European Direct Reduced Iron and Alternative Ironmaking Conference - IRONMASTERS 2020

Wednesday 28 October 2020 - Friday 30 October 2020

Book of Abstracts

Contents

0

CO2 lean reduction of iron ore by use of green methanol

Dr. HARP, Guenter[1]

[1] *Harp Process Chemistry Consulting*

Corresponding Author(s): guenter.harp@harp-online.eu

CO2 lean making of DRI needs normally a combination of natural gas and CCS or green hydrogen as reductant. The properties of methanol makes it an ideal reductant for DRI production. Methanol contains about 12.5 % hydrogen and is after NH3 the best hydrogen storage material. The hydrogen content corresponds to a hydrogen density at a pressure of more than 1000 bar. It is liquid with a boiling temperature of about 65°C, which means that it can be vaporized with hot water. Catalytic steam reforming of methanol lead at about 200°C to conversion in accordance with the following equation: CH3OH +H2O = 3 H2 + CO2 It is an endothermal reaction which can be done at moderate pressure with the assistance of waste heat, which is available within the steel mills process chain. Catalysts for that reaction are the same as for the reverse reaction of hydrogenation of CO2 to methanol. On raising the temperature to about 350°C the methanol is decomposed into H2 and CO in accordance with the following equation: CH3OH = 2 H2 + CO That reaction is catalyzed by a so called high temperature water gas shift catalyst which are based on the element iron. It is also an endothermic reaction with a so called chemical recuperation, which means the transfer of heat into chemical energy. This reaction is predestinated for cooling the hot DRI transferring the methanol into a reducing gas for the pellet reduction in the upper shaft. Liquid methanol is easy transportable, needs low storage volume. Green methanol is made out of biomass or the Power to Liquid (PtL) technology. That should be preferably done in countries with low cost renewable energy based on solar power like e.g. North Africa, the Arabian peninsula, Australia, Chile, or Namibia. A closed CO2 cycle can be built on returning the CO2 from the methanol carbon via known carbon capture and transport as liquid. Based on the production route for green methanol at low electricity price it will be shown that a methanol based reduction of iron ore using the shaft furnace technology is applicable without the need of a hydrogen pipeline and cavern infrastructure, which does not exist in Europe at a sufficient scale.

1

Reduction of Sticking Tendency of Iron Ore Pellets by Using Steel By-product as Coating Material

Prof. SADDIK, Mohamed[1]

[1] *SABIC*

Corresponding Author(s): saddikmb@sabic.com

One of the challenges facing steel producers that rely on direct reduction technologies is the sticking tendency of iron ore pellets, which might lead to disrupting operational procedures. In an effort to reduce the sticking tendency of iron ore pellets, suppliers apply inactive coating materials and steel producers apply an additional coating in the form of slurry prior to charging pellets to the furnace.
In this work, the suitability of steel plant's by-products to be used as a secondary coating material is investigated. In order to determine the optimum coating conditions, their influence on pellets reducibility and sticking index was quantified. The coating condition in question includes dosage amount and slurry concentration of the coating material. Coating amounts were varied in the range of 1-5 kg per ton of ore and slurry concentrations were varied in the range of 5-30% in this study. Thermogravimetric analysis was used to measure the relative reducibility of the pellets under different coating conditions. The reduction conditions were set to simulate reduction temperature and reducing gas composition in Midrex shaft furnace. The samples that exhibited higher reducibility were those at coating condition of:
• 20% slurry conc. & 3.0 Kg /ton iron ore
• 30% slurry conc. & 3.0 Kg /ton iron ore
• 30% slurry conc. & 4.0 Kg /ton iron ore

Sticking index measurements were determined according to ISO 11256 for these samples that showed relatively higher reducibility. Since the samples showed similar sticking index values, an additional optimization analysis in terms of operational cost was carried out. It was concluded that the coating conditions with optimum reducibility and adequate sticking resistance are 3.0 kg per ton of ore and 30% slurry concentration.

2

Thermo-electric model for EAF using DRI as Charge:

Mr. SEEMON, ANILKUMAR[1] ; Mr. RICHHARIA, BIPIN[1] ; Mr. FERNANDEZ, JUAN RAMON[1] ; Mr. SHUKLA, NEERAJ[1]

[1] *HEG LIMITED*

Corresponding Author(s): anil.seemon@lnjbhilwara.com

An Optimization model for mass and energy balance has been developed including all the metallurgical and electrical variable parameters influencing the EAF using DRI as charge. Energy required for melting a DRI based charge is dependent on the type of DRI i.e Coal based or Gas based. It also depends on the Metallization along with the Carbon %, gangue and FeO content. During melting of DRI, energy is also consumed for melting the fluxes, heat losses in the flue gases, losses in electrical circuits, cooling panels, etc.
A lot of work has been done in research to provide the optimum mass and energy balance.
This work is further enhancing the optimum energy balance calculations by considering those variables which were difficult to be incorporated in the earlier models due to the complexity involved. This model makes use of off-gas measurement (ratio of CO/CO2 and the temperature) The result of this model will provide EAF Operator the optimum electrical power input (by controlling the Tap/Curve combination) & chemical energy input (by controlling the Oxygen & Carbon flow rate) at different stages of melting by considering the critical factors like power factor, basicity, CO formation, Carbon required, de-carburization rate at respective stages of melting.
This model significantly helps in estimating the energy consumed for a given metallic charge as well as for the optimization of raw materials, electrical energy, production time, refractory life and thereby the production costs.

3

Application of biomass fuel in iron ore sintering

Author(s): Dr. KIEUSH, Lina[1]
Co-author(s): Dr. KOVERIA, Andrii [2] ; Dr. BOYKO, Maksym [1] ; Mr. ZHU, Zuoqiao [3]

[1] *National Metallurgical Academy of Ukraine*

[2] *Dnipro University of Technology*

[3] *Tohoku University*

Corresponding Author(s): linakeush@gmail.com

In metallurgy, it is essential to obtain and use high quality fuel and reducing agents with low environmental impact. The use of biomaterials as a fuel might help to solve technological and environmental issues of sinter production. Biomass has enormous renewable carbon potential and CO2 neutrality. The main advantages of biomass are the low mineral composition and almost complete absence of sulphur, and the disadvantages are low bulk density, high moisture and volatile matter yield, high oxygen content, alkaline earth metals and relatively low carbon content. The biomass disadvantages as a fuel can be effectively eliminated through its use in compressed form. This will increase the bulk density of the material, give it the necessary size and mechanical strength. An even greater effect of improving the biomass properties as fuel is achieved after its preliminary carbonization. As a result of biomass pyrolysis, the amount of carbon increases, the content of oxygen and nitrogen decreases.

In this study, we investigate the use of some raw and pyrolysis-processed biomass pellet types, for iron ore sintering. As a alternative fuels used commercial pellets of sunflower husk (SFH), conifer wood, wheat straw, and walnut shell. The pyrolysis temperature was set to 673, 873, 1073, and 1273 K, and the proportion of biomass in the fuel composition was set to 25%
For all the test runs of sintering, the composition of the blend was the same, the changes were made only for the biofuel type. It was established that the addition of biofuels to the sintering blend leads to the increase in the gas permeability of the sintered layer. The analysis of the complex characteristics of the sintering process and the resultant sinter showed that the use of wood and SFH pellets leads to the production of sinter with sufficient strength characteristics. Good sintering process and product results were achieved when the sintering blend had a 25% composition of wood or SFH pellets pyrolyzed at 1073 and 873 K, respectively.

4

The changing role of Ironmaking in the Transition to the Hydrogen Economy

Dr. CHEVRIER, Vincent[1]

[1] *Midrex Technologies, Inc.*

Corresponding Author(s): gullrich@midrex.com

The steel sector is one of the largest industrial sources of global CO2 emissions. The mitigation of CO2 emissions is becoming critical in many countries for environmental and taxation reasons. While the natural gas-based MIDREX® Process paired with an electric arc furnace (EAF) has the lowest CO2 emissions of any steelmaking route, there is room to further decrease emissions using hydrogen as a fuel and chemical reactant. The best possibility for significantly reducing CO2 footprint in the future is to use "green" hydrogen as the energy source and reductant to produce DRI/HBI, which can be used as feedstock for steelmaking. This flow sheet concept is known as MIDREX H2TM. The supporting process details, calculations and experimental results that lead to this innovative process will be presented. Unfortunately, hydrogen is not currently available at a sufficient scale and a low cost for rapid adoption. This paper will review the required steps in the transition to (near) carbon-free ironmaking as well as the major technical and economic challenges. As "green" hydrogen becomes available and cost effective, the MIDREX Process can be converted to MIDREX H2 in stages, allowing steelmakers to take advantage of CO2 reduction immediately and further reduce emissions in the future without major capital expenditure.

5

Electrometallurgical steelmaking by Molten Oxide Electrolysis

Dr. FLEISCHANDERL, Alexander[1] ; Mr. KUEHAS, Thomas[1] ; Dr. RAUWERDINK, Adam[2] ; Dr. BRADSHAW, Rich[2]

[1] *Primetals Technologies Austria GmbH*

[2] *Boston Metal*

Corresponding Author(s): thomas.kuehas@primetals.com

To achieve the ambitious goal set by the Paris Climate Action members for CO2 reduction to achieve minimum 80% emission reduction by latest 2050, radical changes to current production technologies for iron and steel are required. More and more governments worldwide demand carbon-neutral production routes for the heavy industries.
One of the visionary innovations is based on the unique and carbon-free direct steelmaking with Molten Oxide Electrolysis (MOE) which is under development by Boston Metal in cooperation with Primetals Technologies. Ultimate target of the MOE process is to reduce the fed iron oxide by "green" electrons instead utilizing carbon-based fuels. MOE utilizes a DC powered electrolysis cell with an inert anode/cathode system. The only products from the process are liquid metal and the by-products electrolyte (slag) and oxygen.
The paper describes the process of the MOE technology, the current development status and an outlook to first industrial demonstrations.

6

Enhancing integrated steel plant strategic planning - a status update for the m.simtop process integration platform

Author(s): Dr. WEISS, Bernd[1]
Co-author(s): Dr. WUKOVITS, Walter [2] ; Mr. NIEL, Johannes [2]

[1] *Primetals Technologies GmbH*

[2] *TU Vienna*

Corresponding Author(s): bernd.weiss@primetals.com

Iron and steel making requires a wide range of different raw materials significantly influencing process performance which demands a continuous optimisation of process routes also with respect to energy efficiency as well as environmental emissions. Steadily changing raw material prices and qualities, market situations and product variations are challenging integrated steel plant operators in production planning and cost optimization. Primetals decided to develop a comprehensive metallurgical flow sheet model library for simulation and optimization 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. In this publication an insight will be given on the competence of mSIMTOP in depicting integrated steel plant operation, enhance raw material planning, show the effect of new raw materials and new internal recycles on realistic examples.

7

Evaluation of CO2-free Production of DRI by Hydrogen and by Ammonia

Prof. HÖLLING, Marc[1]

[1] *HAW Hamburg*

Corresponding Author(s): marc.hoelling@haw-hamburg.de

The steel industry, especially in Europe, is under strong pressure to reduce its CO_2-emissions to fulfill the required climate protection goals. Even a change from the BF/BOF-route to the DRI/EAF-route is not sufficient, if the DRI-production is still based on natural gas. Thus, hydrogen-based reduction is under strong investigation and first pilot projects will be installed. However, hydrogen shows some disadvantages in terms of volumetric energy density. High pressure and volumes are required to store hydrogen for the continuous production of DRI. An alternative reduction agent could be ammonia, which is also CO_2-free, if it is produced by renewable energy. Ammonia shows a much higher energy density, since it can easily be liquified.
In this study, the reduction of iron ore by means of hydrogen and by means of ammonia are investigated. A possible process layout is given for both processes. Process paramters like temperatures, compositions and energy consumption will be determined by the process simulation tool DWSIM.

8

Deactivation of Direct Reduced Iron Using Organic Coating Agents

Author(s): Mr. ALZAYER, Mohammed[1]
Co-author(s): Prof. AHMED, Mohamed [2] ; Mr. ALHARBI, Abdulrahman [1]

[1] *HADEED SABIC*

[2] *SABIC*

Corresponding Author(s): zayeraa@hadeed.sabic.com

One of the challenges faced by steel producers employing direct reduction technology is the deterioration of DRI metallization before being charged into the electric arc furnace (EAF) negatively affecting the metallic yield of produced heats.
The present study considers organic materials that might have the ability to “deactivate” DRI if used as coating agents. These include silicone oil, glycerin, and mineral oil. Each of these materials was evaluated for suitability in terms of chemical and physical properties that might affect the performance and safety when used as DRI coating agents. Parameters affecting oxidizing behavior were varied, including concentration, temperature, and exposure time. Metallization and chemical composition of the coated and uncoated samples were monitored in order to evaluate the effectiveness of the coating agents.
With a slight variation of effectiveness among the different materials, the results proved that such materials have a positive effect if used at high concentration and if DRI faced more severe oxidizing conditions.

9

Progress of non-blast furnace iron-making technologies in China

Author(s): Prof. BAI, Chenguang[1]
Co-author(s): Prof. ZHANG, Shengfu [1] ; Dr. YU, Wenzhou [1] ; Dr. YOU, Zhixiong [1] ; Prof. WEN, Liangying [1]

[1] *Chongqing University*

Corresponding Author(s): yuwenzhoucd@cqu.edu.cn

Non-blast furnace iron-making technology is one of the advanced emerging routes for the development of iron and steel industry. At present time, although the conventional blast furnace process is still the dominant route for the pig iron production in China, but it is also facing the unprecedented pressure of environmental protection, energy conservation, and shortage of raw materials. The different of non-blast furnace iron-making processes have been developed continuously in China for recent years since the society is encouraging the industry to become more green and environmental friendly. Up to now, there are at least two kinds of non-blast furnace iron-making technologies, e.g. Corex and HIsmelt, that have been industrialized successfully and operated well. Additionally, the flash iron-making process, in which the iron ore concentrate is flash reduced by gaseous reductants at temperature above 1423 K, has attracted extensive attentions from the scientists and industry. Obviously, the rapid development of non-blast furnace iron-making processes can help the iron and steel industry to realize the low carbon economy and reduce the emission of greenhouse gases. However there should be a lot of difficulties for its further development. This presentation is just focused on the technique process, equipment innovation, and operation situation of some typical non-blast furnace iron-making technologies in China. Furthermore, a comprehensive comparison of these processes with the conventional blast furnace iron-making was carried out, which can help to further predict the development tendency of these processes.

10

OXYFINES technique for upgrading zinc containing blast furnace sludge

Author(s): Ms. LUNDKVIST, Katarina[1]
Co-author(s): Ms. ROSENDAHL, Sara [1] ; Mr. NYMAN, Fredrik [2] ; Mr. BÖLKE, Kristofer [2] ; Mr. GUSTAVSSON, Lennart [3] ; Ms. WEDHOLM, Anita [4] ; Mr. SÖDERSTRÖM, Daniel [4]

[1] *SWERIM*

[2] *AGA Linde*

[3] *SSAB Europe*

[4] *SSAB Merox*

Corresponding Author(s): katarina.lundkvist@swerim.se

In the Swedish steel industry, much work is put on further increasing the recycling of in plant residual materials, thereby making use of valuable contents and minimising the landfilled amounts. In Swedish ore-based iron production, i.e. SSAB steel plants, roughly 20,000 tonnes of blast furnace sludge (dry weight) is generated annually in the off-gas treatment system. Despite valuable contents in the blast furnace sludge, such as iron (ca. 35%) and coal (ca. 25%), it is currently deposited due to its zinc content and concerns regarding the allowed blast furnace zinc-load.
AGA Linde has developed the OXYFINES technique which is suitable for upgrading zinc containing fine particulate materials, i.e. dust and sludge, thereby generating usable products. The material is fed to an Oxyfuel burner whereby its zinc content is evaporated to a zinc rich dust, intended as a raw material in zinc production, and the non-gasifiable contents, such as iron, forms a zinc free product for utilisation as a raw material in the steel production. The technique is relatively flexible, simple and cost-effective and has been shown to have a high degree of zinc separation and for which sludge pre-treatment, such as drying, is not required.
Pilot set-up and trials using the OXYFINES technique were performed at Swerim's research facility during the year of 2019. In the trials the effects from altering different process parameters were tested and analysed to develop an optimised concept for upgrading the blast furnace sludge. The pilot trials' results showed the required process settings to attain a high degree of zinc separation from the sludge, and to generate an iron oxide product, with ideal characteristics for straightforward charging to the steel production processes, i.e. blast furnace or basic oxygen converter.

11

COURSE50: Innovative ironmaking process project using hydrogen

Dr. SAITO, Koji[1]

[1] *Nippon Steel Corporation*

Corresponding Author(s): saito.5m5.koji@jp.nipponsteel.com

Since 2008,four Japanese blast furnace steelmakers and one engineering company have been working on an innovative ironmaking process using hydrogen. The main research activities of the project consist of two parts. One is the development of hydrogen utilization technology for iron ore reduction using coke oven gas that contains a large amount of hydrogen. The other is the development of CO2 capture technology from blast furnace gas with energy saving. By using these major technologies, the project aims to cut CO2 emissions from steelworks by 30%. The project has successfully completed STEP1(2008-2012), the development of basic technologies and STEP2(2013-2017), the development of comprehensive technologies. As a result, the carbon consumption in the blast furnace was reduced by 10% by the developed reaction-controlling technology. We also developed high-performance chemical absorption and physical adsorption methods to reduce 20% of CO2 emitted from steel works.

12

Calibration of discrete element method parameters for modelling DRI pellets flow

Author(s): Mr. MADADI NAJAFABADI, A. Hossein[1]
Co-author(s): Prof. MASOMI, Abolfazl [2]

[1] *Mobarakeh Steel Company*

[2] *University of Tehran*

Corresponding Author(s): a.madadi@msc.ir

DRI pellets vulnerability to successive collisions and the fine generation is a major concern of iron making industries. During the DR process, transportation, and buffer storage, DRI pellets are subjected to successive pellet-pellet and pellet-wall collisions. Depending on the impact conditions

(i.e., angle, velocity, and force) and the characteristics of the pellets, various kinds of mechanical damages (attrition, fragmentation or abrasion) may occur to the pellets. Application of the numerical, analytical, and experimental methods for analysis of DRIs abrasive damage would result in the improvement of transportation and storage systems in the iron making plans. Such improvements would decrease DRIs mass loss and fine generation during DRIs handling from DR plant to electric arc furnaces. From the analytical or experimental analyses, some predictive models for DRIs damages are obtainable. Such models estimate the extent of damage as a function of material characteristics (e.g., hardness, fracture toughness, and mass-specific energy) and collisions parameters (e.g., energy, force, and velocity). The collisions parameters are obtained by simulation approaches such as the discrete element method (DEM). DEM is one of the most powerful methods for simulation of granular materials such as iron ore pellets and DRIs. This approach is capable of accurately calculating the parameters of particle-particle and particle-wall collisions. However, the accuracy of DEM results depends directly on the precision of the material parameters, which are set as the input variables of DEM simulation. To achieve reliable results in a discrete element method (DEM) simulation, it is necessary to adjust precisely the characteristics and properties of granules. The main properties for DEM simulation are size distribution, density, Young's modulus, Poisson's ratio, and the contact coefficients including restitution, rolling friction, and sliding friction. In the present study, these properties are determined for DEM simulation of direct reduced iron (DRI) pellets. A reliable DEM simulation would contribute to optimizing the handling system of DRI pellets in an iron-making plant. Among the mentioned properties, Young's modulus is the most important parameter, which is usually hard to get for particulate solids. Here, a special method is utilized to precisely determine this parameter for DRI. Finally the determined parameters are experimentally validated using a set of tumbler tests.

13

Bahavior of magnetite based ores during hydrogen-induced fluidized bed reduction

Author(s): Mr. SPREITZER, Daniel[1]
Co-author(s): Mr. ZHENG, Heng [2] ; Prof. SCHENK, Johannes [2]

[1] *Montanuniversitaet Leoben / Chair of Ferrous Metallurgy*

[2] *Montanuniversitaet Leoben*

Corresponding Author(s): daniel.spreitzer@unileoben.ac.at

Hydrogen based direct reduction by the means of fluidized bed technology is one possibility for sustainable ironmaking in the future. On the one hand, the exclusive use of hydrogen as a reducing agent allows an almost CO2 free reduction procedure; on the other hand, iron ore fines can be used directly without a prior agglomeration step. Because of the endothermal character of hydrogen-based reduction reactions, the iron ore has to be preheated to demanded reduction temperature in advance. Thus, a use of magnetite based ores would be beneficial because the heat provided by the exothermic oxidation reaction of Fe3O4 to Fe2O3 could be used during preheating and would lower therefore the primary energy demand. During fluidized bed reduction, magnetite based ores show a high sticking tendency. In this study, a concept is presented to avoid the sticking of the particles during the reduction procedure at reduction temperatures up to 800°C. Therefore the effects of prior oxidation, as well as the role of additives on the fluidization behavior and reducibility, are discussed.

14

HYFOR – A breakthrough technology on the road to zero carbon steelmaking

Author(s): Mr. OFNER, Hanspeter[1] ; Mr. WOLFINGER, Thomas[2] ; Mr. REIN, Norbert[1]
Co-author(s): Mr. HIEBL, Bernhard [1] ; Mr. ROTHBERGER, Johannes [1]

[1] *Primetals Technologies Austria*

[2] *K1-MET GmbH*

Corresponding Author(s): hanspeter.ofner@primetals.com

Due to the increasing amount of CO2 in the atmosphere and the associated climate change new technologies for reducing CO2 emissions in iron making processes are inevitable. Therefore, the steel industry is pushed to make further progress towards higher energy and resource efficiency as well as environmental protection. Under these boundary conditions the HYFOR technology is being developed by Primetals Technologies. HYFOR is a direct reduction process based on fluidized bed technology using hydrogen as reducing agent. The feed material is iron ore concentrate directly from the beneficiation process with a grain size in the range of a conventional pellet feed. Therefore, no agglomeration step (e.g. pelletizing) is required, which means high overall process efficiency and low operation costs. As a result of the usage of hydrogen (generated from renewable energies or natural gas as an intermediate step towards CO2 lean steelmaking) and the avoidance of the agglomeration step a saving of resources as well as a reduction of related CO2 emission is accomplished. Prior research activities with various lab scale fluidized bed reactors at the Chair of Ferrous Metallurgy, Montanuniversitaet Leoben, showed the proof-of-principle of the HYFOR process. The currently developed Hot Bench Scale plant is being built at voestalpine Donawitz to verify the technical feasibility of the HYFOR process and bridge the gap between laboratory scale and industrial scale plant. The HYFOR technology is a solution for the industrial de-carbonization path for iron- and steelmaking in line with the strategy of the EU and allowing at the same time lowest operation cost of the DR/EAF steelmaking route. By using hydrogen and energy generated mainly from renewables, it is possible to achieve the guidelines of the EU Roadmap 2050 to reduce the CO2 emissions by 80 % between 2005 and 2050 with the new HYFOR process.

15

MODERNIZATION OF DRI SHAFT FURNACES TO ENHANCE PROCESS PERFORMANCE AND IMPROVE PRODUCT QUALITY

Dr. GORDON, Yakov[1]

[1] *HATCH*

Corresponding Author(s): iakov.gordon@hatch.com

Gas dynamics and gas distribution in cross-section of shaft furnace play crucial role in increase of furnace productivity, reduction in natural gas rate and DRI quality improvement. Optimum design parameters of gas distribution devises were investigated by means of mathematical modelling, pilot plant and industrial installation studies. New heat transfer co-current schematics of gas and material movement with self-reforming of natural gas in metallization zone, was invented, patented and tested at pilot plant. New Shaft furnace design and improvements where proposed and some new gas distribution devises implemented for shaft furnaces, providing savings in fuel rate, increase in productivity and improvements in quality of DRI.

16

Rising and Failure of Gas Based Direct Reduction Processes

Dr. GORDON, Yakov[1]

[1] *Technical Dkirector, Ironmaking, Hatch*

Corresponding Author(s): iakov.gordon@hatch.com

Beginning of development of gas based direct reduction processes goes back to the end of 19 century. The first industrial application was Wiberg-Soderfors DRI shaft furnace process. The history of development and implementation of various gas based direct reduction processes was studied. The strength and week features of this processes were evaluated. It was shown that economics of the direct reduction process depends on cost of raw material and reducing agent, reliability of equipment and strict application of direct reduction principles. Deviation from these main principles leads to the failure of the new DRI technologies. Results of evaluation allowed to show, why Midrex and HYL are the only successful DRI gas-based processes, while other lost their competitive position and stop operation.

19

AN investigation of equipment fracture and repair in PG Saba Steel HBI plant

Author(s): Mr. TAVALLAI, Hamidreza[1]
Co-author(s): Mr. HASANVANDI, Mohammad [1]

[1] *Persian Gulf Saba Steel*

Corresponding Author(s): htavallai@gmail.com

Saba steel HBI plant, stated in 2018, has faced some uneven problems in plant operation since start up in 2018. The problems recognized to so that requires very careful investigation and study. We in our presentation will show the audience how we have analyzed two of main problems that could be said to be a real HAZOP study. The investigation includes the problem description narratively and photographically, laboratory and metallography results along with interpretation, the repairing procedure and countermeasures to avoid repeating of the same. In conclusion we will find the root cause of the phenomenon discovering the best corrective action to make the process unerring as far as the fracture in the kind is concerned.

20

Environmental upgrades for direct reduction plants (Gas cleaning, Energy efficiency, by-product utilization)

Author(s): Dr. STEINPARZER, Thomas[1]
Co-author(s): Mr. STEINWANDTER, Andreas [2] ; Mr. MILLNER, Robert [3] ; Dr. FLEISCHANDERL, Alexander [3]

[1] *Primetals Technologies Austria*

[2] *Primetals Technology Austria GmbH*

[3] *Primetals Technologies Austria GmbH*

Corresponding Author(s): thomas.steinparzer@primetals.com

Direct reduction technologies move more and more into the spotlight due to their significant reduction of carbon dioxide emissions compared with other ironmaking technologies. This fact as well as their suitability for upgrading to hydrogen based ironmaking routes make direct reduction technologies a corner stone for future sustainable steelmaking business. Even though considering their advantages in terms of carbon dioxide emissions, direct reduction plants have also to comply with the most stringent environmental regulations set by national and local governments. It can be also expected the current environmental requirements will even increase over the next few years.
Within this paper environmental and energy efficiency solutions to upgrade existing gas based direct reduction facilities will be presented. A new dry dedusting system based ceramic filter elements for bottom seal gas as well as waste heat recovery boiler for top gas to increase energy efficiency will be described. In addition to gas treatment and waste heat recovery, by-product recycling resp. utilization solutions like briquetting of dust and sludge including economic feasibility will be given in the paper.
A further possibility to reduce carbon dioxide emissions by a biochemical conversion process will be presented within this paper.

21

4 years of HBI Production at voestalpine Texas LLC

Mr. SCHWARZ, Helmut[1]

[1] *voestalpine Texas LLC*

Corresponding Author(s): matthias.pastl@voestalpine.com

Since hot commissioning in the fall of 2016, voestalpine Texas LLC has been producing high quality Hot Briquetted Iron (HBI) for both internal and external use. The following paper provides a review of the major technical features of the 2 million tons per year HBI plant inclusive of raw materials unloading and handling, iron ore reduction and gas reforming, water treatment and the handling and load-out of HBI. The paper also includes a review of performance of the plant through the commissioning, ramp-up and optimization phases of operation. The past and on-going activities for plant and process optimization are also discussed.

22

Effect of carbon concentration in molten metallic iron on slag-metal separation temperature

Author(s): Prof. OHNO, Ko-ichiro[1]
Co-author(s): Prof. NATSUI, Shungo [2] ; Prof. SUKENAGA, Sohei [2] ; Prof. MAEDA, Takayuki [1] ; Prof. KUNITOMO, Kazuya [1]

[1] *Kyushu University*

[2] *Tohoku University*

Corresponding Author(s): ohno@zaiko.kyushu-u.ac.jp

Toward to "Zero carbon emission" from steel industry, suppression of greenhouse gas emission from ironmaking process should be one of the most important issue. Although one of the promising technologies is hydrogen ironmaking, produced iron should be melted for refining process. Especially, slag-metal separation is necessary for purification. From this point of view, a certain amount of carbon should be necessary to smooth the separation. In order to estimate minimum necessary carbon for slag metal separation, iron-carbon-slag mixture melting and separating behavior was investigate with in-situ observation technique using laser microscope with infrared furnace. The mixture, different kinds of slag compositions were adopted to change their physical properties; melting temperature, viscosity, surface tension, etc. And also, mixing carbon ratios in the mixture were varied to change carbon concentration in metallic part. Following results were obtained. The metal-slag separation behavior was dominated largely by agglomeration behavior of liquid phase of iron. Residual of solid iron phase and/or solid slag phase basically prevent the separation behavior. In other words, the separation surely occurs when both phases of iron and slag change to liquid phase of them. However, the separation can also occur even if a small amount of solid phase still remains in the mixture.

23

Measurement and simulation development of temperature change in molten steel by oxygen blowing and Al-dross addition

Author(s): Mr. KIM, Gyu Wan[1]
Co-author(s): Prof. KIM, Sun Joong [1]

[1] *Chosun University*

Corresponding Author(s): aotmzm0915@gmail.com

The reduction of CO2 emission is one of important issue for the sustainable production of steel in EAF(Electric Arc Furnace). The way to decrease CO2 emissions can be achieved by reducing the use of electrical energy, and by increasing the use of chemical energy without carbon based materials. In general, the chemical energy of EAF can be improved by the heats of oxidation reaction and the carbon combustion. However, by adding carbon based materials into the molten steel, carbon is not dissolved completely due to its high melting points, and floated to the slag layer due to low density. On the other hand, Al dross is a by-products of Al smelting process and it includes 20˜30 mass% of metallic aluminium. The oxidation reaction heat of aluminium in Al-dross is three times higher than that of carbon. In the prior study, the dissolution behaviour of carbon and aluminium in a fuel mixture of coke and Al-dross were measured. The influence of mixing ratio of coke and Al-dross on the dissolution rate constants of carbon and aluminium in molten steel was reported. In this study, the optimized mixing ratio of coke and Al-dross was calculated by the oxidation reaction heat and the formation of Al2O3 in slag. After dissolution of

oxidation materials with optimized ratio, the temperature changes in molten steel was measured with oxygen blowing and simulated by the coupled reaction model.

24

MIDREX H2 - The Road to CO2-free Direct Reduction

Author(s): Mr. MILLNER, Robert[1]
Co-author(s): Mr. ROTHBERGER, Johannes [2] ; Mr. OFNER, Hanspeter [1] ; Dr. RAMMER, Barbara [1] ; Dr. CHEVRIER, Vincent [3]

[1] *Primetals Technologies Austria GmbH*

[2] *Primetals Technologies*

[3] *Midrex Technologies Inc.*

Corresponding Author(s): robert.millner@primetals.com

Since the iron and steel industry is responsible for a portion of 7-10The leading industrial process for shaft based direct reduction is the Midrex process with a market share of more than 80This paper describes the flexible Midrex H2 plant configuration for 30An overview about currently ongoing H2 plant projects based on Midrex shaft furnace technology will be given. Furthermore, a feasibility and case study of a DR plant operation based on H2 will be presented. The advantages of implementation of PEM technology are summarized; e.g. additional DRI/HBI production can be achieved at existing or new Midrex direct reduction plants from H2 and O2 produced by electrolysis. For all plant configurations the CO2 emission rates for different H2 substitution ratios from 100The outcome shows that Midrex H2 will be play an important role in the transition scenario towards CO2-free steel making. Authors: Robert Millner*, Johannes Rothberger*, Hanspeter Ofner*, Barbara Rammer*, Vincent Chevrier* **Primetals Technologies Austria GmbH, Linz, Austria** Midrex Technologies Inc., Charlotte, USA

25

Effect of Sulfur and its Form on Carburization and Melting of Carbon– Iron Ore Composite

Author(s): Dr. MURAKAMI, TAICHI[1]
Co-author(s): Prof. KASAI, EIKI [1] ; Dr. MARUOKA, DAISUKE [1]

[1] *Tohoku University*

Corresponding Author(s): taichi@material.tohoku.ac.jp

Many researches on the reduction of carbon-iron ore composite have been reported to decrease carbon dioxide emission from ironmaking process. There are many types of carbonaceous materials such as coke, dust, coal, and biomass char. Some of them have a certain amount of sulfur which affects the reduction behavior. In this study, effect of sulfur contents, its form, and CaO addition on the carburization and melting of reduced iron of carbon-iron ore composite was evaluated. Carbon content in the reduced iron decreases with increasing sulfur content because the direct contact of carbon to reduced iron through molten slag prevents by decreasing surface tension of slag due to increasing sulfur content in slag. The inhibiting effect of sulfur added by FeS is stronger than that by elemental sulfur to the composite. There is optimum amount of CaO addition to promote the carburization and melting.

26

Development and Successful Evaluation of an Atmosphere-Controlled Furnace for Direct-Reduction Feedstock Studies

Author(s): Dr. NISPEL, Michael[1]
Co-author(s): Mr. SOUCHON, Bryan [1] ; Dr. FIRSBACH, Felix [1]

[1] *Lhoist S.A.*

Corresponding Author(s): michael.nispel@lhoist.com

A novel atmosphere-controlled furnace was successfully developed by Lhoist, which allows the company to take active part in the process transformations of iron and steel making towards a CO2 emission free industry. This furnace is designed to perform qualitative metallurgical research on e.g. reduction behaviors of iron ore feedstocks in controlled mixed-gas atmospheres (CO, CO2, H2, N2, O2, CH4, SOx) until 1000 °C. Despite currently available furnaces, the Lhoist Vario Furnace is additionally designed to fit with three conditions: 1) reduced amount of material per metallurgical test needed, 2) different metallurgical tests available with the same furnace, 3) simulation of different environments such as direct-reduction or blast furnace. The development of the Lhoist Vario Furnace experimental setup and the optimization of internal gas flows will be described as well as the process of adaptation for certain metallurgical tests: e.g. reducibility, swelling, reduction-disintegration. These tests have been performed on two types of industrial pellets. The degree of reduction (RD) for these two types of pellets was determined to be (66.1±0.5)% and (50.9±0.4)% respectively. This experimental setup allows Lhoist to conduct comparative metallurgical studies of iron ore feedstocks e.g. pellets for direct-reduction and blast furnaces.

27

Hydrogen Plasma Smelting Reduction of Iron Ore - Are we on the verge to future Green Steel production?

Author(s): Mr. ZARL, Michael Andreas[1]
Co-author(s): Prof. SCHENK, Johannes [2]

[1] *Montanuniversität Leoben / Chair of Ferrous Metallurgy*

[2] *Montanuniversitaet Leoben*

Corresponding Author(s): michael-andreas.zarl@unileoben.ac.at

The steel industry contributes with around 6% to the worldwide anthropogenic emissions of CO2. Therefore, it is clear that new ways of steel production need to be investigated. One promising technology is the so-called Hydrogen Plasma Smelting Reduction (HPSR), which not only produces steel without the usage of fossil fuels but also is a one-step process from iron ore towards steel. In this, study the circumstances of steel production in Europe and the current state of development of the HPSR process are shown. Aside also, the basic concept and the thermodynamics and kinetics are shortly explained. Furthermore, some detailed information about the field of upscaling research in connection to the arc geometry of the plasma is presented.

28

Investigation of the Effect of Varied Oxygen Content on the Oxidation of an Iron Ore Pellet Bed

Author(s): Ms. ERIKSSON, Anna[1]
Co-author(s): Prof. ANDERSSON, Charlotte [1] ; Prof. AHMED, Hesham [1] ; Mr. DAHLIN, Anders [2] ; Dr. KUMAR, T. Kamesh Sandeep [2]

[1] *Luleå University of Technology*

[2] *Luossavaara-Kiirunavaara AB*

Corresponding Author(s): anna.eriksson@ltu.se

As Sweden is transitioning to hydrogen based steel production, excess oxygen originating from the hydrogen production is likely to be available. A new potential to use extra oxygen to reduce the fuel consumption during production of iron ore pellets has thus emerged within the HYBRIT project [1]. During pelletizing of magnetite iron ore pellets, considerable heat is liberated when magnetite is oxidized to hematite. Increased oxygen concentration in the process gas is expected to promote the exothermic oxidation reaction and consequently reduce the required fuel. Increasing the oxygen in a pelletizing plant would lead to reduced greenhouse gases from the iron and steel industry. The current work is an initial attempt to investigate the effect of varied oxygen partial pressure on pellet induration. The examined material is laboratory produced magnetite pellets

from the Swedish mining company LKAB (Luossavaara-Kiirunavaara AB). The effect of oxygen partial pressure was investigated by interrupted induration experiments at bed-scale in LKAB's Pot Furnace, comprising of approximately 100 kg pellets per bed. Investigated oxygen partial pressures were 0.06, 0.13 and 0.30 atm and thermal profiles were recorded throughout the bed. Pellet strength, porosity and degree of oxidation was analysed at different positions along the bed and oxidation profiles were investigated by a light optical microscopy study on selected pellets. Increased oxygen partial pressure is observed to intensify the oxidation reaction, which results in increased temperature, oxidation degree and pellet strength.

[1] HYBRIT, http://www.hybritdevelopment.com (accessed: 2020-01-24)

29

Sustainable Steelmaking - A strategic evaluation of the future potential of hydrogen in the steel industry

Dr. SKORIANZ, Michael[1]

[1] *Danieli Corus*

Corresponding Author(s): edo.engel@danieli-corus.com

As a result of declining raw materials, environmental pollution and increasing public pressure, countries are urged to deal with the topic of an energy system transformation. Especially fossil energy intensive industries – such as the steel industry – have to revise or change their business models and technology portfolio. Technical developments showed that a sustainable steel production based on hydrogen from green energy seems feasible in the near future. In view of these underlying conditions, both the technology and the future potential of hydrogen for the use in steel production as a substitute for fossil materials is investigated.

30

Addition of DRI/HBI to the Blast Furnace – A Technology to Overcome Top Temperature Limits and Reduce Greenhouse Gas Emissions

Author(s): Mr. CAMERON, Ian[1] ; Dr. SUKHRAM, Mitren[1]
Co-author(s): Ms. BOLEN, Janice [1] ; Mr. TU, Don [1]

[1] *Hatch Ltd.*

Corresponding Author(s): mitren.sukhram@hatch.com

Addition of DRI to blast furnaces has known benefits for increasing productivity and decreasing coke rate. DRI additions to the blast furnace have been revisited to reduce blast furnace CO2 emissions. Carbon taxes may motivate DRI additions to reduce CO2 emissions. Technology changes are needed to overcome the challenges of low top gas temperature. We estimate the maximum amount of DRI that can be added to a blast furnace operation and the related carbon dioxide savings. We consider hot N2 injection to the mid-stack to increase top gas temperature to allow for higher DRI additions.

31

Some insights on interdiffusion in the magnesiowustite solid solution under the conditions of the novel flash ironmaking technology (FIT)

Author(s): Dr. SARKAR, Rahul[1]
Co-author(s): Prof. SOHN, Hong Yong [1]

[1] *University of Utah*

Corresponding Author(s): rahulsarkarmet.89@gmail.com

Recent work by the authors on the interaction of MgO-14.5 wt.% C refractory with Fe/FeO under the conditions of the novel flash ironmaking technology (FIT) developed in the University of Utah showed the formation of a magnesiowustite ((Fe,Mg)O) solid solution. In this work, interdiffusion in the (Fe,Mg)O solid solution has been discussed by analysing the experimental data for two different cases viz. the Fe-MgO-C and the FeO-MgO-C interactions. Kinetics models for each of these cases have been developed based on the counterdiffusion of Fe2+ and Mg2+ cations in the (Fe,Mg)O solid solution. Using the kinetics models and the experimentally determined composition profiles obtained from EPMA, the interdiffusion coefficient (D_(Fe-Mg)) has been determined as function of composition using the Boltzman-Matano analysis. Also, an average value of the interdiffusion coefficient (D [U+0305]_(Fe-Mg)) has been calculated such that it reasonably reproduces the concentration profiles of both cations. The interdiffusion phenomenon was a thermally activated process, as expected, with an activation energy of 375 kJ/mol.

32

CO2 emissions reduction targets achievable thanks to ENERGIRON technology

Mr. HERTRICH G., Ashton[1] ; Mr. PAULUZZI, Dario[1] ; Mr. MARTINIS, Alessandro[1]

[1] *Danieli*

Corresponding Author(s): c.miolli@danieli.it

The last two decades have been marked by significant political changes with a view to slowing global warming and therefore CO2 emissions. Within this context, the European Union is on the front line in promoting a policy to gradually reduce CO2 emissions, thus becoming the first carbon-neutral continent. It aims to cut CO2 emissions by 20%, 40% and 100% compared to 1990 levels, by the years 2020, 2030 and 2050, respectively. The iron&steel industry is one of the major sources of industrial CO2 emissions, having the lion's share of 7/8% of the world's total GHG. Therefore, it is easy to understand that to comply with the targets imposed by European regulations, significant changes have to occur in this industrial sector. Today, steel production mainly relies on Blast Furnace (BF) technology, but it has been widely demonstrated that this route has a major CO2 impact compared with electric steelmaking. In fact, CO2 emissions can be considerably reduced by producing steel in a Direct Reduction Plant (DRP) coupled with an Electric Arc Furnace (EAF); and further savings are possible if the DRP is based on ENERGIRON technology. Indeed, thanks to its energy efficiency and the unique feature of having a built-in CO2 removal system, the Energiron process is able to cut CO2 emissions by another 50%, compared to any other proven DR technology. It is also designed to use hydrogen in place of natural gas as a reducing agent without the need to make major changes to the basic process scheme in order to obtain minimum CO2 emissions. For all these reasons, the ENERGIRON direct reduction technology stands as the most effective to decrease CO2 emissions in iron and steelmaking, and therefore to implement the EU vision for a prosperous, modern and competitive steelmaking industry.

33

Current and future role of DRI and HBI – value-in-use in EAF and BOF applications

Mr. EINFALT, Stefan[1]

[1] *voestalpine Texas LLC*

Corresponding Author(s): matthias.pastl@voestalpine.com

voestalpine has ramped up its 2 Mio. mt p.a. HBI plant in Corpus Christi, Texas end of 2016 and has since then gathered extensive experience not only on the production and use of HBI in its own BOF based steel making operations but also on the products´ supply to its mostly EAF-based international customers. This paper will provide insight on the current and future value-in-use and importance of DRI and HBI in different steelmaking processes. It will focus on optimization of feedstock considering product quality requirements and their future development

on the one hand side and the global need for further de-carbonization of the industrial sector on the other side.

34

70% improvement and more – How LIBS technology enables a new level of CO2 reduction and resource effectiveness in steel making

Mr. ALEXANDER, Schlemminger[1]

[1] *Secopta analytics GmbH*

Corresponding Author(s): alexander.schlemminger@secopta.de

Higher demands for resource and process efficiency have led to increasing requirements on slag making and analysis. But today's technology to homogenize and analyse slag samples takes 7 minutes at the very minimum. With LIBS up to 1000 measurements per second instantaneous slag analysis becomes possible. This presentation displays how LIBS based slag analysis systems not only analyze slags without sample preparation in less than 2 minutes, but also enlarges the scope of operation.
The analysis of Flourine, Chromium and other trace elements or the evaluation of other parameters like homogeneity and automatic counting of metallic Fe-particles.

35

Complex Recycling of Copper Smelting Slags with obtaining Cast Iron Grinding Media and Proppants

Author(s): Dr. KAPELYUSHIN, Yury[1]
Co-author(s): Mr. ADILOV, Galimzhan [1] ; Dr. POVOLOTCKII, Alexandr [1] ; Dr. ROSHCHIN, Vasiliy [1] ; Dr. GAMOV, Pavel [1]

[1] *South Ural State University (National Research University)*

Corresponding Author(s): kapelyushinye@susu.ru

The copper industry at different operational stages produces large volume of wastes. During matte smelting stage slag becomes one of the waste materials that occupies significant territories causing environmental issues. The matte smelting slag contains Si, Fe, Cu, Zn and S. The technological scheme for recycling of copper smelting slags with subsequent obtaining valuable products was provided in present work. The scheme includes solid-state reduction of Fe with further smelting operation for separation of the produced cast iron from slag. During solid-state reduction Zn vapor was trapped. After smelting operation cast iron contained about 1 mass % Cu and 1 mass % S; it was used for production of cast iron grinding media with improved mechanical properties enabling their application for milling of ore minerals. The silicate slag freed from Fe was used for obtaining proppants. The following products are suggested for a Mini Mill plant: cast iron grinding media for crushing of ore minerals and proppants for oil industry.

36

Brainstorming on sustainable ironmaking solutions

Dr. BERTLING, Rainer[1]

[1] *PowerMill GmbH*

Corresponding Author(s): bertling@powermill.eu

This paper will discuss the possibilities to reduce energy consumption and CO2 emissions in the BF process by hot coke, sinter or DRI charging, injection of alternative fuels and potential consequences on the overall process. Such revolutionary changes would have major impacts on the ironmaking process and the respective equipment. After verification with various involved

technology and operation partners such modifications are put on the table to start an open discussion for the development of a more sustainable ironmaking process.

37

IMPROVE ENERGY EFFICIENCY WITH THE RIGHT RECUPERATOR TUBES

Dr. SPAGHETTI, Alessandra[1]

[1] *Sandvik*

Corresponding Author(s): alessandra.spaghetti@sandvik.com

Environmental regulations in the steel and iron world are becoming more stringent during the last years and heat recovery is becoming of central importance. There are several designs of recuperators and the one we're going to discuss is made by tubes bundle. The selection of a high alloyed grades for such pipes would allow you to increase the heat recovery by increasing the temperature of the process and this would also increase the quantity of heat recovered by improving the overall efficiency of your plant with also good impact from the environmental point of view.

38

Model based Analysis of Conventional and Hybrid Steelmaking Routes

Author(s): Mr. SPANLANG, Andreas[1]
Co-author(s): Ms. RECHBERGER, Katharina [1] ; Ms. SASIAIN CONDE, Amaia [1] ; Dr. DERNTL, Michael [1]

[1] *K1-MET GmbH*

Corresponding Author(s): andreas.spanlang@k1-met.com

Modern day steelmaking is on the brink of a wide-ranging transformation from traditional fossil fuel-based processes to low carbon technologies. The challenge of this transformation can be met by the development of novel iron and steelmaking technologies or by optimised operation strategies using existing processes. A first step for plant operators is generally represented by the optimisation and modification of existing blast furnace (BF) - basic oxygen furnace (BOF) plant configurations. This can include an increased use of natural gas or other low-carbon fuels instead of pulverised coal as a substitute reducing agent. An alternative to BF-BOF steelmaking is also given by direct reduction (DR) – electric arc furnace (EAF) based steelmaking. This production route is already considered to be a bridge technology towards low carbon steelmaking due to its use of natural gas instead of coal or coke. A very flexible strategy is offered by the potential combination of both mayor process chains into a hybrid steel production route consisting of BF, BOF, DR and EAF. For all process routes, the CO2 abatement could be further enhanced by the direct utilisation of hydrogen. As a basis for this work, three different process models of BF-BOF steelmaking, DR EAF steelmaking and BF-BOF-DR-EAF hybrid steelmaking were set up in an equation-oriented process simulation environment. The modelling framework enables the depiction of interdependencies between different unit operations of process chains and allows for a comprehensive simulation and comparison of steel production routes. In addition to first principles such as mass and energy balances, the process models also consider the thermodynamic conditions and limitations of the reduction processes. The aim of this work is to compare traditional BF-BOF steelmaking, the DR-EAF based route and a hybrid steelmaking process route with respect to general aspects such as fuel efficiency, carbon dioxide emissions as well as raw material flexibility. Since the production of green hydrogen by novel technologies such as proton exchange membrane (PEM) based electrolysis has reached industrial scale in recent years, potential application areas of hydrogen in these process chains will also be discussed.

39

Ways to Future CO2 Emission Reduction in Steelmaking Primary Operations

Author(s): Mr. BOTH, Ingo[1]
Co-author(s): Dr. KAPPES, Horst [1] ; Dr. KINZEL, Klaus Peter [1] ; Mr. MAGNANI, Stefano [1] ; Mr. TOCKERT, Paul [1]

[1] *Paul Wurth*

Corresponding Author(s): steffen.koehler@paulwurth.com

Climate change and international agreements are calling for radical CO2 emission reduction. Already now, Europe's benchmark (of CO2 emitted for the production of one ton of hot rolled product) for the Emission Certificates Trade Scheme is about 20% lower than the average of well performing European integrated plants' current actual output. Scrap based EAF steel has certainly potential to reduce CO2 emissions, however scrap availability and the need for virgin iron suitable for quality steel products limits its share in overall steel production. Paul Wurth sees realistic opportunities for reaching nearly climate neutral steelmaking within a few decades. The basis would be direct reduction of iron ore products by means of hydrogen produced from steam by a highly efficient solid oxide electrolysis. The electric energy for the electrolytic process and the consecutive EAF steel making will come from non-fossil sources. The paper discusses possibilities of stepwise transforming integrated steel plants into production facilities close to carbon neutrality. It also demonstrates examples of practical ways to reduce CO2 emissions classic ironmaking during the transition period.

40

Hydrogen based direct reduction for CO2-lean steelmaking

Ms. RECHBERGER, Katharina[1]

[1] *K1-MET GmbH*

Corresponding Author(s): katharina.rechberger@k1-met.com

The iron and steel industry accounts for approximately 30 % of the global industrial CO2-emissions. As the reduction potentials of the current steelmaking routes are rather low, the transfer towards breakthrough-technologies is essential to reach the goals of the Paris Agreement which means a reduction of CO2 by 80 %. The hydrogen-based direct reduction (DR) is one of different approaches to realize a CO2-lean steelmaking process. Therefore, the state-of-the-art natural gas based direct reduction acts as a basis for the first step of this transition. This process is already operated with a syngas containing CO and H2 produced out of the natural gas. The high flexibility of the DR-route allows the gradual substitution of natural gas by hydrogen and, in a long-term view, running the process with pure hydrogen. The aim of this work is to point out the possibilities for injecting hydrogen in the direct reduction process and to compare the natural gas based with the hydrogen based steelmaking route in terms of energy demand, CO2-reduction potentials, changes in process conditions etc. As the availability of sufficient amounts of renewable energy to produce green hydrogen will play a dominant role for the decarbonization of the steel industry, the suitability and requirements of the integration of hydrogen generation into industrial systems are presented.

41

A study on the coal-based direct reduction of high-grade magnetite concentrate pellets

Author(s): Prof. ZHU, Deqing[1]
Co-author(s): Dr. GUO, zhengqi [1] ; Prof. PAN, Jian [2] ; Dr. YANG, Congcong [2]

[1] *Central south university*

[2] *Central South University*

Corresponding Author(s): guozqcsu@csu.edu.cn

The short process of electric furnace steelmaking with the burden of direct reduced iron (DRI), is an important process to produce high-quality and special steel, which is characteristic of low energy consumption. Meanwhile, coal-based rotary kiln is one of the most competitive processes for DRI production. In this paper, the high-grade magnetite concentrates with an iron grade of up

to 68% is used as the iron-containing raw material to prepare the DRI by the coal-based rotary kiln direct reduction process. The results show that under the optimum conditions of the reduction temperature of 1100 [U+2103] for 120 min with C/Fe mass ratio of 1.5, the metallization rate and iron grade could reach 98.64% and 94.12%, respectively. The metallized pellets obtained from the best conditions have many advantages, such as high iron grade, few impurities, high added value and a wide range of applications, which could be used in the special steel smelting. However, there are also exist several disadvantages, including low compressive strength and high pulverization, resulting in rotary kiln accretion. In view of these problems, this study proposes many measures to improve the pellet strength and avoid the pulverization in the reduction process, which contains oxidation-roasting to improve the strength of oxidized pellets, stepwise reduction and stepwise coal addition.

42

Coal-based direct reduction behavior of three kinds of typical vanadic titanomagnetite pellets

Author(s): Dr. PAN, Jian[1]
Co-author(s): Dr. GUO, Zhengqi [1] ; Dr. ZHU, Deqing [1] ; Dr. YANG, Congcong [1] ; Dr. SHI, Yue [1]

[1] *Central South Univsrsity*

Corresponding Author(s): guozqcsu@csu.edu.cn

Vanadic titanomagnetite, as a kind of polymetallic symbiosis iron ore, is widely distributed all over the world which has high comprehensive utilization value. Coal-based direct reduction pellets can provide high-quality raw materials for electric furnace smelting. In this paper, the coal-based direct reduction behavior and mechanism of oxidized pellets prepared from imported V-Ti magnetite (IP), two kinds of domestic V-Ti magnetite (PZH and PZHM) were studied. The results show that the swelling rates of three kinds of pellet increased first and then decreased with prolonging reduction duration. The compressive strength of IP reduced pellets presented "V" pattern change. However, the compressive strength of the other two kinds of reduced pellets gradually decreased. The structure of IP pellet reduction products is complete with smooth surface, and there is no bond between pellet. PZH pellet produced "popcorn" structure and even cracked into fragments, with seriously bonding between pellet. The crack morphology of PZHM pellet was between IP pellet and PZH pellet. The main phases in the three reduced pellets are metallic iron, hercynite and almandite, calcium-bearing wustite, iron, calcium-iron pyroxene and anorthite, iron and anosovite, respectively.

43

Review of the Circored process -Has the time finally come?

Author(s): Mr. STEFAN, Tobias[1]
Co-author(s): Dr. NEPPER, Jean-Paul [2] ; Dr. LANG, Sebastian [3]

[1] *Outotec GmbH & Co KG*

[2] *Outotec GmbH & Co. KG*

[3] *Outotec GmbH&Co. KG*

Corresponding Author(s): tobias.stefan@outotec.com

30 years ago, Outotec and its predecessor Lurgi started the development work on reduction of iron ore fines in a fluidized bed with a gaseous reductant. This work culminated 10 years later in the commissioning of the Circored plant in Trinidad as the first industrial operation of direct fine iron ore reduction with only hydrogen as the reducing gas. At the time, hydrogen as the sole reductant was chosen primarily to avoid sticking, a major challenge in iron reduction applications using fines. Recently there has been increasing interest in decarbonizing large parts of the iron and steel industry with many initiatives on their way around the world. In this paper Outotec's experience in the field of iron ore fines reduction as well as in the field of fluidized bed fundamentals is explored. In addition, the history of hydrogen-based reduction and major successes and challenges of the Trinidad Circored plant will be shown. Lastly, the fundamentals and findings of the intensive research and development work over the past 30 years will be discussed. Outotec has

over time constantly invested in its tools, processes and research infrastructure and has tested many different raw materials for their suitability in the process.

44

Holistic CO2e Accounting for Alternative Ironmaking

Author(s): Mr. ELLIOTT, Richard[1] ; Mr. CAMERON, Ian[1]
Co-author(s): Mr. TU, Don [1]

[1] *Hatch Ltd.*

Corresponding Author(s): richard.elliott@hatch.com

The total CO2e footprint of all ironmaking technologies is linked to their material inputs. The CO2e embedded in the production of these feed materials and the logistics of their supply are non-trivial, and complete accounting of these costs – from mine or well head to hot metal – is necessary for a holistic comparison of the emissions footprint of the available ironmaking technologies. Thanks to the many life cycle analyses now available, a holistic accounting of all greenhouse gas emissions can be performed. This work presents a collection of factors for the embedded CO2e in ironmaking feed materials and employs them in a comparative analysis of alternative ironmaking technologies. Results are presented and discussed in the context of Scope 1, 2 and 3 emissions including the contributions of CO2, CH4 and NOx. Of interest are the sensitivity of total emissions to the reductant mix employed and the potential to mitigate global CO2e ironmaking emissions.

45

Sustainable production of low carbon, renewable fuels by fermenting industrial process gasses from the iron and steel industry

Author(s): Dr. VAN DER STRICHT, Wim[1]
Co-author(s): Dr. FLEISCHANDERL, Alexander [2] ; PLATTNER, Tobias [3] ; Dr. NAIR, Prabhakar [4] ; Mr. DE MARE, Carl [1]

[1] *ArcelorMittal*

[2] *Primetal Technologies*

[3] *Primetals*

[4] *Lanzatech*

Corresponding Author(s): wim.vanderstricht@arcelormittal.com

Technological solutions, to utilize process gases from the iron and steel industry for production of fuels and chemicals, are an attractive sustainable and economic approach for industries today. This innovative approach converts carbon and hydrogen-rich off-gases, such as coke oven gas, blast furnace top gas and also converter gas into liquid based energy sources through a biological gas fermentation process to produce preferably ethanol or other chemicals. To produce ethanol, an integrated fermentation system with additional downstream installations is required to treat the fermentation product and waste streams. The treatment of the fermentation waste streams results in a number of by-products, usable for internal or external applications. By returning the by-products to an integrated steel plant or recovering the inherent energy, the fermentation system can be operated in circular system, with minimal waste. The first European commercial scale application of this technology is being developed at the ArcelorMittal steel plant in Ghent with the objective of producing 80 million liters of ethanol per year to be used as renewable transport fuel in a first stage, and as chemical building block on the longer term. We will present the latest developments in the construction of the plant and potential GHG reductions in the steel sector.

46

Measurement and Control of Sinter Bed Permeability

Author(s): Dr. MITRA, Debanik[1]
Co-author(s): Mr. MUKHERJEE, Ashish [1] ; Dr. ROY, Tathagata [1]

[1] *Tata Steel Limited*

Corresponding Author(s): debanik.mitra@tatasteel.com

Importance of air flow through the sinter bed has been a challenge to sinter makers for a long time. This is widely used as a measure of permeability of sinter bed. Measurement of sinter bed permeability was attempted by many in the past, but without much success. The authors have developed a novel technique to measure it successfully and reliably. Based on a novel concept the device has been developed and implemented at SP1, Jamshedpur. The online measurement of permeability has then been optimized with controllable parameters in sinter process. This has resulted in a productivity increase by 4% with a reduction in power rate by 6% at this sinter plant. In sinter plant scenario worldwide, this method promises higher productivity with usage of more inferior grades of iron ores. This method may attract equally encouraging applications in other process plants, such as DRI plant, Pellet Plant and so on. The paper will describe the novel technique and its use in sinter plant.

47

Slag flow and holdup in the coke bed under H2-enriched environment

Author(s): Prof. LEE, Joonho[1]
Co-author(s): Dr. OH, Joonseok [2] ; Mr. KIM, Mintae [1] ; Mr. DEREJE, Degefa Geleta [1]

[1] *Korea University*

[2] *Hyundai Steel*

Corresponding Author(s): joonholee@korea.ac.kr

As global warming became a serious social issue, the steel industry has become a social obligation to reduce carbon dioxide emission. In South Korea, the utilization of In-House H2 gas as a reducing agent in BF operation has been considered one of the promising solutions (COOLSTAR). With increasing H2 gas utilization rate, it is expected that the coke consumption rate as fuel and reductant decreases. On the other hand, due to decreased coke consumption rate, the thickness of the iron ore layer in BF would increase, while the thickness of the coke layer is constant. Consequently, larger amount of slag can be holdup in the coke bed to Impede stable BF operation. Oh and Lee recently found that SiC whisker was formed on the surface of carbon under H2-enriched environment. The SiC whisker formation may affect the slag flow pattern and the slag holdup in the coke bed. Therefore, in the present study, the static and dynamic holdups of liquid slag flow in a packed coke bed with partially coated with SiC were investigated at a temperature of 1723 K by using the three-dimensional combined discrete element method and a computational fluid dynamics model. The simulation results bring about new insight to H2-enriched BF operation.

48

Carbon deposition modelling and control at the shaft-furnace reduction gas oxygen enrichment unit

Author(s): Dr. ALHARBI, Mansour[1]
Co-author(s): Mr. AL-JUTAILI, Abdulaziz [1] ; Mr. AL-HARBI, Abdulrahman [1] ; Mr. AL-ZAYER, Mohammed [1]

[1] *Hadeed*

Corresponding Author(s): harbimn@hadeed.sabic.com

The objective of this study was to investigate the gases flow behavior at the oxygen enrichment unit. In addition, to evaluate the natural gas partial combustion efficiency and carbon deposition rate. To identify the optimum operation parameters that can lead to achieve the minimum natural gas consumption with the highest possible reformed gas temperature and also eliminate and/or reduce the carbon deposition. A CFD model of this enrichment unit was developed to

predict the flow and the gases combustion behaviors around the oxygen tubes. Therefore, this model would help to study the process performance and identify the root cause of any excessive carbon deposition. High natural gas flow rate could restrain oxygen attached to the back wall of the enrichment unit causing hot spot and excessive natural gas cracking attached to the back wall, then this most likely would results to undesirable carbon deposition. The model results recommend that the optimum natural gas flow rate would allowed to burn the oxygen relatively away from the wall causing less natural gas cracking within the reformed gas stream and away from the wall. However, the optimum gases flow rates range should help to achieve the goals of the enrichment units to increase the gas temperature and introduce natural gas.

49

Integration of DRI plants into classical BOF production sites

Mr. DR. AHRENHOLD, Frank[1]

[1] *thyssenkrupp Steel Europe AG*

Corresponding Author(s): frank.ahrenhold@thyssenkrupp.com

Session: DRI as an alternative raw material for iron and steelmaking (applications in blast furnace, EAF etc.)
Integration of DRI plants into classical BOF production sites
The production of quality flat steel products is commonly linked to highly integrated sites which include Hot metal generation via the Blast Furnace route, Oxygen Steelmaking (BOF), Continuous Casting, and subsequent Hot Rolling. Modern DRI plants offer various new opportunities to these sites, especially a wide reduction in CO2 emissions. Nevertheless, the implementation of direct reduction units into integrated metallurgical plants include various challenges. Different approaches have been suggested and will be discussed. Metallurgical aspects need to be considered to maintain product quality which reflect customer demand. Effects on the sites internal and external energy network and on site logistics have to be evaluated and handled. The findings presented can help to tailor solutions on how to integrate DRI plants into the classical flat steel production route.

50

Sustainable Steelmaking – Carbon free steelmaking by Hydrogen Plasma Smelting Reduction

Author(s): Mr. RIMSER, Alexander[1]
Co-author(s): Prof. SCHENK, Johannes [2] ; Dr. SORMANN, Axel [1] ; Mr. ZARL, Michael Andreas [3] ; Dr. BERNHARD, Geier [4] ; Mr. BÜRGLER, Thomas [5]

[1] *K1-MET GmbH*

[2] *Montanuniversitaet Leoben*

[3] *Montanuniversität Leoben / Chair of Ferrous Metallurgy*

[4] *voestalpine Stahl Donawitz GmbH*

[5] *voestalpine Stahl GmbH*

Corresponding Author(s): alexander.rimser@k1-met.com

The climate change, mainly caused by gaseous emissions like CO2, is globally one of the most important subjects. Big efforts are required to solve this problem within the next decades. The European Commission´s low carbon roadmap suggests a reduction of CO2 emissions of 80 % by 2050 compared to 2005 levels. The steel industry, which contributes around 6 % to the worldwide anthropogenic emissions of CO2, is asked to decrease the greenhouse gas emissions.
There are two possibilities to perform low-C economy: Carbon Direct Avoidance (CDA) and Smart Carbon Usage (SCU). In the case of CDA no carbon is being used for iron ore reduction processes. In the case of SCU process integration with reduced carbon input and carbon capture and usage are being performed.

In this paper the CDA path using hydrogen as reducing agent for iron ore will be presented. In a couple of doctor theses on laboratory investigations at the Montanuniversitaet Leoben/Austria since the 1980´s it has been shown that hydrogen – especially in the plasma state – is an excellent reducing agent for iron oxides. Based on the results of these investigations and on actually running laboratory work it has been decided by a consortium of scientific and industrial partners to go a step ahead and to build a bench scale plant for HPRS (Hydrogen Plasma Smelting Reduction). The upscaling from the laboratory to bench scale is in a range from 100 g to 100 kg of iron ore. In this bench scale plant, which is located at the Donawitz site of voestalpine, smelting reduction tests using hydrogen in gas mixtures are being carried out. A transferred plasma arc will reduce and melt down fine grained iron ore in one step. The ore is fed into the plasma arc through a hollow electrode. Main first objectives are a stable process concerning the plasma arc and the continuous feeding, melting and reduction of the iron ore to liquid metal. Results of trials with different plasma gas compositions and different feed materials will be shown.

51

Reduction behavior of self-reducing pellets (SRP) under H2 involved conditions

Author(s): Ms. WANG, Rongrong[1]
Co-author(s): Dr. BABICH, Alexander [2] ; Prof. SENK, Dieter [2]

[1] *Department of Ferrous Metallurgy, RWTH Aachen University*

[2] *RWTH Aachen University*

Corresponding Author(s): rongrong.wang@iehk.rwth-aachen.de

Recently a special attention is being paid on the Hydrogen Direct Reduction (H-DR) process to minimize the CO2 emissions in ironmaking processes. Despite the fact that many components of the H-DR/EAF setup have been tested in industrial settings, key challenges, such as the high cost of renewable electricity still remain for the process. Biomass, as a renewable source of heating and reducing, is also considered to reduce CO2 emissions and promote reductions. Thus, in this study, one type of torrefied biomass was used as an embedded reducing agent to prepare pellets. The produced self-reducing pellets were further isothermally reduced under H2 involved atmospheres at 750-950^{0}C. Mass loss, reduction degree, metallization degree and volume change were examined in a first approach to estimate the reduction process and mechanism.

52

Production of Metallic Iron from the Pudo Magnetite Ore using End-of-Life Rubber Tyre as Reductant: The Role of an Underlying Ankerite Ore as a Fluxing Agent on Productivity

Author(s): Mr. ABOTAR, Emmauel[1]
Co-author(s): Mr. DANKWAH, James Braford [2] ; Dr. KOSHY, Pramod [3] ; Prof. DANKWAH, James Ransford [4]

[1] *Minerals Engineering Department, University of Mines and Technology, Tarkwa, Ghana*

[2] *Future Industries Institute, University of South Australia, Mawson Lakes, Adelaide, SA 5095, Australia*

[3] *School of Materials Science and Engineering, University of New South Wales, Sydney, New South Wales 2052, Australia*

[4] *1Minerals Engineering Department, University of Mines and Technology, Tarkwa, Ghana*

Corresponding Author(s): eabotar@umat.edu.gh

This research work investigated the nature of a nonmagnetic ore from Pudo and its fluxing effect on the extent of reduction of the Pudo titaniferous magnetite ore using pulverised samples of charred carbonaceous materials generated from end-of-life vehicle tyres (ELT) as reductants. Reduction studies were conducted on composite pellets of the Pudo titaniferous magnetite iron ore containing fixed amounts of charred ELT and varying amounts (0%, 10%, 15%, 20%, 30%, 40% and 50%) of the nonmagnetic fluxing material in a domestic microwave oven and the extent of reduction was

calculated after microwave irradiation for 40 minutes. Analyses by XRF, SEM/EDS and XRD of the nonmagnetic ore revealed an Ankerite type of ore of the form Ca0.95Fe0.95Mn0.1(CO3)2. From the microwave reduction studies it was observed that premium grade metallic iron can be produced from appropriate blends of the Pudo iron ores using ELT as reductant, with a measured extent of reduction up to 103.8%. Further, the extent of reduction was observed to increase with an increase in the amount of the nonmagnetic ore that was added as fluxing agent.

53

SALCOS - Potentials and requirements of a flexible, hydrogen based deep decarbonization of primary steelmaking

Mr. HILLE, Volker[1]

[1] *Salzgitter AG*

Corresponding Author(s): yvonne.dworak@asmet.at

Today, primary steel worldwide is predominantly produced via carbon based processes as the BF/BOF route. Consequently, steelmaking is responsible for more than 7% of global anthropogenic CO2 emissions, leaving the decarbonization of this industrial sector as challenging as societally important.
Luckily, nature offers an alternative to carbon: It can be replaced by hydrogen as chemical reactant and by electrical energy as source of process heat, leading to virtually complete decarbonization in the end - but as a prerequisite it will first be necessary to change primary steelmaking equipment to suitable direct reduction reactors combined with downstream electric arc furnaces (DRP/EAF route).
As one of the first movers in this field, Salzgitter AG has coined the term „Carbon Direct Avoidance, CDA“ for the „hydrogen approach“ and - since 2015 – is proposing the respective gradual transformation project SALCOS (Salzgitter Low CO2 Steelmaking), based on the stepwise implementation of DRP/EAF processes into our existing integrated steelworks, operating the direct reduction reactor(s) flexibly with ever increasing shares of hydrogen, replacing natural gas. CO2 emission reduction is targeted to reach -95% compared to current levels.
Steelmaking will remain energy intensive, thus – if this industry shall have a future in Europe – society has to ensure the production and continuous supply of sufficient amounts of renewable energy.
Anyway, despite being the most sustainable, efficient as well as effective decarbonization pathway for steel, CDA with its obvious technical feasibility could not yet be realized on an industrial scale: As the cost of CO2 lean steel production will rise significantly compared to the benchmark classical route, first a respective political and economic framework is needed to create and incentivize a market for „green“ steel in Europe – and soon.

54

Handling and Transportation of DRI: Safety First

Mr. BARRINGTON, Chris[1]

[1] *International Iron Metallics Association*

Corresponding Author(s): cbarrington@metallics.org

As the industry association for the Ore-based Metallics industry IIMA is very much concerned with the safe handling and transportation of DRI. With the expected growth in DRI production and shipment as part of the pathway to carbon-neutral steel production, it is important that best practice in this area is shared as widely as possible. The presentation will cover the regulatory framework governing the international shipping of DRI in all its forms (DRI, HBI and DRI fines), together with the main practices and precautions necessary to address the inherent hazards of DRI, from production site to final destination. With NGO consultative status at the International Maritime Organisation, IIMA is able to participate in the development and implementation of maritime regulations. The presentation will also examine the regulatory roadmap for new forms of DRI that may come to market in the coming months and years.

55

Carbon-neutral Steelmaking: pathway for DRI

Mr. ATHERTON, John[1]

[1] *International Iron Metallics Association*

Corresponding Author(s): cbarrington@metallics.org

Many steel industry roadmaps toward the very significant reduction of CO2 emissions required by the political agenda in many countries envisage the DRI/EAF system as a key component along the pathway to carbon neutrality in steelmaking. In this respect, IIMA is putting together a white paper on some key practical issues that need to be considered beyond the macro-level issues such as availability and cost of power and hydrogen. These include adequacy of raw material supply to support significant growth in DRI production, the value-in-use of DRI produced with hydrogen in EAF steelmaking and the impact of a reduced carbon footprint on EAF operations, as well as some longer term qualitative aspects of scrap supply. The presentation will share some of IIMA's thoughts and concerns on such issues.