Alert Direct Reduction & Alternative Processes (February 2016)

1. DRI/HBI – exploding the myths. Sara Hornby, Jorge Madias and Francisco Torre. Read more
2. Recovery of multi-metallic components from bottom ash by smelting reduction under plasma environment. A. Mandal, O. Sinha. Read more
3. Effect of temperature on morphology of metallic iron and formation of clusters of iron ore pellets. J. De Alencar, V. De Resende, L. De Castro. Read more
4. Chloridization and reduction roasting of high-magnesium low-nickel ore followed by magnetic separation to enrich ferronickel concentrate. S. Zhou, Y. Wei, B. Li, H. Wang, B. Ma, C. Wang. Read more
5. Phosphorus migration during direct reduction of coal composite high-phosphorus iron ore pellets. C. Cheng, Q. Xue, G. Wang, Y. Zhang, J. Wang. Read more
6. Kinetic study on gas molten particle reduction of iron ore fines at high temperature. Y. Qu, Y. Yang, Z. Zou, C. Zeilstra, K. Meijer, R. Boom. Read more
9. A comprehensive static model of an iron bath smelting reduction process with thick slag for alumina-rich iron ore. Y. He, B. Tang, Q. Li, Z. Zou. Read more
10. MIDREX combination plant – designed for changing market conditions. G. Wallwork, B. Voelker. Read more
12. COREX - an answer for hot metal production in a changing environment. S. John, W. Sterrer, J. Wurm. Read more
13. FINEX - An old vision of the iron and steel industry becomes reality. J. Shibu, C. Boehm, W. Sterrer, N. Rein. Read more
15. Analysis on direct reduction technology of shaft furnace with hydrogen-rich gas. C. Cao, F. Zhang. Read more

Steel Times International, January-February 2016
DRI/HBI – exploding the myths. Sara Hornby, Jorge Madias and Francisco Torre
Half a century of DRI/HBI electric arc furnace (EAF) use, coupled with low-cost American natural gas (NG) suggests a needed review of trends and controversial issues surrounding this alternative iron source (AIS). Aspects such as iron ore quality and operational influence; DRI stockpiling and transportation auto-ignition; optimum charge design, temperature and mechanism; compositional impact on EAF operation and performance; oxygen/carbon balance; and chemical energy need to be addressed.

Metallurgical and Materials Transactions B, February 2016
Recovery of multi-metallic components from bottom ash by smelting reduction under plasma environment. A. Mandal, O. Sinha
A new concept for maintaining inert atmosphere with high temperature ~1973 K (1700 C) inside the furnace during smelting reduction was described, in which recovery of metallic values from wastes was done in the presence of metal bath which acts as a solvent. Nitrogen plasma arc was generated by passing current and nitrogen gas through a hollow graphite electrode. In this way, the heat for reduction reactions and
melting of metal and slag phases under inert atmosphere was maintained. The mixture of bottom ash and carbonaceous reducing agent was fed in the form of pellets near the plasma zone above the liquid iron bath, used for the absorption of reduced metals after reduction of oxides present in the wastes. Percent recovery of metallic values and different consumption parameters were calculated. It was observed that aluminum, iron, and silicon could be recovered effectively from the wastes.

**Effect of temperature on morphology of metallic iron and formation of clusters of iron ore pellets.** J. De Alencar, V. De Resende, L. De Castro
The increase of the reduction temperature in direct reduction furnaces has been a recurring tool due to the benefits that it provides to the process. However, its increase cannot be performed without taking into account some considerations, since the sticking phenomenon is directly correlated with it and could lead to permeability problems and reactor performance. An analysis of the formation of pellets clusters at different temperatures was carried out with focus on morphological characterization of reduced materials to better understand the causes and effects of these actions. The results showed a correlation between the morphology of the metallic iron present in the samples and the clustering index. At low reduction temperatures, 1123 K (850 C), the iron formed is eroded and deformed and the cluster hardly remains after tumbling. When forming iron with fibrous structure, 1223 K (950 C), the clustering index increases because of anchor points which make the material to stick together. Finally, under the effect of high temperature and long time, it generates fresh precipitated iron, enhancing the resistance of the clusters so that they cannot be separated.

**Chloridization and reduction roasting of high-magnesium low-nickel oxide ore followed by magnetic separation to enrich ferronickel concentrate.** S. Zhou, Y. Wei, B. Li, H. Wang, B. Ma, C. Wang
The chloridization and reduction roasting of high-magnesium, low-nickel oxide ore containing 0.82 pct Ni and 31.49 pct MgO were investigated in this study. Mineralogical investigation indicated that 84.6 pct of nickel was associated with silicates, and nickel was well distributed in mineral in the form of isomorphism. A series of chloridization tests with different added proportions of sodium chloride and coal along with different roasting temperatures and times was conducted. The results indicate that for a ferronickel content of 7.09 pct Ni, a nickel recovery of 98.31 pct could be obtained by chloridizing the laterite ore at 1473 K (1200 C) for 20 minutes with the addition of 10 wt pct sodium chloride and 8 wt pct coal followed by the application of a 150-mT magnetic field. X-ray diffraction indicated that the nickel is mainly present in the form of ferronickel, which can also be detected by SEM-EDS. Compared with the roasted ore with no added chlorinating agent, the ore roasted in the presence of sodium chloride exhibited enhanced ferronickel particle growth.

**Phosphorus migration during direct reduction of coal composite high-phosphorus iron ore pellets.** C. Cheng, Q. Xue, G. Wang, Y. Zhang, J. Wang
This study investigated the direct reduction process and phosphorus migration features of high-phosphorus iron ores using simulated experiments. Results show that iron oxide was successfully reduced, and a Fe-Si-Al slag formed in carbon-bearing pellets at 1473 K (1200 C). Fluorapatite then began to decompose into Ca3(PO4)2 and CaF2. As the reaction continued, Ca3(PO4)2 and Fe-Si-Al slag reacted quickly with each other to generate CaAl2Si2O8 and P2, while CaF2 turned into SiF4 gas in the presence of high SiO2. A small amount remained in the slag phase and formed CaAl2Si2O8. Further analysis detailed the migration process of the phosphorus into iron phases, as well as the relationship between carburization and phosphorus absorption in the iron phases. As carbon content in the iron phase increased, the austenite grain boundary melted and formed a large quantity of liquid iron which quickly absorbed the phosphorus. Based on the results of simulation and analysis, this paper proposed a method which
reduced the absorption of P by the metallic iron formed and reduced P content in metallic iron during direct reduction.

Ironmaking & Steelmaking, November 2015
Kinetic study on gas molten particle reduction of iron ore fines at high temperature. Y. Qu, Y. Yang, Z. Zou, C. Zeilstra, K. Meijer, R. Boom
A kinetic study of gas molten particle reduction has been carried out using a high temperature drop tube furnace at the typical conditions of the smelting cyclone of the HIsarna ironmaking process. The results demonstrated that particle size has a significant effect on the reduction rate of fine iron ore particles and that the reduction ability of H2 is two to three times higher than that of CO at high temperature. It was found that almost all of the Fe2O3 in the iron ore particles was reduced to Fe3O4 and FeO in the first 210 ms. The morphology images of the partially reduced spherical particles showed that a liquid FeO product layer was formed outside the solid Fe3O4 unreacted core. The kinetic analysis revealed that the rate controlling step of the gas molten particle reduction was the diffusion of Fe3+ in the liquid product layer and that the activation energy was ~156 kJ mol⁻¹.

COREX is an industrially and commercially proven smelting reduction process. The shaft furnace (SF) for the direct reduction of iron ore is one of the two major reactors of COREX. In the new design of COREX-3000 SF in Baosteel, China, a new technique called areal gas distribution (AGD) has been adopted. With the installation of two AGD beams, the cross-sectional area varies in a complicated manner, which will affect the burden descending behaviour. This work uses a slot model to investigate the solid flow behaviour in the SF by discrete element method. The applicability of the discrete element model is validated. The results confirm that the flow profile in SF with AGD evolves from a flat to wave and finally to W profile as the solids descend. A triangle shaped free area is observed under the AGD beam, which is the main channel for gas flow into the shaft centre. Increasing the discharging rate has an effect of decreasing the quasi-stagnant zone size, but does not affect the macroscopic motion of particles and flow pattern above the bustle. The cross-section of AGD channel increase with the increase in the discharging rate. Under the asymmetric condition, the solid flow pattern is asymmetric. The influence of AGD on macro- and microscope properties of solid flow in SF is also evaluated. This investigation reveals that AGD beams affect the particle uniform descending in bustle zone and increase the complexity of normal force distribution.

ISIJ International, October 2015
Large amount of dust and sludge recovered during cleaning of iron and steel making process gases are annually put on landfill or intermediate storage. These by-products have high contents of iron (Fe) and carbon (C) that potentially could be utilized in the steel industry. However, due to the presence of impurity compounds as well as the unsuitable physical properties, these by-products cannot be recycled directly. The main objective of the present study is to investigate the possibilities to recover the valuable components Fe and C in these by-products and thereby decrease the need of landfills at the steel plants as well as reduce the consumption of virgin materials, including fossil coal, and reduce CO2 emissions. A recycling route has been investigated by means of laboratory trials and FactSage thermodynamic modeling. Four different blends of BF and BOF dusts and sludges are prepared in predetermined ratios. Reduction behavior of each blend is studied using TG/DTA/QMS and in-situ high temperature X-ray
diffraction. High temperature physical properties like softening, swelling and melting are also investigated by means of heating microscope. The obtained results indicate the feasibility of both minimizing the impurity elements as well as recovering of valuable components.

A comprehensive static model of an iron bath smelting reduction process with thick slag for alumina-rich iron ore. Y. He, B. Tang, Q. Li, Z. Zou
In order to make comprehensive utilization of alumina-rich iron ore, a two-step three-vessel smelting reduction process is proposed, including the Rotary Hearth Furnace (RHF) for the pre-reduction of alumina rich iron oxide pellet, the Smelting Reduction Vessel (SRV) with a thick slag bath for the final reduction and melting of pellet, and the Gas Reforming Furnace (GRF) for reforming the exhaust gas from SRV. A three-level lances arrangement is designed to improve the energy utilization and production condition of the SRV. An overall process model is established for the whole process to calculate the mass and heat consumptions of all sections of the process, and to investigate the effect of operation conditions on the process performance. With 80% heat transfer efficiency of post combustion, the recommended post combustion ratio (PCR) of the SRV gas is 55% and the pellet metallization rate (PMR) is 80%. A zoned model of the SRV is developed to calculate the mass and heat balances of each reaction zones and especially to optimize the operation conditions. The recommended PCRs in the upper slag and lower slag are 15% and 0% respectively. The coal-only injection method is recommended in the lower slag.

Direct from Midrex, August 2015
MIDREX combination plant – designed for changing market conditions. G. Wallwork, B. Voelker
Opportunity is often the mother of invention. The decision in the early 1980s to amend the Sabah Gas Industries (SGI) plant supply contract to produce hot briquetted iron (HBI) is a good example. Leading up to the SGI project (Editor’s note: plant now owned and operated by Antara Steel Mills, a Lion Group company), Midrex had the idea of designing a reduction furnace to discharge hot DRI (HDRI). Several development programs were conducted in parallel by Midrex and its licensees. The result was a marriage of the proven MIDREX Shaft Furnace design with technical innovations that allowed for uniform discharge of HDRI and assured consistent gas and product flow characteristics. The MIDREX Hot Discharge Furnace has proven to be a keystone technological development. This innovative design has since gone on to be at the heart of a direct reduction plant that gives operators the ability to respond quickly and effectively to changing market conditions - the MIDREX Combination Plant

METEC & 2nd ESTAD, June 2015
Use of hard coal fines as reduction agent in smelting reduction processes through processing by binder briquetting. R. Lohmeier, H.-W. Schröder, H. Heckmann
The development of alternative smelting reduction processes, especially COREX and FINEX, has reached the state of reliable industrial plants. The advantage of these technologies is the potential use of thermal hard coal as reduction agent. That means feasible raw material in a wide range of rank is available at lower costs in comparison to high quality coking coal which is necessary for the traditional iron making in a blast furnace. For stable operation the COREX/FINEX process needs to be fed with coal lumps. But thermal hard coals usually contain 30 to 50 % fines which are not feasible for direct feeding into COREX/FINEX melter-gasifier. To make the substantial amounts of these fines suitable for the smelting reduction processes they have to be agglomerated using binder briquetting technology in an optimal manner. For the optimization of the briquetting process systematic investigations on the process variables, e. g. briquetting pressure, briquetting temperature and grain size distribution, are necessary. Furthermore
the type and amount of binder have both much influence on the briquettes quality and their process behavior in COREX/FINEX meltergasifier. In addition they are important economically factors. Besides this the pre- and post-treatment (e. g. mixing and drying) have also much impact on the briquettes quality and will be investigated, too. The aim is to identify optimal values for the briquetting parameters and the best type of binder for each coal as well as investigations on its mode of action. The presented results will give an insight in the systematic research on the mentioned process parameters. For the experiments typical COREX/FINEX hard coals from deposits in Australia and South Africa are used. As binder various amounts of bitumen (matrix-type binder), molasses in combination with calcium hydroxide and polyvinyl acetate (both film-type binder) are applied and tested.

COREX - an answer for hot metal production in a changing environment. S. John, W. Sterrer, J. Wurm
The COREX Process is still beside the FINEX® technology the only industrially realized alternative to the blast furnace route for the production of hot metal. Changes in the technology itself which subsequently improved operation of the operating COREX plants and thus process economics and changes of external factors e.g. general decrease in raw material quality, increase and availability of energy cost (especially natural gas) and nowadays strictly enforced environmental laws might make it worth to carefully re-evaluate the COREX technology. Current COREX pre-projects clearly show an increasing demand for the “by-product” COREX export gas for power production and for the production of DRI. Based on the economic evaluation of different COREX gas based plant concepts in comparison with the traditional blast furnace route it can be shown, that the COREX technology is highly competitive in the challenging iron and steel producing environment.

FINEX - An old vision of the iron and steel industry becomes reality. J. Shibu, C. Boehm, W. Sterrer, N. Rein
Rising energy demand and steadily decreasing quality of raw materials due to the global resource depletion are great challenges to the steel production today. The FINEX® Process has been developed jointly by POSCO, Korea and Primetals Technologies Austria, to provide the iron making sector with the capability to lower hot metal production costs, environmental pollutions and to increase the flexibility in terms of operation and the choice of raw materials. FINEX is a new technology combining a gas-based reduction in a series of fluidized bed reactors and a reduction smelting in a melter gasifier. Commenced in April 2007, the first 1.5Mtpa commercial plant has demonstrated the competitiveness as an alternative iron making route. Another 2.0 Mtpa, third generation FINEX (3G) plant was recently Installed at POSCO, Pohang Works and has been operating satisfactorily since its blow-in in January 2014. Based on the well-proven plant concept, new process features, the highly competitive production costs and environmental advantages, the FINEX Process can be considered as a competitive alternative to the conventional blast furnace iron making route.

Development of partially reduced iron production technology in travelling grate. S. Son, M. Wang, J. Park, H. Jeong, B. Cho
The manufacturing techniques of pre-reduced agglomerate in travelling grate or grate-kiln process have been developing in POSCO. The new process, named POSCO Pre-Reduced Agglomeration process (PosPRA) is based on the reduction of coal containing iron ore briquette in travelling grate. Reduction behaviors of coal containing iron ore briquette under oxidizing atmosphere were measured to estimate the possibility of producing the pre-reduced agglomerate in travelling grate. The control of reduction temperature and oxygen potential in the range 1100-1200°C and below 10 vol%, respectively is very important to increase the reduction efficiency of coal containing iron ore briquette in travelling grate. In pot grate test, the metallization degree and
compressive strength of pre-reduced agglomerate are obtained about 55% and over 150kgf/p, respectively. The possibility of producing the pre-reduced agglomerate in travelling grate was confirmed. It was also investigated by softening and melting test that the mixing of pre-reduced agglomerate with sinter as burden materials is effective method to improve the permeability in blast furnace.

**Analysis on direct reduction technology of shaft furnace with hydrogen-rich gas. C. Cao, F. Zhang**

The optimal reduction gas composition of shaft furnace with hydrogen rich gas is analyzed, considering the combined effect of chemical reaction thermodynamics conditions and reaction heat balance. The results show that in the current level of temperature drop, the optimal ratio between H2 and CO is 1 to 2 in order to obtain as high as possible gas utilization rate. The laws of thermodynamics of coke oven gas reforming by carbon dioxide are studied through thermodynamic calculation. The ratio between H2 and CO of gas products of coke oven gas reforming by CO2 is lower than by H2O. It would be less than 2.0 the H2/CO value of gas product of coke oven gas reforming by CO2 while the addition of CO2 is more than 20 percent. Higher temperature and lower pressure is favorable to the reforming by CO2 and the reforming temperature should be more than 1000°C considering the factors that the rate of reforming and reduction potential of reducing gas etc. The value of H2/CO, which is mainly depending on the addition of CO2, can be adjusted effectively by adjusting the amount of CO2 and H2O.