreight Speditions GmbH
2 voestalpine Stahl Donawitz GmbH
3 Rail Cargo Logistics - Austria GmbH
Innofreight Speditions GmbH is a privately owned company with its headquarters in Austria. Its business area is developing and operating innovative railway transport solutions consisting of special tailor-made containers and wagons together with loading and unloading systems. For the coke and coal supply Innofreight developed the MonTainer, the most innovative container on the European market. It is a strong and reliable open-top-container offering maximum payload and volume. The unloading is done with a highly automated container tipping machine which was implemented in Donawitz in October 2015. With this technology it is possible to have up to 30% higher payload per block train and to reduce the number of trains up to 22% for coke deliveries to Donawitz by conveying the same amount of coke - leading to significant cost saving. For the transport of iron ore Innofreight, together with voestalpine and ÖBB have developed the RockTainer ORE. Due to the use of the voestalpine alform® welding system the container’s tare weight was reduced to a minimum. As a benefit the RockTainer ORE offers 7% up to 25% higher payload compared to standard ore wagons.

**Pelletising** - Board: 72 / 93

**SIMULATION BASED PELLET-PLANT DESIGN**

*Author(s):* FALLER, MICHAEL

*Co-author(s):* HIEBL, BERNHARD; WIRTH, MATHIS; REDL, REINHARD

1 PRIMETALS Technology GmbH

Today the iron making business in general and with it metallurgical plant design and engineering faces a highly competitive environment. The pelletizing sector, whether for new plants or for revamping and optimization of existing plants, is challenged by economic pressure by competitors, deteriorating raw material quality, more stringent environmental regulations and remote plant locations often with limited electrical power, fuel and auxiliary media supply. Maintaining competitiveness demands more accurate equipment specification and engineering as well as optimized technical solutions concerning raw materials, fuel and auxiliary media. Nowadays simulations based on mathematical models for the physical and chemical phenomena occurring in the pelletizing process allow accurate calculation and prediction of the most important process parameters. Although many literature data is available, experimental validation and data acquisition for parameter adjustment as well as product quality and guarantee-figure evaluation by pot gate tests is indispensable. This paper gives an insight into Primetals simulation tool, the pot grate test facility for experimental test work and the combination and concurrence thereof.

**Pelletising** - Board: 104 / 111

**PELLETIZATION OF MALAYSIA MAGNETITE CONCENTRATES AND ITS PROPERTIES OF GAS-BASED DIRECT REDUCTION**

*Author(s):* PAN, JIAN

*Co-author(s):* BAI, BING; HUANG, WEIQUN; SHI, BENJING

1 Central South University

Direct reduction pellet production has become one of the hot spots developments, and the production of high quality pellets is an important guarantee. In this research, the pelletizing behaviors of one Malaysia magnetite concentrates was studied, including the effect of induration parameters and different basicity on the strength of pellets. Then the correlation between pellets basicity and properties of gas-based direct reduction by HYL process was investigated. The results show that the compressive strength of product pellets can reach over 2500 Newton per pellet while the green pellets made of Malaysia magnetite concentrates are preheated at 800°C for 7min and fired at 1250°C for 10min respectively, and with the increase of basicity, the strength of product pellets increased significantly. In addition, product pellets with nature basicity had superior mineral compositions and microstructure, and the product pellets possess good direct reduction performance which have good reducibility, lower swelling index of only 4.53%, and lower temperature disintegration (RDI-3.15mm only 8.24%). This kind of Malaysia magnetite concentrates is suitable as pellet feed and meet the demands of gas-based direct reduction by HYL process.
Blast Furnace Modelling - Board: 5 / 15

BLAST FURNACE HEARTH ASSESSMENT BY COMBINING AU-E AND THERMOCOUPLE DATA

Author(s): CHOMYN, KYLE
Co-author(s): PHILLIPS, STEPHEN; GORBANI, HAMID

1 Hatch Ltd

Inverse geometry heat transfer analysis using thermocouple data is often used to estimate the remaining refractory thickness in a blast furnace hearth. However, multiple combinations of refractory / skull thickness solutions exist for a single set of thermocouple data. The results of this method are also sensitive to the quality of thermocouple data. An alternative approach uses non-destructive Acousto Ultrasonic-Echo (AU-E) measurements to provide an estimate of the refractory wear profile and identify irregularities. This paper describes a combined approach that uses both thermocouple data and AU-E measurements to eliminate uncertainties in the typical hearth thermal assessment methodologies. This combined approach can also estimate the skull shape and thickness, even with limited thermocouple data. Changes to the system can be quickly determined based on thermocouple history data. Warning temperatures can be identified, and potential design changes can be investigated. This assessment can help prolong the blast furnace campaign life.

Blast Furnace Modelling - Board: 24 / 18

PREDICTION OF BURDEN DISTRIBUTION OF BLAST FURNACE BY USING DEM

Author(s): MIO, HIROSHI
Co-author(s): NARITA, YOICHI; INAYOSHI, ATSUSHI; MATSUZAKI, SHINROKU; ORIMOTO, TAKASHI

1 Nippon Steel & Sumitomo Metal Corp.

The objective of this paper is to develop the particle flow simulation in a charging process of a bell-less type blast furnace by using Discrete Element Method (DEM). The particles behaviour in a rotating chute was modelled, and the burden distribution was analysed. The measurement of the particle behaviour in a scaled-down experimental blast furnace was also carried out to validate the simulated results. The simulated results were compared with the experimental ones, and the good agreement between them such as an ore-coke ratio (O/C) and a particle size distribution was given.

Blast Furnace Modelling - Board: 71 / 19

IRON ORE PELLET REDUCTION BEHAVIOR IN POTENTIAL LOW CO2 BLAST FURNACE SCENARIOS

Author(s): KEMPPAINEN, ANTTI
Co-author(s): WANG, CHUAN; ELSAYEDMOUSA; HAAPAKANGAS, JUHO; SUOPAJÄRVI, HANNU; FABRITIUS, TIMO

1 Process Metallurgy Research Unit
2 Swerea MEFOS, Process Integration Department

The future of the low emission blast furnace (BF) ironmaking might result in significant changes in the applied reductants. Today, majority of the Western Europe blast furnaces are operated with pulverized coal injection, but alternative renewable reductants such as torrefied biomass or charcoal could also be applied in BF injection. In addition, top gas recycling blast furnace (TGR-BF) technology could provide partial solution to CO2 emission mitigation. Use of bioreducers or top gas recycling will change the reducing gas composition in the BF shaft, which has impacts on the iron burden reduction. The objective of this research is to evaluate the effect of the low emission reductants and technologies on the iron oxide reduction reactions in the blast
furnace shaft. A blast furnace model with comprehensive heat and mass balances is used in this research work to compute the reducing gas atmosphere in BF shaft in different cases: 1) typical pulverized coal injection as the reference case, 2) various bioreducer (torrefied biomass and charcoal) injection cases and 3) TGR-BF case. The ferrous burden reduction under different conditions is investigated by thermogravimetric experiments. Reducibility and swelling of the iron ore pellets are investigated together with microstructural analysis from the reduction experiments. The obtained results can be used to evaluate the impact of bioreducers and top gas recycling on the blast furnace efficiency.

### Blast Furnace Modelling - Board: 101 / 20

**SINTER – NUT COKE INTERACTION AND BEHAVIOUR DURING CONVEYOR BELT TRANSPORTATION AND DISCHARGE: A DEM STUDY**

**Author(s):** CHIBWE, DESIDE

**Co-author(s):** PINSON, D.J.; AUSTIN, P.; BIASUTTI, M.; CHEW, S.J.; MONAGHAN, B.J.; EVANS, G.M.

1 University of Newcastle
2 BlueScope Steel
3 University of Wollongong

Ironmaking blast furnace (BF) operation and control is quite a challenging task due to the “black box” nature of the process. The difficulty is further aggravated by the fact that the overall performance of the furnace is simultaneously influenced by both in-furnace and out-of-furnace processes. However, the difficulty can be somewhat mitigated through application of empirical knowledge, carrying out appropriate measurements and numerical modelling. A bell-less top BF charging system equipped with a conveyor belt burden delivery arrangement is the basis of this work. The current study presents a discrete element method (DEM) simulation of sinter and nut coke interaction during conveyor belt transportation and discharge into parallel furnace top materials bins. Both qualitative and quantitative analysis of the burden flow streams and trajectories have been compared to experimental measurements of the same equipment geometry. The results obtained are useful in aiding the understanding of behaviour, interactions, mixing and segregation characteristics of the burden flow. Further, the results provide a basis for future improvement of the charging system with ultimate objective of achieving improved understanding and control of the nut coke distribution within the ferrous charge and thus optimizing chemical reactions, heat and mass transfer between solids and fluids.

### Blast Furnace, Operation and Control - Board: 98 / 32


WARREN, PETER; FISHER, DAVE

1 Materials Processing Institute
2 BRITISH STEEL

During the short 179 week 4th campaign of Redcar blast furnace, persistent cash constraints led to a number of compromises concerning the limits of raw material quality and composition, particularly for high PCI rate operation. At the modest productivity required, high coke quality enabled low fuel rate, high PCI operation at a relatively high lump ore proportion. Poor quality coke led to a number of severe process upsets.

### Blast Furnace, Operation and Control - Board: 108 / 33

**IMPACT ON COMBUSTION CONDITIONS FROM TUYERE INJECTION SETTINGS**
The impact from lance design, blast parameters and type of injection materials on combustion conditions in the raceway have been investigated both theoretically and in operational injection tests in the LKAB Experimental BF (EBF). A CFD model for the EBF is developed and the modelling results validated with experimental data deduced from additional monitoring devices including high-speed camera and temperature measurements at the tuyere. The conditions with two different lances (coaxial and swirl-tip) and the injection of medium volatile coal with or without addition of torrefied biomass or lignite coke is explored as well injection of torrefied biomass only. Kinetic parameters for volatilisation, combustion and gasification of injection material used in the CFD model were determined by using thermo-gravimetric analyses (TGA). Consistency between modelling results and monitoring data was stated and the impact from different injection conditions is discussed.

IDEAL BLAST FURNACE PROCESS

Novolipetsk Steel is the key company within NLMK Group. The company includes all steelmaking and servicing facilities. Iron ore raw materials and fluxes for sinter production are delivered from mining and concentration plants of the Group. Coke at the company and at Altai-Koks - the Group’s plant - is produced from purchased coal. In order to improve competitiveness, starting from 2013 at all production stages of the company and plants supplying raw materials and coke to it, systematic work has been performed aimed at improvement of processes according to the principles of the approved concept “Ideal technology”: - compliance of quality and consumption of burden and process fuel with conditions of physical and chemical processes in facilities necessary for achieving required product quality; - maximum use of design capacities of facilities; - environmental friendliness. As a result, within 30 months of the company’s operation coal purchasing for production of coke calculated per ton of hot metal has been reduced by more than 14%, production of hot metal, steel has increased by 10-15%, and 3-5%, respectively, production capacity of blast furnaces has grown by 15-25 %.

RESERVES FOR RAISING THE EFFICIENCY OF BLAST FURNACE PROCESS

Improved coke and sinter quality have facilitated an intensification of the blast furnace (BF) operation due to higher gas top pressure, blast rate and blast oxygen content, as well as the flow rate of injected fuel. Specific BF productivity has increased 15-30% accompanied by a reduction in fuel rate. The increased gas intensity of melting has facilitated faster indirect wustite reduction without any negative impact on the reduction efficiency.
PID COMBUSTION – DEDICATED CONTROL FOR AIR ADMISSION IN A HEAT RECOVERY COKE OVEN AT TKCSA

Author(s): FERREIRA JUNQUEIRA, YAN SAMUEL
Co-author(s): HENRIQUE, NEUSSIAS INOECIENO; COELHO, ROBSON JACINTO; DE ANDRADE, LUIZ AFONSO; EFFGEN WERNESBACH, CHARLES HUMBERTO; DE OLIVEIRA PINTO, ULISSES; DE SOUSA DE ARAUJO, GLAUBER; DE SOUZA AZEVEDO, SANDRO; PEREIRA, RAFAEL PEDROSA

1 Thyssenkrupp CSA, Brazil

The cooking process in a Heat Recovery Coke Plant is founded on the burn of volatile matter, present on coal as primary fuel. A second unwanted reaction occurs by the combustion of coke. This undesired burning process is called Burn Loss. The amount of air sucked to the oven was controlled by an automatic system which open or close the valves using as main variable Time. During the control by Time various influences which occur in process are not considered, and consequently not all process potential to produce coke are used. The control developed by the maintenance, operation and technical unit team in TKCSA, named PID Combustion, was focused on a self-taught system, able to recognize the disturbs of the process and admit only the amount of air required for each oven. Mathematical, statistical calculations and the heat historical of the oven are evaluated by the PID Combustion which will optimize the mix of gas and air on the oven. The main benefits after deployment were: collectors temperature decrease (preservation of assets), oven production capacity increased (increase cooking speed) and suction optimization along the ovens in the same collector.

Cokemaking, Operation and Control - Board: 83 / 103

OBTAINING DETAILED MINERAL AND MINERAL/MACERAL ASSOCIATION INFORMATION IN COKE OVEN FEED COAL SAMPLES BY OPTICAL IMAGE ANALYSIS

Author(s): HAPUGODA, PRIYANTHI
Co-author(s): O’BRIEN, GRAHAM; KRAHENBUHL, GREGOIRE; WARREN, KARRYN

1 CSIRO

The amount and type of different mineral species in coke oven feed coal, the size of these mineral grains and their association with fusible and infusible macerals can have a significant impact on coke quality. The Coal Grain Analysis (CGA) system is an optical reflected light microscope imaging system that collects mosaics of contiguous high resolution colour images to provide detailed information on particles up to 8mm in size. The systems capability has recently been extended by developing optical mineral markers which provide details on the minerals present in samples. To develop the “Mineral Markers” images collected from a scanning electron microscope (SEM) and an optical microscope were registered. The distribution intensities for each individual component were compared to ensure correct identification of each mineral species. Supervised learning algorithms combined with other parameters such as variation in colours and textural information were used to develop an optical mineral marker database which is able to identify two different clay minerals, quartz, siderite, calcite, pyrite and apatite. Incorporation of these mineral markers into the CGA system will provide a cost effective mechanism to obtain mineral abundance, size and mineral/maceral association information on a particle by particle basis in a single analysis.

Cokemaking, Operation and Control - Board: 87 / 104

APPLICATION OF I600 FROM THE CSR TEST AS A MEASURE OF PILOT OVEN COKE STRENGTH

Author(s): KOVAL, LUKAS
Co-author(s): SAKUROVS, RICHARD; HOCKINGS, KIM; VINING, KEITH

1 CSIRO
Coke cold strength is typically measured using standardised coke strength indices (ASTM, IRSID and JIS). When all coke cold strength tests are performed at full scale, collective weight of 45 kg of product coke is required. However, pilot or research at bench scale coking may not result in sufficient coke yield for standardised testing. In these cases, an I600 test, which is equivalent to the CSR I-drum test without pre-reaction by CO₂ and utilises only 400 g of coke for duplicate test, could be used. As part of the pilot scale coking program completed for BHP Billiton at Commonwealth Scientific and Industrial Organisation (CSIRO), the I600 test was introduced to supplement standard coke testing practice. The aim of this work was to determine the relationships between the results of I600 test and commonly used coke strength indices. The main conclusion of this study was that I600 correlated best with indices which had most similar test conditions (particle size, drum revolutions). Moreover, significant improvement of the CSR prediction equation using CRI by incorporating the I600 index was found. In addition, influence of coal preparation and coking conditions on I600, CSR and CRI relationship was also evaluated and the findings were reported.

Cokemaking, Operation and Control - Board: 106 / 105

APPLICATION OF ORGANIC POLYMER IN COKE MAKING- TATA STEEL SCENARIO

Author(s): NAG, DEBJANI¹
Co-author(s): DAS, BIDYUT ¹ ; DASH, P. S. ¹

¹ Tata Steel

Pelletising - Board: 73 / 94

APPLICATION OF THE HYBRID FLOTATION IN IRON ORE - PNEUMATIC FLOTATION FOR REMOVAL OF SULFUR

Author(s): PETZOLD, LUKAS¹
Co-author(s): MARTENS, JAN ¹

¹ Primetals Technologies Austria GmbH

Primetals successfully established the Hybrid Flotation Technology, which differs from the standard pneumatic flotation cells, on the non-ferrous mining market. The growing demands for high grade pellet feed with low content of silica and sulfur also makes that technology very interesting for the use in iron ore beneficiation. Primetals conducted a laboratory campaign with the in-house laboratory Hybrid Flotation Cell. The cell was used for a test campaign to remove sulfur from an iron concentrate containing 67% Fe and 1.3% S. 80% of the mass was smaller than 97 μm while 30% of the mass was smaller than 20 μm. The target was to reduce the sulfur content in the final iron concentrate to less than 0.4% by meeting a Fe-recovery of at least 95%. The test results show an overachievement of the target and the potential of the Hybrid Flotation applied as rougher-cleaner combination to produce an iron concentrate with significantly reduced sulfur content.

Pelletising - Board: 89 / 95

EFFECT OF IRON ORE CHARACTERISTICS ON THE WATER –IRON ORE INTERACTION

Author(s): HIGUCHI, TAKAHIDE¹
Co-author(s): LU, LIMING ²

¹ JFE Steel Corporation

²
The interaction of fine iron ore powders with water plays an important role in iron ore granulation, an important step in iron ore sintering, and is usually assessed based on the determination of wettability, or contact angle, of iron ore powders. Generally, iron ores which have a lower contact angle show more efficient granulation. The Washburn capillary rise (WCR) technique has been widely used for determining wettability of porous materials and powders. This paper reviews past research on the water-iron ore interaction and introduces a test method developed based on the WCR technique to measure the dynamic interaction of the iron ore powders with water. Ores of different characteristics were selected and characterised. The effect of ore characteristics on its interaction with water and therefore, granulation performance, was discussed in detail.

**THE OXIDIZING PELLETIZATION OF MANGANESE ORE FINES AND ITS CONSOLIDATION MECHANISM**

**Author(s):** ZHU, DEQING

**Co-author(s):** HU, XUN ; ZHANG, FENG ; LI, ZIYUN

1 School of Mineral processing and Bioengineering, Central South University

Oxidizing pelletization of imported high combined water bearing manganese ore fines was conducted by simulating grate-kiln process in electric tube furnace, and its consolidation mechanism was revealed by the determination of the mineralogy of fired pellet. The raw manganese ore fines were finely ground by HPRG for preparing pellet feed with specific surface areas of 2563 cm²/g and bentonite was used as binder. The good quality green balls were made under the conditions of 2.0% bentonite, 16% moisture and balling in disc pelletizer for 7 min, and drop numbers of 23.1 times from 0.5 m height, compressive strength of 10.20 N/pellet being achieved, respectively. The green balls were then preheated at 1050°C for 10 minutes and fired at 1340°C for 15 minutes, the mechanical strength of fired pellets reaches 2711 N/pellet. The consolidation mechanism of fired manganese ore pellets is the interlinkage of recrystallized hausmannite and black manganese grains by solid diffusion. In the meantime, some manganate liquid phases are formed with multicomponents, mainly consists of K2O•2.4Al2O3•1.7MnO•13.8SiO2, which form bonding phases between coarse particles of hausmannite and black manganese. Both the solid hardening and liquid phases bonding maintain the high mechanical strength of fired manganese ore pellets.
designed tailor-made to fit each customer’s needs. Ease of maintenance and longer intervals between major maintenance interventions are further design criteria.

Sintering, Design and Equipment - Board: 113 / 108

PROTECTING SINTERING PLANTS – DURABILITY, SUSTAINABILITY AND EFFICIENCY IN WEAR PROTECTION

LASKOWSKI, JENS

1 Welding Alloys GmbH

The presentation “Protecting Sintering Plants - Durability, sustainability and efficiency in wear protection” shows new approaches and developments for increasing the lifetime and efficiency of wear protection in the high temperature area of agglomeration plants (and related) to maintain cost-optimized production in agreement with environmental requirements. Scientific analyses of crucial parts with focus on common products and how they affect (and are affected) by other parts in the process chain and how to minimize influence on the lifetime of parts or plant availability. In support, the presentation considers the different welding wires and hardfacing qualities for generic structures, regarding the newest developments in welding technologies. Although this presentation is apparently approaching these topics in a sintering plant, it can be applied to multiple plants with the same issue; high temperature abrasion from heavy bulk within the steel industry.

Sintering, Design and Equipment - Board: 18 / 134

TECHNOLOGIES FOR IMPROVEMENT OF SINTER PLANTS

Author(s): HOFFMANN, MATHIAS

Co-author(s): KASS, GILLES; NOUAILLE-DEGORCE, GILLES; SCHWALM, THOMAS; SCHULAKOW-KLASS, ANDREJ

1 Paul Wurth S.A.

2 Paul Wurth Deutschland GmbH

Upgrading and de-bottlenecking by improving the existing becomes more and more important in these economically demanding times. PAUL WURTH is proposing a series of solutions that tackle the challenges of production and maintenance cost reduction, productivity increase, emission reduction. Optimized sintering starts with a precise control of the humidity of the raw mix, followed by automatic humidity adjustment before and after nodulizing. Sinter production cost can be reduced by using finer iron ore, which however requires some adaptations to counterbalance the effect of the finer granulometry. Extensive tests have been conducted employing high intensive mixers, fine-tuning the permeability of the raw mix when using fine ores. The positive effects of the addition of burnt lime combined with a high intensive mixing arrangement will be described. Reline of ignition hoods can be either focused on reducing the quantity of internal return fines, reducing the gas or solid fuel consumption or increasing the production rate. The vertical burner technology is being further developed and promoted for these purposes. The paper will give insight into recent references and describe further technologies for improving existing plants. Special focus will be put on the auditing capabilities of PAUL WURTH in relation to process improvements as well as to servicing.

Sintering, Design and Equipment - Board: 141 / 156

NEW TYPE OF PARTITION WALLS IN A PELLETIZING PLANT: A THERMO MECHANICAL ANALYSIS

Author(s): MARschall, Hans Ulrich

Co-author(s): NADER, CESAR G. J.; HEHENSTREIT, GERALD; WILHELMI, BRUNO
Blast furnaces do not operate properly with fine-grained iron ore. To make use of such ores, they must be processed efficiently into pellets in high scale traveling grate pelletizing plants. Pellets are small balls of iron ore. Such furnaces are lined with thousands of tons of refractories that play an important role in operation stability and energy efficiency. Partition walls are a critical part of the design by dividing the process area above the grate into different temperature zones. These partition walls situated above the traveling grate and span across the width of the furnace walls. This paper describes the development of a new type of partition walls supported by finite element analysis of the thermo mechanical behaviour of those walls.

Keynote - Prof. Schenk - Board: 112 / 115

EVALUATION OF THE CAPABILITIES OF DIRECT AND SMELTING REDUCTION PROCESSES TO ENHANCE THE ENERGY EFFICIENCY AND TO REDUCE THE CO2 EMISSION OF THE STEEL PRODUCTION IN EUROPE

Author(s): SCHENK, JOHANNES
Co-author(s): LÜNGEN, HANS BODO

1 Montanuniversitaet Leoben
2 Steel Institute VDEh, Germany

The processes of direct reduction and smelting reduction are alternatives to the blast furnace route for the production of metallic feed material from iron ore avoiding cokemaking. The natural gas-based direct reduction processes have lower CO2 emissions in comparison to the coal-based liquid hot metal producing processes “blast furnace” and “smelting reduction”. Regarding energy consumption all three routes are of equal value. For an application of the routes that form an alternative to the blast furnace in Europe the integration into an existing integrated iron and steel works is evaluated. A replacement of the blast furnace – converter route by gas-based direct reduction with a subsequent electric steelmaking with the target to reduce CO2 emissions does not seem economical feasible under the current situation in EU28. New technologies for the production, storage and distribution of hydrogen from CO2-free renewable energy sources are under development. If they achieve industrial scale maturity the production of metallic feed material for steelmaking from iron ore without CO2 emission will become technological achievable.

Blast Furnace, Operation and Control - Board: 12 / 161

STUDY ON EROSION OF LARGE BLAST FURNACE HEARTH AND TECHNIQUES TO PROLONG CAMPAIGN LIFE OF HEARTH

Author(s): XU, WANREN
Co-author(s): MAO, XIAOMING ; SONG, WENHU ; HUA, JIANMING

1 Baoshan Iron and Steel Co., Ltd.

In this paper, the investigation on erosion of hearth sidewall lining of 3BF(campaign life of 19 years) and 4BF(campaign life of 9 years) at Baosteel and analysis of erosion reasons have been done. The paper expatiated the production techniques and maintaining measures to control rising hearth sidewall temperature and erosion of large size blast furnaces at Baosteel, such as improving permeability of deadman and decreasing circuiting flow density of hot metal in hearth by increasing blast energy or center coke charging operation; controlling erosion at areas near taphole by intensifying the tapping management and prolong length of the tapholes, and so on. Based on the investigation results of carbon brick damage at 4BF, the paper have expounded the base and importance of ensuring construction quality and carbon slurry quality, ensuring higher heat transfer effect of stave-lining system for prolong lifetime of hearth. Based on the operation practice of Baosteel BFs, the viewpoint that maintaining a stable solidified iron layer (protecting
layer) on hot surface of carbon brick are the key for prolong campaign life of hearth, has been discussed deeply, and the opinions, suggestions about the design and installation positioning of stave-carbon brick system have also been put forwards.

Blast Furnace, Operation and Control - Board: 21 / 133

BLAST FURNACE PROCESS OPTIMIZATION WITH CLOSED-LOOP EXPERT SYSTEMS – 25 YEARS OF EXPERIENCE

Author(s): BETTINGER, DIETER
Co-author(s): FRITSCHEK, HARALD; KRONBERGER, THOMAS; SCHALER, MARTIN; SCHÜRZ, BERNHARD

Back in 1991 voestalpine Stahl Linz, an Austrian integrated steel producer, and Primetals Technologies, a metallurgical plant builder and engineering company from Linz, Austria, joined forces and started the development of an integrated process optimization system for blast furnaces. This cooperation resulted in the successful development of a closed-loop expert system for blast furnaces which supports more than 10% of the world hot metal (HM) production. The first part of the paper describes the structure of the process optimization system and focuses on the latest developments of the process models. It describes the core rule groups and the possibilities of project specific adaptations of the expert system and it outlines the application of the closed-loop concept for a variety of operational conditions. The second section of the paper gives an overview of the worldwide references of the process optimization system for blast furnaces and reviews recent installations. The paper concludes with an outlook on the short term improvements and developments of the optimization system and it discusses the long term vision of a fully automatic blast furnace.

Blast Furnace, Operation and Control - Board: 139 / 155

BLAST FURNACE PERFORMANCE WITH HIGHER PELLET IN BURDEN

Author(s): RAUT, GOUTAM KUMAR
Co-author(s): REDDY, A SRINIVAS; KUMAR, ASHOK

Tata steel Indian Blast Furnaces are started using pellet in burden since April 2012. This was the first time to switch from sinter and lump ore to sinter, lump ore and pellet in burden. Several operational issues faced during early days with charging pellet, raising pellet percentage and deciding its chemistry. The paper is an attempt to show operational hurdles faced and count measures taken while switching from low to high pellet in burden for stable blast furnace operation and also describes changes adopted in pellet composition to improve blast furnace efficiency.

Blast Furnace, Operation and Control - Board: 7 / 16

STRUCTURAL ASSESSMENT OF BLAST FURNACE HEARTH REFRACTORY SYSTEM

Author(s): MALEKI, MAJID
Co-author(s): DARIVANDI, NEDA; VAN DER WOUDE, CHAD; CHOMYN, KYLE; LEE, GRACE; PHILLIPS, STEPHEN; GHORBANI, HAMID

Assessment of the structural behaviour of the hearth refractory system in the design or repair stage can reduce risks associated with design innovations and hearth modifications. Information such as likely cracking and gap formation locations can be used to optimize the hearth bricking pattern,
materials, and expansion allowances, and better interpret thermocouple data by considering changes in the heat transfer properties. This paper presents a novel 3D structural refractory assessment methodology for the blast furnace hearth under thermal and mechanical loads and pressures experienced during furnace operation. This methodology takes into account refractory cracking and crushing, mortar joint compression, separation, and frictional sliding, inelastic ramming mix behaviour, as well as nonlinear steel shell deformations using advanced finite element analysis. This assessment approach provides insight into likely damage in the refractory system and can be used to optimize the hearth performance and extend the campaign.

Blast Furnace, Operation and Control - Board: 115 / 151

DEVELOPMENT AND IMPLEMENTATION OF NEW MEASURING AND MONITORING SYSTEMS TO SUPPORT BF CONTROL

Author(s): RONGSHAN, LIN
Co-author(s): RAUSCH, HARALD 1 ; HARTIG, WALTER 1 ; WU, LIJIA 1

1 DILLINGER, AG der Dillinger Hüttenwerke

For optimal blast furnace control, suitable measurement and monitoring systems are required. This paper focuses development and implementation of 3 new measurement devices and methods at ROGESÁ in Dillingen: 1) sonic gas temperature measurement, 2) a camera-based monitoring system at tuyere level, and 3) EMF and strain gauge measurement to determine the liquid level in the hearth of the blast furnace. These measurement and monitoring systems are installed and successfully tested in the recent years. The information obtained is used to optimize the furnace control for enhancing the BF performance.

CO2 Reduction and Energy Saving - Board: 17 / 82

HELPING TO ADDRESS ENVIRONMENTAL CONTROL IN IRON ORE PROCESSING, IRON MAKING, AND COKE HANDLING OPERATIONS THROUGH THE USE OF COMPUTATIONAL FLUID DYNAMICS (CFD)

Author(s): WOLOSHYN, JENNIFER
Co-author(s): BLACKMORE, ADAM 1 ; PLIKAS, TOM 1 ; JOHNSON, WAYDE 1

1 Hatch Ltd.

Environmental regulation and economic conditions demand greater efficiencies in the control of emissions and fugitive releases in iron ore processing, iron making, and coke handling operations. This paper provides an overview of recent applications of Computational Fluid Dynamics (CFD) to this aspect of the industry. The case studies discussed include: 1) NOx reduction expected by the utilization of a low NOx burner in an iron ore induration kiln, 2) effectiveness of Flue Gas Recirculation (FGR) in reducing NOx emissions from a waste heat boiler burning blast furnace gas, coke oven gas, and natural gas, 3) the design optimization of a blast furnace taphole hood, 4) dust control in the conveyance of coke, and 5) Nitrogen purging of a cold box in a coke oven battery. It is demonstrated through the case studies that CFD is an effective tool for reducing technical risk in the design phase, evaluating various solution options to arrive at the most practical and cost effective solution, and for quantifying the reduction in emissions and fugitive releases to be expected through implementation of the proposed solutions.

CO2 Reduction and Energy Saving - Board: 27 / 83

NEW IRONMAKING PROCESS TO ENHANCE THE FLEXIBILITY OF ENERGY SUPPLY AND USE OF LOW GRADE RESOURCES

Author(s): NOUCHI, TAIHEI
Co-author(s): TAKAHASHI, K.; SATO, M.

1 JFE Steel Corporation

Saving energy and reducing CO2 emissions from the steel works are important issues for the steel industry. Because heat loss at the blast furnace is already less than 10% of input energy, saving energy at the blast furnace decreases the energy supply to downstream processes in the steel works. However, it is possible to reduce energy consumption for agglomeration processes such as coking and sintering without reducing the energy supply to downstream if the regulations applied to burden material strength can be relaxed. The inner volume of an oxygen blast furnace can be reduced to half that of a conventional blast furnace with the same production because the productivity of the oxygen process is almost double that of the conventional furnace. As a result, the blast furnace burden load is reduced, and regulations on burden strength can be relaxed. In this paper, the burden load and amount of energy saving of the oxygen blast furnace were evaluated by using the Discrete Element Method and a heat and energy balance model, respectively. Energy supply is also a societal responsibility for steel works, especially after the Great East Japan Earthquake of 2011. Therefore, the energy balance of the oxygen blast furnace under operation as a gasification furnace was also evaluated.

CO2 Reduction and Energy Saving - Board: 28 / 84

CO2 ULTIMATE REDUCTION IN STEELMAKING PROCESS (COURSE50 PROJECT)

Author(s): TONOMURA, SHIGEAKI

Co-author(s): KIKUCHI, NAOKI; ISHIWATA, NATSUO; TOMISAKI, SHIN; TOMITA, YUKIO

1 Nippon Steel & Sumitomo Metal Corporation
2 Kobe Steel Ltd.
3 JFE Steel Corporation
4 Nippon Steel & Sumikin Engineering Co., Ltd
5 Nisshin Steel Co., Ltd.

Four blast furnace steel makers and one engineering company in Japan have been prosecuted in the “CO2 Ultimate Reduction in Steelmaking Process by Innovative Technology for Cool Earth 50 (COURSE50) Project”, since FY2008 as a National Projects commissioned by New Energy and Industrial Technology Development Organization (NEDO). The target of COURSE50 is a reduction of approximately 30% in CO2 emissions in the steel manufacturing process. Two technologies are investigated, a) Reduction of iron ore by using hydrogen and hydrocarbon-containing coke oven gas to suppress CO2 emissions from blast furnaces, and b) separation and recovery of CO2 from blast furnace gas with chemical absorption method and physical adsorption method by exploitation of unused waste heat in the steel works. The operation trials at LKAB’s experimental blast furnace in Luleå in cooperation with LKAB and Swerea MEFOS were carried out. In the case of operation trials injected COG and reformed COG (RCOG), the increase in H2 reduction instead of C direct reduction that is a huge endothermic reaction, makes the input of C decreased comparing the reference period. Based on these results, we have developed further scheme of decreasing the C direct reduction in the blast furnace using blast control method.

CO2 Reduction and Energy Saving - Board: 34 / 85

COKE DRY QUENCHING: A SOLUTION FOR ENVIRONMENTAL CONTROL AND ENERGY SAVING

Author(s): ESPOSITO, ANTONIO

Co-author(s): CALCAGNO, RICCARDO; FABBRI, ANDREA; LAMBARDI, FRANCESCO

[Coke Producers are asked today to reduce environmental emissions and main resources’ consumptions (mainly water and energy sources). Optimization of energy requirements has already been approached and technology has now reached a good design level. Next challenge is to maximize the recovery of materials and energy, considering a not traditional approach for European market.}
The sensible heat in coke pushed out of oven chamber is usually lost during traditional coke wet quenching, necessary to reduce the coke temperature for the storage and the following use in steelmaking processes. CDQ technology is a sample on how Paul Wurth reaches the energy saving goal and offers an alternative to traditional quenching. With the adoption of CDQ process, a considerable amount of sensible heat of the coke can be recovered by producing steam, suitable to produce energy by a turbine. The energy produced will decrease the net consumption of coke making process and the overall CO2 emissions into atmosphere. Coke dry quenching reduces also the water consumptions in comparison with traditional quenching. CDQ technology allows an energy saving of 35-40% of energy consumption of coke oven and at the same time it can minimize CO2, dusts and sludges’ emissions.

**CO2 Reduction and Energy Saving - Board: 44 / 86**

**THE CIRCULAR ECONOMY: CARBON RECYCLING AND THE IRON INDUSTRY**

**Author(s):** FLEISCHANDERL, ALEXANDER¹
**Co-author(s):** PLATTNER, TOBIAS ¹ ; NAIR, PRABHAKAR ² ; WOLF, CARL ²

¹ Primetals Technologies Austria GmbH
² LanzaTech, USA

LanzaTech and Primetals are enabling a resource revolution in the steel industry that supports a circular economy, by decoupling the use of natural resources and the generation of waste from economic growth. Microbial fermentation of carbon and hydrogen-rich off-gases, such as, blast furnace top gas, direct reduction gas and also converter BOF gas to produce ethanol or other basic chemicals, substantially mitigates CO2 emissions while simultaneously reducing NOx, SOx and particulate emissions. The fuels and chemical products produced in this manner deliver superior economic returns. The ethanol product has up to a 87% reduction in greenhouse gases (GHG) compared to conventional gasoline, and reductions between 30% and 50%, per MJ energy recovered, when compared to combustion of those gases for power generation. Carbon recycling has the potential to open up vast new resources for making lowcarbon chemicals and fuels that displace petroleum without the environmental concerns associated with crop- and land-based bio-products. Through a process of gas fermentation, waste carbon can be kept in the material cycle, demonstrating innovative industrial growth solutions without compromising the environment. Through a process of industrial symbiosis LanzaTech and Primetals offer industries the opportunity to monetize wastes and residues while improving air quality around the industrial zone and adding value by creating useful products. For example steel mills recycling carbon emissions to produce ethanol and aviation fuel.

**Direct Reduction - Board: 22 / 77**

**DRIPax™ – THE NEW GENERATION OF DR PLANT PROCESS OPTIMIZATION**

**Author(s):** KLINGER, ANGELIKA¹
**Co-author(s):** ALTENDORFER, ALOIS ¹ ; HUGHES, GREG D. ² ; GUPTA, DURGESH R. ³

¹ Primetals Technologies Austria GmbH
² MIDREX Technologies, Inc.
³ Qatar Steel Company

DRIPax™ is an integrated process optimization system for MIDREX DR Plants jointly developed by Primetals Technologies and MIDREX Technologies. This new system was installed for the first time at the MIDREX DR plant Module 2 of Qatar Steel and is now successfully in operation at this plant. The installation at Qatar Steel demonstrates the high prediction accuracy achieved with the new product quality prediction models. Having an accurate prediction – hours before the measured data are available – supports quick decision-making to keep quality targets. As a result, a more consistent DRI quality can be achieved. Due to the improved control of the DRI quality within a tight band limit, significant savings can be expected at the EAFs when the DRI
is fed there later on. The DR Plant Expert System, a rule-based advisory system to assist panel operators in decision-making, was developed in a next step to further enhance the system. This expert system will be launched for the first time within the scope of the process optimization system installed at the new MIDREX DR Plant of voestalpine Texas LLC.

**Direct Reduction - Board: 130 / 90**

**HIGH-CARBON DRI THE FEEDING MATERIAL TO IMPROVE PERFORMANCES AND DECREASE CO2 EMISSIONS IN BOTH BF AND EAF**

**Author(s):** PAULUZZI, DARIO

**Co-author(s):** MARTINIS, ALESSANDRO; MARTINEZ, JORGE

1 Danieli
2 Tenova HYL

The use of DRI can help steelmakers facing the more and more tough environmental policies and market competition of modern times. Even better results can be obtained by using high-carbon DRI, a pre-reduced material with minimum 3.5% Carbon content, most of which in iron carbide form. This upgraded quality is the result of specific direct reduction's operating conditions, that are peculiar to the Energiron Zero-Reformer process. Adding high carbon DRI to blast furnaces' feed mix allows to decrease CO2 emissions and at the same time to increase the productivity, without any modification to the design of blast furnaces. Further optimizations to the overall process can be achieved by feeding BFG and/or COG to the direct reduction (DR) plant, so that it will operate in symbiosis with the blast furnace. In those cases in which the CO2 emissions must be decreased to the minimum level technically achievable, the integration of an Energiron direct reduction plant with an electric arc furnace (EAF) will provide the lowest carbon footprint for high-quality steel production. Ezz Rolling Mill opted for this solution in its new facility in Egypt, where the Energiron III plant recently started production. This direct reduction module quickly achieved remarkable performances and reached nominal capacity in less than one month of operation.

**Direct Reduction - Board: 29 / 78**

**APPLICATION OF MIDREX TECHNOLOGIES IN INTEGRATED STEEL PLANTS; POSSIBLE REDUCTION OF ENVIRONMENTAL IMPACT AND OPEX**

**Author(s):** PERATO, MARCO

**Co-author(s):** MAGNANI, STEFANO; ASTORIA, TODD; MICHISHITA, HARUYASU; MEIER, LARS

1 Paul Wurth Italia
2 Midrex Technologies
3 SMS GmbH

A constantly increasing focus is, nowadays, put on the CO2 and environmental impact of the steel industry, especially in EU and Japan. This can be seen as an unique opportunity for the steel producers to improve their reputation amongst the public community, too often loaded with unjustified prejudices. Even if the measures required to meet the ambitious target of EU to decrease CO2 footprint of steel industry by 50% in 2050 are calling for breakthrough changes in the process route, the incremental and optimized application of existing technologies continuously innovated to maximize their suitability in this new scenario, are an interesting possibility for the steel producers in the mid-term. This paper depicts the various scenarios resulting from the application of Natural gas based and syngas based MIDREX technology within an integrated plant exploiting the possible combinations given by the process gas available and the different process routes to produce liquid steel. An overview on the expected environmental benefits, and on the OPEX of the resulting plant configuration will be provided. Suggestions on how to maximize the reduction of CO2 FOOTPRINT of the Iron-making and steel-making sections in integrated plants though this approach will be explained with quantified examples.
Direct Reduction - Board: 61 / 79

SELECTION AND IMPLEMENTATION OF IRONMAKING TECHNOLOGY – EXPERIENCE, PRINCIPLES AND RISKS

Author(s): GORDON, YAKOV
Co-author(s): KUMAR, SUNIL

1 Hatch Ltd.

Understanding and managing the risks associated with the introduction of a new technology in the highly capital-intensive, large volume and low-margin iron and steel industry, is a key to effectively implementing a lasting change. Hatch has developed a robust methodology for process technology selection for the iron and steel industry to address the risks. The methodology is based on a two-stage approach in which the first stage includes short-listing of the best technologies based on results of mass and energy balance modelling, and a simple financial evaluation as well as risk analysis. The second stage involves a detailed analysis using refined input data, mass and energy balance modelling, capital and operating cost estimation, as well as a detailed financial analysis of the best technologies selected. To illustrate the critical elements of this methodology and the analysis required for the successful selection of ironmaking process technology, a Case Study covering the evaluation and selection of the best (most-suitable) ironmaking technologies for an Iron and Steel Company located in the European part of the Russian Federation, is presented in this paper.

Direct Reduction - Board: 133 / 81

EFFECT OF HEATING RATE ON THE PROPERTIES OF TWO NONCOKING COALS USED IN TUNNEL KILN DIRECT REDUCTION OF IRON PROCESS

Author(s): TOLOUE FARROKH, NAJIBEH
Co-author(s): FABRITIUS, TIMO; ASKARI, MASOUD

1 Sharif University of Technology
2 University of Oulu
3 Sharif University of Technology, Tehran

Effect of heating rate on the properties of two non-coking coals in thermal regime of tunnel kiln direct reduction of iron (TKDRI) process has been investigated. The low rate heating condition of raw materials in refractory crucibles of tunnel kiln was simulated in a vertical TGA for two different non-coking coals. The heating rates of 1.5, 3 and 7 oC/min from room temperature to 1100 oC were chosen for non-isothermal heating of coals. Coal mass and volumetric changes were observed during the test by TGA and dilatometry analysis. XRD and scanning electron microscopy of raw coals and chars were used to analyse the effect of heating rates on coal and char structure. The results showed Maximum Rate of Devolatilization (MRD) shifts to higher temperatures with increasing the heating rate (HR). According to coal dilatometry, high volatile coal shows more sensitivity to heating rates than high-carbon coal. The effect of heating rate on char reducibility arises from changes in char reactivity and structural ordering. Lower heating rates lead to higher char reducibility and more ordered structure.

Ironmaking Fundamentals - Board: 42 / 68

EFFECT OF VOLATILE MATTER OF COAL ON VOLUME CHANGE AND REDUCTION OF IRON ORE/COAL COMPOSITE PELLETS

Author(s): HAO-HSUN, CHANG
Co-author(s): IN-GANN, CHEN; KE-MIAO, LU; SHIH-HSIEN, LIU

1 NCKU, Department of Materials Science and Engineering
In the ironmaking processes via the carbothermic reduction with the tall-bed reactor, the composite pellets can be rapidly reduced to highly metallized direct reduced iron (DRI) with high productivity under high temperature. However, the volume change of the pellets during the reduction will affect the efficiency of heat transfer from the freeboard to the tall-bed pellets inside the reactor. In this study, coals with different volatile matter (VM) content but with fixed C/O = 0.95 were used to prepare the composite pellets for the reduction experiments. The in-situ digital camera was used to record the morphological changes and volume change of pellets throughout the reduction experiments. The microstructure and phase composition of DRI specimens were analyzed by scanning electron microscopy (SEM) and X-ray diffraction (XRD). The metallization degree of DRI specimens was also analyzed. Differential scanning calorimetry (DSC) was applied to investigate the characteristics of VM pyrolysis in coal. In this study, it was shown that the swelling of pellets could be resulted from the quick and large VM released from the coal pyrolysis due to the rapid rise of internal gas pressure of pellets. It was also found that the shrinkage degree of pellets increased as the VM content of the coal increase. And, more metallic iron grains can be found in the microstructure of the DRI specimens reduced from the composite pellets with high VM coal.

EXAMINATION OF COKE REACTIVITY USING MICRO-CT ANALYSIS

Author(s): JENKINS, DAVID R.¹
Co-author(s): MAHONEY, MERRICK R. ; DEEV, ALEX ; DONNELLY, JASON ; DAVIDSON, ROWAN ; MAYO, SHERIDAN

¹ CSIRO

We performed micro-CT imaging and analysis on coke CSR lumps, before, during and after reaction under conditions aimed at replicating the standard CSR test. The aim is to develop a stronger mechanistic understanding of the reactivity of cokes made from different coals, by examining the change in coke microstructure as the high-temperature reaction with CO2 progresses. Individual coke lumps were imaged at the Australian Synchrotron, then reacted with CO2 for 30 minutes, imaged again, and the process repeated until a full 120 minutes of reaction have occurred. The resulting 3D images of coke microstructure show the effect of transport control versus reaction control, as well as the selective reaction of different components of the samples. Results have been obtained for cokes produced from 5 different coals, and the reaction was carried out at two different temperatures (1100°C and 900°C). Micro-CT analysis involves the determination of the size distribution of pores and pore walls, identification of individual IMDC components and finite element analysis to determine measures of strength and gas diffusivity. In this case, we examine how these features of the microstructure change as the CSR reaction progresses, giving us the ability to determine the key elements of the structure that affect its strength as the reaction progresses.

TOWARDS PREDICTION OF COAL CONVERSION BEHAVIOUR IN THE BLAST FURNACE

Author(s): HO, HAI THONG¹
Co-author(s): BABICH, ALEXANDER ¹ ; SENK, DIETER ¹ ; FRANK, JANA ¹

¹ RWTH Aachen University

Pulverised coal injection (PCI) has been commonly established into the blast furnace (BF) operation practice. However due to volatile coal market, blast furnace operators are often forced to change coals used for injection. Handling new coals presents a great challenge. An estimation of their compatibility in the blast furnace process based on chemical analysis alone is often not sufficient. The coal composition may change from mining area and origin. The chemical compounds (proximate and ultimate analyses) are an important indicator for selecting coals
suitable for BF injection. However, these are not the only criteria, which have a significant impact on coals conversion behaviour. Factors such as particle size and size distribution, calorific value, ash fusion temperature, ash composition, maceral composition, porosity/specific surface, pore characteristics, grindability etc. also play an important role. At the Dept. of Ferrous Metallurgy (IEHK) at RWTH Aachen University a method to rank the efficiency of coal conversion in the BF raceway has been developed. It is based on the weighting of the effects of chemical, physical and mechanical properties on PC conversion and not fitted for specific BF operation conditions. Calculations are based on coal characteristics and injection mainly conducted at the IEHK. The results have been collected in a database and were evaluated. Different coal properties, which influence the conversion behaviour, were identified and ranked. The model approach estimates the conversion behaviour of coals under the raceway conditions. This aspect is an important part in evaluating the suitability/compatibility of coals for BF injection.

Ironmaking Fundamentals - Board: 32 / 66

EFFECT OF SILICA ON THE REDUCTION KINETICS OF CaO-Fe2O3-SiO2 SYSTEM

Author(s): DING, CHENGYI
Co-author(s): LV, XUEWEI; XUAN, SENWEI; CHEN, YUN; TANG, KAI

Chongqing University

The CaO-Fe2O3 (CF) system is the most significant binding phase for fluxed sinter, of which the reducibility becomes a vital index having great importance on the evaluation of sinter qualities. SiO2 is the necessary composition of SFC (SiO2-Fe2O3-CaO) generated from CF. Investigation on the isothermal reduction of CaO-Fe2O3 with addition of 2, 4, 8% (mass percent) SiO2 in a continuous stream of 30% CO and 70% N2 at 850, 900 and 950°C was carried out by thermogravimetric analysis (TGA). The results indicate that CF2S and CF4S has little improvement on reduction degree, but activates the reduction with faster rates than CF. The reduction of samples with 8% silica is not only highly accelerated but also proceeds most easily. The rate analysis revealed that reduction of Fe3O4 to FeO and subsequent process from FeO to Fe overlaps for CF reduction whereas Fe2O3 to Fe3O4 and subsequent process from Fe3O4 to Fe overlaps for CF8S reduction. Reduction of CF8S is described by the Avrami-Erofeev equation with two-dimensional shrinking reaction, whereas reduction of CF2S and CF4S are expressed first by the Avrami-Erofeev equation with two-dimensional shrinking core reaction, followed by the two-dimensional phase boundary controlled reaction.

Cokemaking, Operation and Control - Board: 50 / 129

COMMISSIONING OF 60 KG MOVABLE WALL OVEN AT THYSSENKRUPP STEEL EUROPE AG

Author(s): SCHULTEN, MARC-ANDRE
Co-author(s): STISKALA, VIKTOR

Thyssenkrupp Steel Europe AG

Coke plant operators follow numerous coal blending criteria in order to satisfy quality, operational and financial targets of coke production. To meet such specifications the portfolio of coals in use shall not only include prime coking coals but also coals which play an important role in blend performance and cost optimization process. Selection of coals for industrial coke making applications calls for implementation of comprehensive test programs in order to avoid a situation that placing any new coal into a blend would jeopardize the overall blend performance or represent a risk to safe plant operation. To address the issue, thyssenkrupp Steel Europe AG (tkSE), to which Schwelgern coke plant serves as major coke supplier, has recently commissioned a moveable wall test oven, hence accomplishing another significant investment into the company’s future. The coal blend performance parameters such as internal gas pressure and oven wall pressure represent the most valuable outputs of the executed test programs as much as coke cold strength and coke hot strength results do. The paper outlines the steps that have been taken in the efforts to achieve required value in use of a small scale test facility when applying the test results to industrial scale
of Schwelgern coke plant. The paper is not only focusing on performance adjustments of the oven itself but it is also covering implemented modifications in handling of produced coke.

Cokemaking, Operation and Control - Board: 66 / 143

THE NEW GERMAN PAH-REGULATIVE INFLUENCING COKEMAKING AT SCHWELGERN PLANT

LISZIO, PETER

1 KBS Kokereibetriebsgesellschaft Schwelgern GmbH

A new German law, regulating the workers stress by Polycyclic Aromatic Hydrocarbons (PAH), was published in summer 2015. This article will outline the medical considerations that lead to this new regulation in overall and for cokemaking in detail. The author was involved in the working group preparing the new regulations representing the interests of domestic cokemaking industry. All German coking plants started a measuring campaign to determine the actual workers stress at domestic facilities and developed a measure catalogue for reduction effective workers stress. The article will outline some results of this campaign and illustrate the concrete protection measures realized at coking plant Schwelgern in Duisburg.

Cokemaking, Operation and Control - Board: 81 / 146

OPTIMIZATION OF COAL PREPARATION PLANT IN LINZ

ABFALTERER, THOMAS

1 voestalpine Stahl GmbH

The requirements concerning the coke quality for the blast furnaces of voestalpine increased steadily in the past few years. To achieve this improved coke quality, on the one hand side the raw material base had to be changed and on the other hand side the coal pre-treatment and the blend preparation had to be enhanced. Originally the coal preparation plant at the coke oven plant voestalpine was designed in 1940. Although during the years a modern hammer crusher and a separation unit for impurities had been installed, the coal preparation plant was not state of the art anymore. In the course of this project the coal preparation plant was improved to ensure a constant blend quality and thus meet the requirements concerning coke quality of the blast furnace.

Cokemaking, Operation and Control - Board: 119 / 106

CHANGING BULK DENSITY IN CARBONISATION BLENDS

POULTNEY, RUTH

1 MATERIALS PROCESSING INSTITUTE, UK

Bulk density in coal blends is often associated with moisture content. However, moisture is not the only factor affecting charge density. Investigations of single coal and blend crushing and screening, with crushing of oversize only, have demonstrated that the crushing regime affects coal particle size distribution. Oven charge density also benefits from oil addition to coal blends, with some oil types being more effective than others. Optimising particle packing improves charge density in coke ovens and is beneficial because it decreases shrinkage and increases coke strength. Potential packing densities of blends have been assessed by calculating the skewness and kurtosis of the particle size distributions. Research has shown that optimum crushing for top charged blends requires a size distribution with 71-73% <2 mm and 38-40% <0.5 mm, with such blends producing similar coke quality to oiled blends that have undergone standard industrial crushing. The greatest benefits are obtained from optimising both crushing and oiling, which have the potential to improve coke yield and coke quality. Increasing charge density can be used either
to increase coke oven yield or to maintain coke quality when increased proportions of poorer coals are included in cheaper blend formulations. Size distribution, moisture, oiling and blend composition all affect coal blend density.

**Blast Furnace, Operation and Control - Board: 58 / 27**

**CAREFUL CONTROL OF REFRACTORY LINING CONDITIONS ENSURES PROLONGED CAMPAIGN OF BLAST FURNACE**

**Author(s):** VINOGRADOV, EVGENY

**Co-author(s):** KARIMOV, MIKHAIL; DMITRIEV, ALEKSANDR; SOKOLOV, ALEKSANDR; KOSENKOY, YURIY; GORDON, YAKOV; SADRI, AFSHIN; YING, WINNIE

1 Cheromzovets Metallurgical Combine – Severstal
2 Hatch Ltd.

Intensive operation of blast furnace allows increase in production of hot metal and profitability of Iron & Steel Works. However, blast furnace life could be sacrificed if no measures are taken to protect refractory lining and to build stable accretion. CherMK and Hatch developed a systematic approach to monitor conditions of BF hearth lining using Acousto Ultrasonic-Echo (AU-E) non-destructive testing developed by Hatch. Multiple testing of blast furnaces revealed problematic areas with accelerated refractory deterioration and minimal thickness, formation of elephant foot, extent of accretion and speed of refractory wear, cracks and other anomalies. Improvement in coke quality, periodical staves washing, the addition of titania, grouting etc. were recommended and implemented to prolong furnace life while maintaining the intensity of furnace operation.

**Blast Furnace, Operation and Control - Board: 59 / 28**

**ENERGY EFFICIENT TECHNOLOGY TO PRODUCE HOT METAL FROM TITANIA-MAGNETITE ORE**

**Author(s):** ZAGAINOV, SERGEI

**Co-author(s):** FILATOY, SERGEI; FILIPPOV, VALENTIN; GORDON, YAKOV; GILEVA, LARISA; JIMOH, S.; LAZOVICH, ALEXANDER

1 Ural Federal University (URFU)
2 Novo-Lipetsk metallurgical combine
3 Nizhe-Tagilskiy metallurgical combine
4 Hatch Ltd.

The overall carbon rate supplied by coke and supplemental fuels is proposed as the parameter for energy efficiency estimation. The following measures ensure high energy efficient operation of blast furnace, operating with titania-magnetite burden: maximum possible top pressure; optimal slag composition; usage of special fluxes; maximum intensity of blast furnace operation; optimal distribution of ore load at the furnace top; optimization of raw material granulometry; optimal combination of coke, PCI and natural gas injection depending on coke and supplemental fuels qualities. All of these allowed to run NTMK-EVRAZ blast furnaces with overall carbon consumption of 400–410 kg carbon/thm maintaining the specific productivity at 3–3.3 thm/m3/day (working volume) level.

**Blast Furnace, Operation and Control - Board: 60 / 29**

**OPTIMAL DISTRIBUTION OF SUPPLEMENTAL FUEL AND OXYGEN AMONGST FURNACES IN BLAST FURNACE SHOP**

**Author(s):** SPIRIN, NIKOLAI

1
The optimization model of optimal allocation of supplemental fuel and oxygen resources amongst blast furnaces in a blast furnace shop taking into account the change in smelting parameters was developed. This model allows to predict parameters of injected fuel efficiency for individual blast furnace in various technological situations. The model considers the static characteristics describing the influence of changes of melting conditions on overall economic indicators of the furnaces and includes the external and internal limitations on operation of individual blast furnaces and overall blast-furnace shop. Information - modelling optimization system of allocation of natural gas in a blast-furnace shop was developed and implemented. This model includes: input and adjustment of data; calculation module; optimization; output and the analysis of the results. The results of comparative assay of allocation of natural gas on the basis of operating data of the blast-furnace shop of OJSC “Magnitogorsk Iron and Steel Works” with 8 blast furnaces were obtained and implemented. Analysis of the results shows that the optimization model of joint distribution of natural gas and oxygen allows effective usage the available fuel and energy resources, taking into account the technological limitations in the operation of individual furnaces as well as a blast furnace shop in general.

Blast Furnace, Operation and Control - Board: 77 / 30

ADVANCED SIGNAL PROCESSING OF TUYERE PRESSURE DATA TO DETECT REDUCED HOT WIND THROUGHPUT AND RACEWAY BLOCKAGES

Author(s): PUTTINGER, STEFAN
Co-author(s): STOCKER, HUGO; SCHUSTER, ELMAR; LUNGLMAYR, MICHAEL; LANG, OLIVER; KOFLER, IRMELA; PIRKER, STEFAN

The present study deals with the analysis of blast furnace hot wind pressure data representing the wind throughput. In the frequent event of temporary tuyere blockages the flow rates for the affected tuyere section is reduced and is thus recognizable in the pressure signals. In case when the blockages last for a longer time, additional fuel supplies like pulverized coal injection (PCI) must be switched off, to reduce the risk of damage on the tuyere system and blast furnace lining. This is usually implemented in the process control system by using a certain threshold level of the wind throughput. However, as the individual pressure transmitters tend to show a drift in their absolute values due to ageing and other effects, this approach is not able to react properly to all kinds of raceway blockages. This study aims to find a more general approach of pressure signal analysis to provide a more precise detection of abnormal raceway behavior. The automatic signal processing of several hundred hours of blast furnace pressure data, allows to build a statistic and classification of various types of raceway blockage events. To check the significance of detected blockages the signal processing results are compared with tuyere video data.

Blast Furnace, Operation and Control - Board: 85 / 31

THE LONG WAY TO PCI IN LINZ – FIRST OPERATION EXPERIENCE

Author(s): RUMMER, BERNHARD
Co-author(s): THALER, CHRISTOPH; FEILMAYR, CHRISTOPH

1 voestalpine Stahl GmbH
In November 2014 the pulverized coal injection (PCI) at blast furnace A in Linz was started followed by the coal injections into blast furnace 5 and 6 in February 2015. Up to this moment reducing agents like heavy oil, crude tar, coke oven gas, waste plastics and natural gas have been injected into the three blast furnaces (BFs). Due to the limited space around the BFs it was decided to implement the new PCI plant as two separate units. The coal preparation unit for grinding and drying (GAD) and the injection unit located next to the BFs are connected by an intermediate pneumatic conveying (dense phase) of about 1,800 m. In order to minimize the potential risks of a break down in the coal grinding unit and to guarantee the smooth flow of fine coal within the conveying pipes a raw coal preparation plant equipped with crushers, screens, magnetic and non-magnetic separators was installed in front of the coal grinding unit with the aim of removing metals, wood, plastics, etc. After the start up and ramping up the injection rate the optimisation of the injection control system was one of the key challenges.

Keynote - Dr. Yi - Board: 129 / 116

UPDATES ON THE FINEX®, A COMMERCIALLY PROVEN ALTERNATIVE IRON-MAKING PROCESS

YI, SANG-HO¹

¹ POSCO

POSCO launched in 1992 the FINEX® development program in cooperation with Primetals Technologies (formerly VAI) in order to create an alternative ironmaking process to compete with the blast furnace process and operating on low-grade, low-cost raw materials. As indicated in Figure 1, POSCO has been successful in commercialization of the process through a series of scale-up development from a 15 t/day model plant started in 1996 to a 150 t/day pilot plant in 1999 followed by a 0.6 MTPA FINEX® demonstration plant in 2003. Upon successful demonstration of the process, the first commercial FINEX® plant with a capacity of 1.5 MTPA was constructed at Pohang Works and commenced operations in April 2007. Based on the successful results of the first commercial plant, the second commercial plant with a capacity of 2.0 MTPA was built at Pohang Works and the plant has been put into operation since January 2014. Up to now, it has shown noticeable operational results in the aspect of performance, raw material, environment, and energy. They indicate that the process is not completed but can be continuously evolved to be suited to various local conditions. POSCO is poised to make a significant contribution to the global steel industry with an innovative ironmaking technology, FINEX®.

Smelting Reduction - Board: 67 / 99

FINEX® - AN INNOVATIVE AND ENVIRONMENT FRIENDLY IRONMAKING PROCESS

Author(s): SHIBU, JOHN¹
Co-author(s): ÖFNER, HANSPETER¹ ; REIN, NORBERT¹ ; YI, SANG-HO² ; SHIN, SUNGKEE²

¹ Primetals Technologies Austria GmbH
² POSCO Ltd., Seoul, Korea

The steelmaking is based on the use of hot metal and scrap, whereas hot metal is produced by the reduction of iron ores mainly in today’s dominating technology, the blast furnace route. Beside the blast furnace, raw material preparation in the form of coke-making and agglomeration of fine ore in the sintering plant is required. The innovative process concept of FINEX® offers an alternative blast furnace route and produces identical hot metal, however without coke oven and sintering plant. The unique characteristics of the FINEX® Process, its ability to use low-cost raw materials, the competitive production costs and environmental advantages and the well proven plant concept demonstrate that the FINEX® Process can be considered as a competitive alternative to the blast furnace route. Main topics of this presentation are the description of development steps during the design stage of the recently installed Finex® F-2.0M plant, a review of operating results from the FINEX® F-2.0M plant and new technological developments concerning energy efficiency in the FINEX® off-gas.
Smelting Reduction - Board: 68 / 100

COREX® - AN ALTERNATIVE FOR HOT METAL PRODUCTION IN A CHALLENGING ENVIRONMENT

Author(s): BÖHM, CRISTIAN
Co-author(s): STERRER, WOLFGANG; WURM, JOHANN; RAMMER, BARBARA

1 Primetals Technologies Austria GmbH

The COREX® process is beside the FINEX® technology the only industrially realized alternative to the blast furnace route for the production of hot metal. Changes in the raw material sector in respect of decrease in quality, strictly enforced environmental laws, minimization of CO2 emissions and positive operation results of COREX® reference plants make it worth to carefully re-evaluate the COREX® technology in comparison with the traditional ironmaking technology. Integrated Plant concepts based on COREX® offer solutions for future challenges of the iron- and steelmaking industry, which include:

- Economical hot metal production
- Efficient and economic export gas utilization for power, DRI or syngas production
- Lower raw material cost, higher raw material availability
- Environmental friendly high grade steel production

The economic evaluation of different COREX® gas based plant concepts in comparison with the traditional ironmaking technology shows that the COREX® technology is competitive in the challenging iron and steel producing environment.

Smelting Reduction - Board: 93 / 101

THE STUDY OF CORE-BORED TAPHOLE CLAY USED IN FINEX

Author(s): JONG MOON, PARK
Co-author(s): DO MUN, CHOI; YUN JAE, CHOI; JEONG HO, LEE; CHANG HYUNG, LEE

1 CHOSUN REFRACTORIES, Co., Ltd
2 POSCO, Pohang, Korea

Advanced iron-making process, called FINEX, is known as an innovative iron making process which has better cost competitiveness and environment-friendly compared to typical Blast furnace process. FINEX demands high performance taphole clay quality rather than blast furnace due to its high tapping speed and high pressure in the furnace. To satisfy its requirements numerous experiments have been carried out such as raw material improvement and increasing the strength of taphole clay. However, these experimental results have not been consistent with field trial results mostly which lead to many trial errors. Fortunately, we had an opportunity to take core bored sample of taphole clay from the FINEX revamping which has been operated during 18 years since Nov. 1995. From the sample of shut-downed FINEX in July of 2014, we could inspect deterioration, reaction condition, and damage pattern in the hearth. The present paper introduces material improvement test results for FINEX taphole clay which may put an end to previous trial errors.

Cokemaking Fundamentals - Board: 3 / 44

THE EFFECT OF BINARY AND TENARY MINERAL COMBINATIONS ON THE REACTIVITY OF A COKE ANALOGUE

Author(s): LONGBOTTOM, RAYMOND J.
The effect of the mineral matter on the reactivity of a coke analogue was examined through the addition of binary and ternary combinations of magnetite (Fe3O4), troilite (FeS) and quartz (SiO2). The use of coke at a laboratory scale has issues arising from its heterogeneity and complex nature. The coke analogue was developed to help alleviate these issues, being a laboratory tool that has a simplified carbon structure and in which the mineral content, particle size and distribution is largely controlled. The reactivity of the coke analogue with CO2 was measured using a TGA system at 1100°C under conditions similar to that of the CRI test. For binary combinations of magnetite-quartz and troilite-quartz, increasing quartz content (and subsequently decreasing the iron content) was found to decrease the reactivity of the coke analogue. The change in the reactivity of the troilite-magnetite binary system was found not to be simply additive, with combinations of troilite and magnetite giving higher reactivities than would be expected from a simple proportional approach. The ternary magnetite-troilite-quartz system was found to largely follow the trends found in the bounding binary systems.

NEW THEORY OF COAL BLENDING BASED ON NOVEL THERMOPLASTICITY MEASUREMENT; PERMEATION DISTANCE

Author(s): DOHI, YUSUKE
Co-author(s): FUKADA, KIYOSHI; YAMAMOTO, TETSUYA; MATSUI, TAKASHI; SUMI, HIROYUKI; SHIMOYAMA, IZUMI

In this study, a novel measurement method for coal thermoplasticity was developed, where permeation distance of thermally plastic coal into glass beads layer placed on the coal sample was measured. The permeation distance was roughly correlated with MF, however large deviation was observed especially for high fluidity coals. The deviation clearly showed the difference of coke pore structure and strength after carbonization although the differences cannot be detected by conventional Gieseler plastometer method. Therefore, the coal evaluation method and prediction model of coke strength can be upgraded more accurately by integrating the new method into the MOF diagram system. Through the application of new theory, improvement of coke-quality control was achieved at commercial coke plant.

EFFECTS OF BRIQUETTE BLEND ON PACKING STRUCTURE OF FINE COAL PART

Author(s): MASAHIKO, WATANABE
Co-author(s): KUBOTA, YUKIHIRO; UEBO, KAZUYA; NOMURA, SEIJI

Briquette blend coking process (BBCP) is one of the coal pre-treating technologies. In this process, a part of coal charge is briquetted, and the briquettes thus produced are charged into a coke oven chamber with the fine coal. The briquette blend leads to an increase in a coal bulk density in the coke oven chamber, which contributes to the improvement of coke strength. In contrast, there have been several studies that the briquette blend causes a decrease in bulk density of the fine coal part. As the coal bulk density is the main factor to determine coke strength, it is important to clarify the factors which decrease the coal bulk density in the fine coal part.
We proposed a method to evaluate the packing structure of the coal charge which contains the briquettes by X-rays CT device. First, in order to simulate the packing structure of coal charge in a coke oven chamber, blended coal which contains briquettes was fallen into a box (internal dimension: 150 mm square) by free-fall. Successively, we observed the distribution of coal bulk density in the box by X-ray CT device in detail. As a result, we found the low bulk density areas were formed locally around briquettes. Moreover, we proposed the method to measure the width of the low bulk density area by image analysis.

THE EFFECT OF BROWNCOAL ADDITION ON COKE STRENGTH

Author(s): SONG, TENGFEI¹
Co-author(s): ZHANG, JIANLIANG¹ ; WANG, GUANGWEI¹ ; XU, RUNSHENG¹ ; LIU, SIYUAN² ; QIAN, HAITAO²

¹ School of Metallurgical and Ecological Engineering, University of Science and Technology Beijing,
² School of Metallurgical and Ecological Engineering, University of Science and Technology Beijing

The superior coke is one of essential condition for blast furnace stable and anterograde operation. Thus, the goal of the coking process is producing high-quality coke. Under the current situation of the increasingly shortage of coking coal, how to get rid of the dependence on high quality coking coal in the coke making production is a serious problem that iron and steel must be confronted with. In this work, fundamental research was conducted on the possibility of using brown coal as a raw material for coke making in order to achieve the purpose of use of abundant brown coal resources. Experimental result showed that the Drum index decreased with an increase of brown coal addition. Results obtained testified that the higher surface area of coke with brown coal addition caused a decrease in coke strength. In order to attain suitable coke strength, the addition of brown coal should be kept to be low level, which the weight ratio of brown coal was supposed to be less than 6%.

APPLICATION OF SMALL ANGLE NEUTRON SCATTERING TO UNDERSTAND NANOPOROSITY OF COKES

Author(s): SAKUROVS, RICHARD¹
Co-author(s): GRIGORE, MIHAELA ; KOVAL, LUKAS ; SOKOLOVA, ANNA ; REHM, CHRISTINE

¹ CSIRO Energy

The area of the surface of a coke that is accessible to gas is one important predictor of its reactivity. During burnout the surface area of the coke increases, and the rate of this increase differs between cokes. This increase has been attributed to the presence of fine closed pores in cokes that open up on burnout. Although it is certain that such closed pores exist, much is unknown about their nature. For instance, the size distribution of these closed pores and how it varies between cokes has not been previously measured. Small angle neutron scattering (SANS) is a technique that is especially useful for determining the total pore size distributions on the nanoscale size – from 1nm to 1 μm. SANS can also be used to distinguish between pores that are accessible to fluids from those that are not. In this study, six samples of cokes prepared from Australian coals (two cokes prepared in research coke ovens, and inertinite- and vitrinite-rich fractions of two coals coked in a 70 g oven), have been examined using SANS and Ultra Small Angle Neutron Scattering (USANS) to determine their relative pore size distributions and the fraction of pores that are closed as a function of pore size over the size range 1nm to 1 μm. New findings include:

- Nearly all fine (<5nm radius) pores in cokes are closed. For the cokes investigated, the fraction of closed pores increased with decreasing pore size from < 25% at about 1 μm, 50% at 250 nm radius, rising to over 90% closed for pores of less than 5 nm radius.
For cokes made from maceral concentrates, the number of pores in the cokes made from inertinite concentrates was far greater than those from the corresponding vitrinite concentrates, especially around 50 nm. However, the number of pores of <5nm radius was present to an equal extent in both cokes.

The fact that in some cokes even comparatively large pores are closed suggests that some pore closure occurs during the coking process after the volatiles have been released.

**Blast Furnace, Design and Equipment - Board: 124 / 51**

**THE USE OF PLASMA TORCHES IN BLAST FURNACE IRONMAKING**

**Author(s):** SUKRAM, MITREN

**Co-author(s):** PATEL, NISHIT 1; CAMERON, IAN 1; SUBRAMANYAM, VEENA 2; GORODETSKY, ALEX 2

1 Hatch Ltd
2 Alter NRG Corp

Plasma torch technology was studied by several blast furnace developers in the 1970s as a means to reduce coke consumption. The developers planned to use electrical energy rather than blast oxygen enrichment to increase coal injection through the tuyeres. In the early 1980s, development work stopped over concerns with plasma torch electrode life. Since this time, Westinghouse Plasma Corporation improved torch reliability with industrial experience in solid-waste-to-energy facilities, as well as metallurgical applications. With an increasing need to reduce blast furnace greenhouse gas emissions, plasma technology offers an opportunity to lower the coke rate and related carbon dioxide emissions. Alter NRG and Hatch assessed the merits of superheating the hot blast air using plasma torches. Coke rate savings, electrical purchase requirements, CO2 emission rates, and a financial analysis to implement plasma torches are presented.

**Blast Furnace, Design and Equipment - Board: 110 / 50**

**KÜTTNER’S PULVERIZED COAL INJECTION TECHNOLOGY – LATEST DEVELOPMENTS**

**Author(s):** REUFER, FRANZ 1

**Co-author(s):** SCHOTT, ROBIN

1 Küttner GmbH & Co. KG, Germany

In the past 30 years the development of pulverized coal injection technology has been driven by the cost optimization for blast furnace operation. Today blast furnace operators are facing one more very important topic for their hot metal production: CO2 emissions. By further improvement of the injection technologies even in small steps Küttners efforts in this field are significant. An optimized coal injection system can reduce the CO2 emissions and can contribute to save expenditure for CO2 certificates which will more and more put blast furnace operation under pressure in particular in Europe and Germany. Küttner’s long-lasting strategy in the field of injection technology was and is supporting blast furnace operators to sustainably reduce the coke rate by maximizing the amount of injected pulverized coal for the production of hot metal. The report shows what has already been achieved by implementation of various technology steps like dense phase transportation, the reduction of transport and injection gas to a minimum, the OxyCoal technology, preheating of pulverized coal, the use of oxygen in the wind enrichment and the combined injection of pulverized coal and gas. Last but not least, economical aspects by using PCI with regard to the presented optimization steps will be discussed.

**Blast Furnace, Design and Equipment - Board: 138 / 109**

**LONG LIFE COPPER STAVE FOR BLAST FURNACE OF NIPPON STEEL & SUMIKIN ENGINEERING**
GOTO, MAKOTO

1 Nippon Steel & Sumikin Engineering CO., LTD.

Nippon Steel & Sumikin Engineering (NSENGI) has constructed 80 or more Blast Furnaces since 1974. This paper introduces technologies of new type copper stave which NSENGI performed improvement and development continuously. From around 1990, a lot of Blast furnaces have been using copper staves for cooling. Though, quite a few of them have faced with some troubles. They can be roughly divided into two types: wear of working surface and water leakage from the welded portion on the channels. In terms of water leakage, it can be resolved by NSENGI’s staves enabling weld-less structure. On the other hand, in these days more and more troubles of premature wear have been reported from all over the world. In the worst case, the lifetime was only 3 years after starting. As the failure of staves results in significant damage to stably operating, the measure against wear is a very important issue. Thus, NSENGI has put effort into the development of new type copper stave with wear resistant. Since the accretion layer which can be piled up and stuck on the surface often fall off due to operation fluctuation, copper stave should be designed to be prevented from wear even without accretion. Generally, sliding wear speed between two objects depends on “contact force” and “scratching speed”. Therefore, copper stave is assumed to be protected from wear by decreasing above two parameters. NSENGI achieves it by applying the special shape of stave inner surface by utilizing the unique manufacturing method of embedding steel pipes in a copper casting. As results of applying them to actual BF, the assurance of more than 15 years lifetime has been confirmed. The furnace profile is maintained for long time by applying above wear resistance copper stave, and the reduction of running cost with stably operating will be realized.

Blast Furnace, Design and Equipment - Board: 55 / 128

BLAST FURNACEMODERN DESIGN – MODULAR CONSTRUCTION

Author(s): VAN LAAR, REINOUD
Co-author(s): VAN STRAATEN, VICTOR

1 Danieli Corus BV

This paper summarizes the results of a comparison of two modern blast furnace designs. These designs include similar hearth, upper stack and throat armor technologies, but differ on the lining selection for bosh, belly and stack. The first design includes copper plate coolers, graphite and silicon carbide. The second design includes copper stave coolers. Results of a partial reline modular construction case study are described for the first design. This demonstrates the feasibility of reducing shut-down duration for a partial bosh, belly and stack reline to 40 days. A complete reline can be realized within 70 days. This is comparable to the shut-down duration for the second design using copper stave coolers.

Blast Furnace, Design and Equipment - Board: 84 / 47

EQUIPMENT FOR THE INJECTION OF TI-CONTAINING POWDERS INTO THE BLAST FURNACE TUYERES

WOLF, CHRISTIAN

1 Velco GmbH

The injection of powdered Ti-carriers is a proven solution for protecting the refractory in the blast furnace hearth. One strategy is the injection just close to the arisen hot spot. However, for this the existing PCI systems cannot be used. It is required an additional unit with specific safety devices. Using case studies at several customers worldwide, different features and possibilities will be shown. If no Ti-carriers are required, the installation can be used for injecting other materials.
Blast Furnace, Design and Equipment - Board: 94 / 48

BLAST FURNACE COOLING STAVE DESIGN

Author(s): SMITH, MARTIN
Co-author(s): FLETCHER, JEREMY; HARVEY, RICHARD; HORWOOD, ROBERT

1 Primetals Technologies

Critical to any blast furnace campaign is the quality of the cooling system design. Over the many years of blast furnace history, cooling systems have evolved and changed to give an optimum design that provides long campaign life balanced against cost. In recent years, the latest evolution of the cooling system design, in the shape of the copper stave, has been seen as state of the art and an established feature on a large number of furnaces around the world. When first put forward, the copper stave was marketed as the ultimate cooling element since it not only provided a cooling function but also self-protected by forming an accretion layer. More recently, on some furnaces that have copper staves in their design, significant problems have arisen during operation, causing premature failure of the staves and reduced campaign life. This paper will review the evolution of the copper stave design and illustrate the latest techniques being applied by Primetals Technologies in this critical area of blast furnace design.

Blast Furnace, Design and Equipment - Board: 78 / 163

DEVELOPMENT OF REACTION BONDED SiC BRICK WHICH HAVE HIGH THERMAL CONDUCTIVITY FOR BLAST FURNACE

Author(s): HONG, YUN CHEOL
Co-author(s): YUN, SOON IL; KANG, HAE SEONG

1 CHOSUN REFRACTORIES, Co., Ltd.

Recently, the tendency of Blast Furnace type is changing to Cooling Plate type from Stave Type. High thermal conductivity and abrasion resistance is the most important demand characteristics of refractories for the Cooling Plate Type. Therefore, graphite block and SiCBrick are used for shaft installation to take advantage of their excellent thermal conductivity and abrasion resistance of SiC brick. Our development has drastically improved its bonding strength by formation of $\beta$-SiC in its matrix firing under reducing atmosphere with special binding system. As it has over 30 W/m.K (at R.T) of thermal conductivity and over 200 MPa of compressive strength, we want to introduce its mechanism and characteristic.

Cokemaking, Design and Equipment - Board: 35 / 56

DEVELOPMENT OF A VERTICAL CHAMBER COKING OVEN FOR UPGRADING LIGNITES OR SUB-BITUMINOUS COAL

Author(s): SPÖTTLLE, MATTHIAS
Co-author(s): KIM, RONALD; TSCHIRNER, UWE

1 ThyssenKrupp Industrial Solutions AG

The vertical chamber oven is a cooperation of thyssenkrupp Industrial Solutions (tkIS) and the TechnischeUniversitätBergakademie Freiberg (TU BA Freiberg). The project is organized in the way that tkIS is engineering the process and TU BA Freiberg execute all the needed tests in the laboratory especially treatment of raw coal, briquetting, heating regimes and chemical and physical analysis of potential educts and products.

Cokemaking, Design and Equipment - Board: 38 / 58
STUDIES ON MINERALOGICAL AND THERMO-MECHANICAL PROPERTIES OF DENSE SILICA BRICKS FOR COKE OVEN SOLE AND WALL LINING

Author(s): PANDA, B K
Co-author(s): PRASAD, BIRENDRA; SWAIN, S C

1 OCL India Limited

The life of a coke oven is greatly influenced by its design and the quality of brickwork construction and uniformity of physical, chemical and thermo-mechanical properties. Earlier, while selecting the quality of silica bricks, importance were being given to conventional properties like Apparent Porosity, Bulk Density, Cold Crushing Strength, Permanent Linear Change, Refractoriness under Load and Specific Gravity only. Subsequently creep, Reversible Thermal Expansion and Residual Quartz were considered relevant. Different types of silica bricks are required to design various portions of coke oven battery to increase its effectiveness and environmental needs. The Silica refractories used for sole area are normally of dense quality with apparent porosity around 16%. Different methods are adopted during manufacturing of dense bricks, for example high forming pressure and special additives. In this paper studies are being made to correlate the physical & thermo-mechanical properties of dense silica bricks with its behavior towards creep & thermal expansion at different temperatures. RQ content of different bricks are studied for expansion behavior along with microscopic study to trace desired mineralogical phases present; for concluding the best suitable dense silica bricks.

Cokemaking, Design and Equipment - Board: 118 / 60

REFRACTORIES FOR COKE OVEN WALL - OPERATOR’S PERSPECTIVE

Author(s): ANDREEV, KIRILL
Co-author(s): V. WIJNGAARDEN, M.; PUT, P.; TADAION, V.; OERLEMANS, O.

1 Tata Steel Europe

After successful campaign of more than 40 years the walls of the coke plant 2 of Tata IJmuiden are being replaced. Our paper addresses the issues of the selection and sourcing of the refractory materials for the new walls. Material properties formalised in the specification are reviewed. Those are compared with the properties of alternative silica refractories available on the market. Both conventional silica bricks and relatively new fused silica blocks are evaluated. The discussion is based on thermo-physical data obtained in-house and plant experience. It is argued that due to specific lining design and material properties the coke oven wall refractories are not off-the-shelf products that can be sourced on a short notice from any supplier. An extensive pre-order effort is mandatory before the acceptable material and supplier are selected and the order is placed.