Co-chair – Scientia Prof. Veena Sahajwalla Director of The Centre for Sustainable Materials Research &Technology (SMaRT@UNSW)

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Venue: Conference & Residential Centre UNSW, Sydney

The Symposium brings together participants from both industry and academia to address some of the Ironmaking challenges. This Symposium aims to update current state of Ironmaking technologies and identify future pathways for reducing GHG impact of Ironmaking and raw materials for sustainable development.

Sustainable Ironmaking in the 21st Century - An Australian Perspective

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The Australian steel industry is a relatively small but efficient and profitable segment on the global steel map. Considerable restructuring has taken place in order to preserve and improve its international competitiveness. The focus of this presentation is technology development in its broadest sense, through coverage of some operational improvements, technical advancements and future plant activities, together with the necessary research for positioning the business in a 10-year timeframe. An emerging sustainability thrust around process integration, and developments in alternate ironmaking are discussed.

1. **Structural changes and operations:**
    a. General comments around context setting for the steel industry
    b. Introduce a key point Process Integration point - a message around what sustainability means for an integrated plant
2. **Raw materials availability/quality**
    a. Supply and quality of raw materials
    b. Start to introduce sustainability challenges with predicted poorer quality RMs
3. **Key Operational improvements**
    a. Recent plant improvements (BF5, OpUp)
    b. Cokemaking process changes (semi-soft, selective crushing)
    c. Water management
4. **Assessment of Key Opportunities with focus towards sustainable Ironmaking**
    a. Two to three selected technology implementations around the sustainability theme [eg GHG setting work
    b. Evaluation of sustainable technologies [ULCOS benchmarking + Australian perspective, biomass, higher oxygen usage etc]
    c. Process Integration (incl ISEEM) approach
5. **Conclusions**

Factors Affecting the Sustainability of Steel Industry

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This paper deals with two factors affecting the sustainability of steel industry; one is technical and the other is not technical.

First consider the reduction of iron ore ($FeO_{1.5}$) to produce metallic iron by carbon. The reaction can be formulated by either

$$FeO_{1.5} + 1.5\ C = Fe + 1.5\ CO \qquad [1]$$

, or

$$FeO_{1.5} + 0.75\ C = Fe + 0.75\ CO_2 \qquad [2]$$

Obviously, reaction [2] requires 50 % less carbon than reaction [1]. For many years, hence, reaction [2] rather than [1] has been favored from the view point of production cost. However, reaction [2], in turn, corresponds to the emission of CO_2. Needless to say, in recent years, there is a strong incentive to reduce the emission of CO_2 from ironmaking processes. The key to meet such requirement would be an alternative source of carbon. If such alternatives were available at very cheap rate, then reaction [1] would be much favorable, because this reaction corresponds to zero CO_2 emission. Waste wood, plastic and paper would be such cheap alternatives. It is also noted that both reactions (1) and (2) are exothermic, hence requires heat, which can be obtained through combustion of carbon.

Second, in addition to energy and environmental considerations as exemplified above, we need to think of another factor which would affect very significantly the sustainability of steel industry. Unfortunately this author is obliged to mention that steel industry, particularly in Japan, is unpopular among students, and is facing to serious difficulties in recruiting technical students of good quality. Discussion will be made on the reasons why steel industry is not popular among students.

Sourcing Metallurgical Coal/Coke – Key Challenges to Today's Iron & Steel Making

Arun Kumar Jagatramka

Guajarat NRE Coke, India

World steel production has today reached the pre crises levels. Steel production is primarily steered by China which accounts for about 50% of global production followed by the Asian countries like Japan and India. There is a dynamic shift in steel production growth and consumption being noticed in the global arena. China is set to lead the pack and is way ahead of other countries with projected production of around 900 million tonnes by 2020, followed by India set to cross the 200 MT mark and South America primarily being led by Brazil crossing the 100 MT mark by 2020. In contrary, the developed block like the North America, Western Europe and East Asia, the growth is going to be stagnant with production hovering around the 150 MT mark in the current decade. With China powering ahead and the developing nations like India, Brazil and Russia also on a steady growth path, the steel industry growth story is here to stay. Restarting of blast furnaces elsewhere and a tendency to move towards higher productivity would further boost steel output. This invariably creates a strong demand for steel making raw materials. Raw materials like met coal and coke would also see upward price trend on constrained availability and increased demand. The big question that we are confronted is - Is there a potential of insufficient raw materials for forecast production??

Coking coal, one of the key ingredients in steel making would experience a strong growth and would mirror the steel growth. Hard coking coal growth is expected to be at a CAGR (2005-2020) of approx 5% globally, with over 10% in China, India and Brazil. Chinese demand remains the key driver followed by Japan and India. China today turning as a net importer of coking coal has added competition to the already constrained supply market of the commodity. Australia is the prime source of coking coal worldwide accounting for about 60% of global supply. It is estimated that demand for coking coal by 2020 would reach to around 400 MT. There are not enough sources that are in sight as of today which is capable to meet the increasing demand. New potential sources like Mozambique, Eastern Russia and Indonesia are still untested and have either severe logistics bottlenecks or doubts on quality and ash content. Australia, the major potential source has its own limitations of logistics & capacity. Hence, with accelerated recovery, coking coal supply will find it difficult to meet demand and the real anxiety over resources would be when seaborne demand breaches >>400Mt tonnes/year. Coking coal price too would remain extremely high for some years – introduction of quarterly pricing and impacts are being experienced.

In the met coke sphere as well we are experiencing the similar criticality in supply. China till 2007 used to export about 12 MT – 14 MT of met coke, catering to about 50% of world trade, but has suddenly come down to as low as ½ MT of met coke exports in 2009 due to levy of 40% export price by the Chinese government, discouraging coke export. Permanent closure of around 11 Mtpa coke capacity in Europe will lead to a reduction of export capability of Poland and Czech Republic, prime suppliers of merchant coke to Europe. Added to it is the undersupply in coking coal. Once coke trade returns to levels of around 30 mtpa (say by 2012), it is difficult to comprehend how other countries would meet the shortfall of China's 14 Mtpa export capacity. We are literally staring at a met coke shortage by as early as 2011 if the factors mentioned above do not change overnight which seems unlikely. Coke shortages are likely if China does not export as previously. Export from other traditional exporter like Japan is also on the decline. Polland, Columbia and CIS (Russia & Ukraine) remain the major suppliers, but the big question is - would they be able to meet the 12 – 15 MT deficits. As an alternate source it opens opportunity for merchant coke producers from traditional coke importing nations like India to increase capacity and come in to try to contribute towards bridging the widening demand supply gap. Blast furnace coke price has been on a steady rise in face of the shortage and eminent undersupply to meet the forecast pig iron production, which is being projected.

Development of Iron-making Technologies in Japan

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1. Introduction

The environment surrounding the iron and steel industry has changed greatly. This paper describes the technology adopted by the Japanese iron and steel industry to cope with changes in global demand, changes in the availability of coal and iron ore resources, correspondence to equipment superannuation, and energy conservation.

2. Recent Production Conditions and Changes in Production Structure

The Japanese production of crude steel and pig iron was changing by the economic growth of BRICS or the worldwide economic conditions. The transition of the number of blast furnaces and the inner volume of the blast furnaces is introduced.

3. Changes in the Availability of Coal and Iron Ore Resources and Progress of Pretreatment Technologies

3.1 Changes in circumstances of iron ore resources

Japanese steel industries are changing the imported foreign iron ore resources on the condition of cost reduction or high productivity of blast furnaces.

3.2 Process of iron ore pretreatment technologies

Many measures to increase production have been implemented. An example is introduced.

4. Correspondence to Equipment Superannuation

4.1 Extension of blast furnace life

The technology for hearth brick life extension is introduced.

4.2 Extension of coke oven life

To extend coke oven life, Nippon Steel Corp. has established technology for diagnosing and repairing the damage of firebrick walls, named DOC.

5. More Efficient Operation and Operational Stability

5.1 Development of hybrid bonded lump ore for blast furnaces that harmonize with resources and the environment

The technology that was developed by Kobe Steel, Ltd. changes low quality ore to lump ore by using the softening and melting phenomenon of coal.

5.2 CO_2 reduction in the sintering process by NG blown into the sintering machine

JFE Steel Corp. developed the Secondary-fuel Injection Technology for Energy Reduction (Super-SINTER). In this process, NG is blown in from the upper layer in the sintering bed.

5.3 Start up of SCOPE21 type new coke oven battery

In Nippon Steel Oita Works, No.5 Coke Oven, which is the first commercial coke oven of the SCOPE type, started operation on February 1, 2008 and stable operation is being continued now.

5.4 Improvement of productive efficiency of blast furnace

New numerical simulation technology adopted in the iron-making process, Search for efficient operation with an experimental blast furnace, NG injection to blast furnace are introduced.

6. Conservation of Energy and CO_2 Reduction Technology

6.1 Innovative iron-making process

The key technology is a compound material made of ferrous oxide, carbon material and metallic Fe.

6.2 COURSE 50

The development consists the development of hydrogen practical use technology, the development of cheap production technology of hydrogen, the CO_2 separation & collection technology in blast furnace gas and the utilization technology of waste energy for CO_2 separation & collection in ironworks.

7. Conclusions

The resources will change dramatically and the environmental problem is now the major challenge for humans and the Earth. We must exert the greatest possible efforts to solve these problems.

Application in Metallurgical Industries of Semi-coke Produced from Low Rank Coals in China

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China has abundant coal resources. The reserves of non-coking and low rank coals, such as open burning coal, non-caking coal and weakly caking coal, are about 484.3 billion ton and they are about 42.3% out of total coal reserves of China. This kind of coal concentrated mainly in Shenfu region of Shanxi, Eerduosi region of Inner Mongolia, Datong region of Shanxi and Xinjiang is low ash, low sulfur and low phosphorus content and high calorific value. So the semi-coke produced from these coals possesses the same advantages and also high reactivity and high resistivity. Due to the high quality and low price, the semi-coke is widely used in ferroalloy and carbide calcium making, gasification for fertilizer making and so on. Now, the production capacity has reached 30 million ton annually and the yearly production is about 20 million ton.

The first large scale vertical retort with capacity of 0.6 million ton per year designed by Sinosteel Anshan Research Institute of Thermo-energy Co., Ltd was constructed at Shenmu Shanxi and it was put into production in Sep. 2007.

For leading development of semi-coke production healthily and regularly, the semi-coke industry has been brought into regulation and administration of “Permission Conditions of Coking Industry” revised in 2008 which was published by Ministry of Industry and Information and realized in Dec.2008.

As a carbon reduction agent the semi-coke is applied in ferroalloy production and the power consumption is reduced about 369kwh and the reduction agent is economized about 98kg for production of per ton of 75% silicon ferroalloy. Up to now about 5Mt of semi-coke is used annually for ferroalloy production in China.

Due to the low ash, high fixed carbon, high reactivity and low price, the semi-coke has been used as injection fuel instead of anthracite. The industrial experiments show it can be injected into blast furnace with volume from 450m^3 to 3200m^3 and the injection ratio from 15% to 60%. And now the semi-coke consumption for blast furnace injection is about 1Mt per year and increases rapidly.

The industrial test of large size formed foundry coke made from semi-coke is carried out now. The research and test work of semi-coke as fuel used in ore sintering instead of coke breeze

and in ore pellet making with carbon are carrying out. The test work of semi-coke instead of small piece of metallurgical coke mixed with ore material for blast furnace charge is carrying and good results have been obtained.

Keyword: semi-coke, low rank coal, ferroalloy making, PCI, ore sintering, ore pellet making, formed foundry coke making

Quantifying the influence that the composition of the individual coal grains in coke oven feed has on coke quality.

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Prior to cokemaking coal is usually milled to about 85% passing 3.35 mm in order to obtain good coke strength by balancing bulk density in the oven and contact between coal grains. As well, conventional wisdom is that the amount of large inert particles should be kept low to prevent the formation of regions of poor bonding and weakness in the coke. Selective grinding techniques which preferentially reduce the size of inerts have been used to improve coke strength. Coal is a heterogeneous material so it is expected that individual grains of milled coal could be present as pure components of a single maceral (i.e. vitrinite, or inertinite) or mineral, or as composite grains, possibly as a function of the inherent coal properties and of the milling practice.

A detailed work program was conducted to establish the influence that the composition of the individual coal grains in coke oven feed, as opposed to bulk maceral composition, has on coke quality. Three coals were used in the work program. Coal A had a R_vMax of 1.5% and was from the Moranbah Coal Measures/German Creek Formation. Coal B was comprised of 2 parent coals each with a R_vMax of approximately 1.2% from the Illawarra Coal Measures. Coal C had a R_vMax of 1.5% and was from the Rangal Coal Measures.

Each coal was washed in the BMA Barney Point pilot wash plant to produce a vitrinite rich fraction (VRF) and an inertinite rich fraction (IRF). For each coal these fractions were milled to different size distributions then blended in the same ratio to produce coal samples with the same overall bulk quality and grind but different VRF and IRF grinds. Five different VRF and IRF grinds were coked for each coal using the same coking conditions. The only variable between tests was the grind of the VRF and IRF fractions.

Optical imaging techniques were used to analyse size fractions of the coke oven feeds to determine the distribution of macerals and grain types through the size fractions and the size distributions of the grain types. Nine size fractions were analysed for each coke feed sample. All five coke oven feed samples were analysed for Coal A, and three of the five coke oven feed samples (very coarse VRF/very fine IRF, normal grind and very fine VRF/very coarse IRF) were analysed for Coal B and for Coal C.

It was found the size distribution of the maceral groups and the grain types were altered by the different milling schemes and that this affected strength of the coke prepared.

For Coals A and B the abrasion indices showed increasing coke strength as the amount of fine non-fusible dominated grains increased or the amount of the coarse non-fusible dominated grains decreased. The former had more utility as a predictor of coke strength over the full range of abrasion indices. This is consistent with conventional wisdom.

Coal C, which has relatively low dilatation showed the reverse tendencies and differs from conventional wisdom. For this coal there was also a positive correlation between coke volume breakage strength and the amount of large composite grains in the coal sample. It is speculated that because of its relatively low dilatation coal C may not contain sufficient and/or sufficiently fluid material during coking to effectively bond all the inerts. Hence for this coal, fine grinding of the inerts may produce less close association with the bonding phases. This may be detrimental for coke strength when insufficient expansion occurs during the plastic stage to bridge the gap. This could explain why composite grains were positive for volume breakage strength. Fine grinding of inerts also produces a higher surface of material that needs to be bonded into the structure.

Update on ACA COAL21 Fund; Funding, Strategic Intent, Status of Projects

Jim Craigen

ACALET, Australia

The Australian Coal Association (ACA) is the industry peak body representing the interests of coal producers in this country. It primary role is to make representations to the Australian Government, and to a lesser extent State Governments, on key policy issues relevant to its members, recent examples being the Carbon Pollution Reduction Scheme and the Mineral Resource Rent Tax. The ACA also runs two technical programs on behalf of its members.

The first of these programs is the Australian Coal Association Research Program (ACARP). Established in 1993, ACARP is a research funding program directed to all aspects of the safe, environmentally responsible and profitable production of coal. This includes exploration, underground and open cut mining, coal preparation, technical marketing, road, rail and sea transport, and abatement of greenhouse gas emissions that result from mine operation. The area of ACARP activity most directly relevant to ironmaking is the provision of technical support to the marketing of metallurgical coals, with a primary focus on exports.

The second funding program is the COAL21 Fund, which was established in 2006 to facilitate the early demonstration of CO_2 emissions abatement technologies, with an initial focus on coal-fired power generation. A strategic portfolio of project investments has been established, all of which have a range of stakeholders including power generators, equipment and technology suppliers, federal and state governments as well as the ACA. Consideration is now being given to expanding the scope of the COAL21 Fund to include abatement of CO_2 emissions from other industries that use coal, including ironmaking. While power generation is by far the largest source of global CO_2 emissions from the use of coal, and the one attracting the majority of the political and media attention, the ACA is mindful that over 50% of Australia's coal exports are metallurgical coal and is developing options in consultation with its members.

Electromagnetic Processing of Materials (EPM) and Its Application to Environmental Engineering

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3 Graduate School of Engineering, Tohoku University, Japan

EPM seems to have good prospects for the future not only in the materials processing but also in environmental technology by the help of superior features like contactless processing and clean heating & melting. In the present paper, the authors will commentate on the potential of EPM to avoid environmental issues of energy, resources and hazardous wastes by the use of the functions of Lorentz force and Joule heating. Firstly, the situation of environmental issues will be introduced, which should be solved to realize sustainable society. And then, some applications of EPM to environment-friendly technology will be cited, which have been performed by the authors' group. The first example is the spherical solar cell that saves Si amount by direct fabrication of Si cell from the melt with higher yield than the traditional flat cell. Imposition of intermittent electromagnetic pinch force enables uniformly sized Si drops from a liquid jet in a high production rate. The second example is the weight reduction of vehicles by the replacement of steel with aluminum alloy for under body parts. Higher speed production of semi-solid slurry of Al-Si alloy for die-casting is achieved with the imposition of EMS to semi-solid manufacturing process. The third example is the electromagnetic fabrication of functionally graded particle-reinforced aluminum alloy having good deformability and hard surface. Aluminum screw for assembling wrought aluminum products is one application to avoid contamination of aluminum scrap by iron and to deliver the particle-dispersed aluminum to the particle resource. Final example is the electromagnetic vitrification of hazardous solid wastes. A susceptor-type-electromagnetic melting system having high efficiencies of heat generation is proposed for treating coal-fly ash and asbestos-containing wastes. In addition, the electromagnetic melting of low-level radioactive wastes is proposed to homogenize the melted waste before disposal.

A Sustainable Approach to Manage Dust Emission during Transport of Iron Ore and Coal

John Planner

Director Introspec Consulting, Australia

The management of dust emission during transport, stockpiling, reclaiming, and ship loading is a major issue for Australian iron ore and coal industries as output continues to expand. To meet sustainability objectives, particularly with respect to increasing community expectations, it is necessary for all sections of these industries to implement improved dust management.

The approach in the first instance involves application of water, effective enclosure of dust sources, minimized spillage and collection. However, to achieve the level of dust management required to allow major increases in throughput with no increase in dust emission levels, the approach must also involve the application of research into the dustiness characteristics of each individual iron ore and coal type.

Responses received from communities in close proximity to bulk handling and transport operations indicate that major environmental concerns are related to;

- Health issues which may result from poor air quality
- Nuisance dust deposition
- Possible health effects from dust in drinking water from rainwater tanks

Introspec Consulting has conducted research of bulk materials dustiness characteristics. Research has been conducted at the University of Newcastle to determine the relationship between dustiness and moisture content. Wind tunnels have been used to simulate the exposure of bulk materials to typical operational and weather conditions.

Investigation has determined the speed at which dust lift-off can occur from the surface of bulk materials, and the relative performance of stockpile surface treatment using water spray or chemical veneer application. Wind tunnel tests, using 1:50 scale model rail wagons, have been conducted at the University of Sydney to develop an understanding of dust emission from the surface of trains transporting bulk materials. Wind tunnel results were verified by computer modelling.

Additional research has shown that chemical agglomeration can be successfully used to reduce the fines content of bulk materials, achieving a range of benefits including control of dust emission, reduction in water content to control dust emission, and improved bulk flow properties.

Potential health issues related to trace elements from dust in domestic rainwater tanks have also been investigated to verify compliance with Australian drinking water standards. Samples from residential rainwater tanks adjacent to bulk handling facilities have been analysed for content in trace elements, internationally known to be related to health issues.

Outcomes from the research have been used to reduce dust emission from mining operations, rail transport, and port terminals throughout Australia. Dispersion modelling has been conducted, verified by on-site air quality sampling, to ensure that emission levels achieve compliance with environmental regulations.

Effect of mechanical offset agitation on mixing

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Keywords: Particle dispersion, Mechanical offset agitation, Water model, Impeller, Inclined vortex

In the steelmaking processes such as the desulphurization and dephosphorization processes, effective dispersion methods of low-density and fine particles are requested. Water model experiments are carried out in this study to promote quick and uniform dispersion of the particles into a molten metal bath contained in a cylindrical vessel in these processes. The bath is mechanically agitated by means of an impeller settled on the prescribed position of the bath.

When the impeller is placed at an offset position, an inclined vortex is generated under specific conditions. The dynamic behaviors of the inclined vortex can be classified into three types: stable, intermittently developed, and undeveloped types. The stable vortex is found to enhance the agitation efficiency significantly.

Particular emphasis is placed on the effects of the rotation speed of an impeller and the geometrical conditions of the impeller and the bath on the formation of a inclined vortex, the dynamic behavior of the vortex, and entrapment of low-density and fine particles into the bath.

Factors that influence the reactivity of the carbonised inertinite- and vitrinite-rich fractions with carbon dioxide

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In cokes, inertinite-derived material is reported to react more readily than vitrinite-derived material with carbon dioxide at high temperature. This difference has been attributed to the difference in carbon structure. However, since mineral matter is more associated with inertinite-rich components than with vitrinite-derived components, and recent findings have shown the importance of catalytic mineral matter in determining coke reactivity, it is likely that a large part of the difference in reactivity is due to the greater mineral matter content of the inertinite-derived component. This possibility is examined here. Inertinite- and vitrinite-rich fractions were prepared from four Australian bituminous coals in order to determine the dominant factors that affect reactivity of the carbonised maceral-rich fraction. The selection of the coals was based on rank, mineral matter content and ash chemistry. As expected, consistent differences were observed between the properties of the carbonised inertinite-rich fractions and their corresponding vitrinite-rich fractions. The size of anisotropic microtexture of the vitrinite-rich fractions was smaller than that for the inertinite-rich fractions because of the lower heating rate used for their preparation; the vitrinite-rich fractions swell more, which leads to high porosity in the carbonization product. The carbonised inertinite-rich fractions were characterised by much greater micropore surface area and smaller L_c than their corresponding vitrinite-rich fractions. The levels of catalytic mineral matter in the carbonised inertinite-rich fractions were significantly greater than in the carbonised vitrinite-rich fractions. The reactivity tests performed on the carbonised maceral-rich fractions at approximately 900ºC using carbon dioxide showed that the carbonised inertinite-rich fractions were far more reactive than their corresponding carbonised vitrinite-rich fractions. The increased reactivity of the carbonised inertinite-rich fractions was found to be mainly due to their greater levels of catalytic mineral phases and to some extent due to greater micropore surface area. Carbon crystallite height (L_c) did not appear to show a strong effect on the initial reaction rate.

Conversion of the OST pellet plant from hematite to magnetite feed and the development of an energy based efficiency program

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The Whyalla OST grate-kiln pellet plant was originally designed to process Iron Knob hematite fines and was commissioned in 1968 to produce export pellet. Over time the pellet plant became the primary source of iron units to the integrated Whyalla steelworks; making up 80% of the Blast Furnace iron unit feed. In 2004 Project Magnet was initiated to change the feed of the Whyalla Steelworks from hematite to magnetite and thereby extend the life of the steelworks beyond the then 10 year life of the hematite resource by using magnetite ore sitting beneath the existing Iron Duke hematite ore body. On the 5th December 2007 the Whyalla OST pellet was fed with magnetite concentrate for the first time. Conversion of the steelworks to a magnetite feed involved a series of significant developments however the current presentation will focus on changes to the pellet plant operation. In addition the development of a process to identify, prioritise and implement opportunities to reduce both energy demand and carbon footprint, as they pertain to the pellet plant, will be described.

HADEED – The Saudi Iron & Steel Company - Working towards a sustainable future

Mansour Al-Harbi, Syed Niaz Ahsan, Mohammad Essa Samman

Metals Technology, SABIC T&I, Saudi Arabia

In order to be sustainable, the Iron & steel Industry has always been looking for ways and means to enhance productivity, conserve energy and utilize waste streams.

HADEED, the Saudi Iron & Steel Company, is one of the leading DRI based steelmaker with 05 DRI modules and EAF steelmaking facility.

The presentation will discuss how SABIC / HADEED have successfully implemented programs to enhance Energy utilization and recycling of waste by-products.

Note: Dr. S. N. Ahsan is working as Chief Scientist and Mohammad Essa Samman as Research Engineer at Metals Technology, SABIC T&I, Al-Jubail, Saudi Arabia.

View Points and Possibility of Innovation of Blast Furnace Ironmaking

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Reduction of CO_2 emission is the most important subject in the blast furnace operation. The key point of reduction of CO_2 emission is to decrease the Fe-FeO-CO-CO_2 equilibrium temperature theoretically as shown in Fig.1. Considering the equilibrium temperature is decided by the carbon solution loss reaction, an acceleration of its reaction might be the key technology in the blast furnace ironmaking. Recently, various methods such as the alkali addition to the coke and the carbon composite agglomeration have been studying to accelerate the carbon solution loss reaction and the iron ore reduction. In these studies, it was found that the beginning temperature of carbon solution loss reaction was decreased by the vicinity arrangement of ore and coke. It shows the possibility for innovation of blast furnace ironmaking. This paper introduces the acceleration of iron ore reduction and carbon gasification reactions in the vicinity arrangement of ore and coke as shown in Fig.2

Key words: CO_2 emission, blast furnace, carbon solution loss reaction, reduction, vicinity arrangement of ore and coke

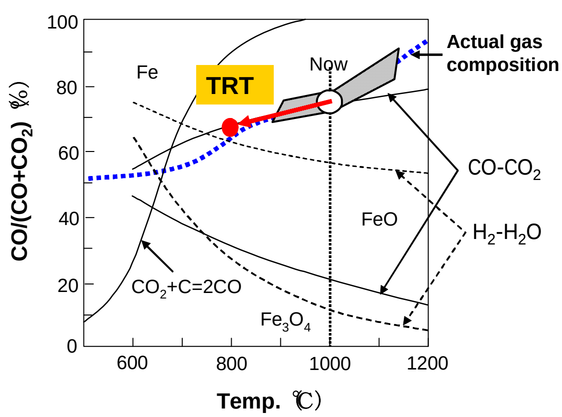

Fig.1 Fe-FeO-CO-CO_2 equilibrium in the blast furnace.

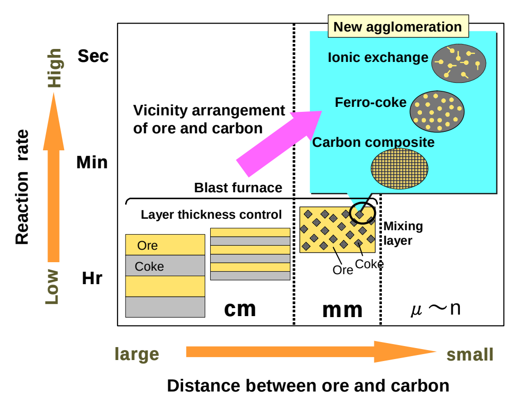

Fig.2 Acceleration of reaction rate by vicinity arrangement of ore and coke.

Clean Green Steel Making- Assessing the Technology Options

Garth Peters, Leigh Harris, Michiel Freislich & Steve Gale

HATCH, Australia

Environmental legislation is rapidly changing- especially around energy efficiency and greenhouse gas (GHG) emissions. Steelmakers are challenged to choose the right investment when-

- Adapting existing assets.
- Meeting growing demand.

Existing plant can be retrofitted to improve efficiency and reduce emissions. There are limits to the improvement that can be achieved and it is important for asset owners and regulators to understand these limits when setting performance targets. With the help of the novel GHG Carbon Abatement Process (G-CAP™), Hatch is helping steel companies and others achieve the right balance in target setting.

New technologies offer the potential to breakthrough energy efficiency and emissions limits faced by even the best of conventional plants. At the same time these technologies enable iron to be produced closer to the mine- reducing emissions from transport.

We compare the energy efficiency and GHG emissions of the major iron making routes. We have considered DRI with coal gasification and the option of carbon capture and sequestration (CCS) in detail.

This technology allows iron to be produced with only low rank coals as a fuel/reductant- no need for expensive metallurgical coal or natural gas. Low rank coal is generally more widely available than metallurgical coal or natural gas, hence increasing the probability that the Ironmaking plant can be sited close to the ore body.

Carbon (CO_2) capture is an integral part of efficient DRI processes- by improving the capture and adding a sequestration step the process becomes clean. Our findings are that low rank coal gasification, CRI and CCS combined can reduce GHG emissions by an order or magnitude compared with conventional processes.

Measurement of phase diagrams and in-situ observation of melting and solidifying behaviors for the CaO-SiO_2-FeO_x-Al_2O_3-MgO system at various oxygen partial pressures

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Iron ore sintering is an important process to supply sinter ore for blast furnace operation. Iron ore powder is mixed with coke and lime to be burnt in the sintering machine. Formation of liquid phase and control of solidified structure is the key technology to maintain sinter quality such as strength, reducibility, melting and softening behaviors, and so on.

The CaO-SiO_2-FeO_x system is the primary oxide mixture for sinter ore production. Although phase diagrams for the CaO-SiO_2-Fe_2O_3 system at air atmosphere and for the CaO-SiO_2-FeO system at the equilibrating condition with metallic iron are well known, very few phase diagram for the CaO-SiO_2-FeO_x system at the intermediate condition has been reported so far. In addition, MgO is added to sintering material to keep the sinter ore quality since high quality iron ore has been depleted and Al_2O_3 content in iron ore is increasing recently. Therefore, it is also required to clarify the effect of Al_2O_3 or MgO addition on the phase diagram for the CaO-SiO_2-FeO_x system.

In the present study, the phase diagrams for the CaO-SiO_2-FeO-Fe_2O_3 system were measured at moderate oxygen partial pressures by chemical equilibration technique at 1573 K, and the effect of Al_2O_3 and/or MgO addition was also investigated. Furthermore, the melting and solidifying behaviors of oxides with changing oxygen partial pressure were directly observed by a confocal scanning laser microscope.

The liquid area of the phase diagrams tended to enlarge toward SiO_2 corner while $2CaO \cdot SiO_2$ saturating region expanded with lowering oxygen partial pressure from 2.1×10^{2} to 1.8×10^{-3} Pa. Al_2O_3 addition tended to enlarge the liquid area. On the contrary, MgO addition reduced the area at high FeO content region.

Solidification time decreased with increasing (mass%CaO)/[(mass%CaO)+(mass%SiO_2)] ratio with changing oxygen partial pressure between 2.1×10^{4} and 2.1×10^{2} Pa and the effect of FeO content was not obviously observed. On the other hand, relationship between melting or solidification time with changing slag composition and oxygen partial pressures between 0.18 and 1.8×10^{-3} Pa was not clearly observed and the duration was shorter compared to those between 2.1×10^{4} and 2.1×10^{2} Pa.

Technologies for Sustainable Blast Furnace Ironmaking

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Steel industry is one of the most energy-intensive industries, accounting for about 4% of world greenhouse gas emissions. The raw materials and ironmaking processes involved account for ~90% of emissions in the steel industry. Various technologies have been developed for sustainable blast furnace ironmaking. Understanding the fundamentals for these technologies is important. Mathematical modelling, facilitated by physical modelling, provides a cost-effective way for process understanding, design and optimization. This study will briefly review the current developments in ironmaking, and then discuss the role of process modelling and optimisation in the development of new technologies for sustainable ironmaking. Two examples are given in details: modelling of a specific technology- pulverized coal injection; and modelling of the whole blast furnace operation. It is demonstrated that they will play a significant role in improving process efficiency and reducing CO_2 emission, important to sustainable blast furnace ironmaking.

Progress of the Australian Steel Industry CO_2 Breakthrough Program

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This program is the Australian steel industry's contribution to the WorldSteel Association's "CO_2 Breakthrough Program" and comprises two projects that commenced in late-2006. Funding has been by the two steel companies (OneSteel and BlueScope Steel) and the Australian Government via CSIRO and also the Centre for Sustainable Resource Processing (to June 2009). The projects are:

- Use of Biomass in the Iron and Steel Industry
- Heat Recovery from Molten Slags through Dry Granulation

Since the time of our paper to the 2nd International Symposium on Sustainable Ironmaking (September 2008), there have been several areas of significant progress:

- *Preparation of a tonnage sample of low-volatile charcoal.* 20 t of hardwood logs were pyrolysed in beehive coke ovens at around 1000°C. The product was crushed to size, dried, characterised and secured in airtight plastic-lined paper bags.
- *Industrial trial of low-volatile charcoal as a steel ladle recarburiser*. This trial was conducted at OneSteel's Sydney EAF steel mill where charcoal was substituted for the standard recarburiser. The results indicated improved and more consistent recovery of carbon, and only marginal pick-up of hydrogen.
- *Combustion testing of various charcoal products for blast furnace tuyere injection.* Hardwood and softwood charcoal samples with volatile matters from 4 to 19% have been tested under simulated BF conditions (coaxial lances, 1200°C air blast with O_2 enrichment). All charcoal samples burned well and behaviour was shown to be similar to coal having much higher volatile matter.
- *Approaches to production of high density charcoal*. Preliminary tests have shown promising pyrolysis results using either pre-compressed wood pellets or heating under compression.
- *Fundamentals of the pyrolysis of woody biomass*. Laboratory tests on the kinetics of pyrolysis have permitted the quantification of the main factors affecting the

performance of pyrolysis reactors. Work is underway towards the development of a continuous process for production of bio-chars, bio-oil and bio-gas from biomass sources.

- *Development and testing of the first dry slag granulator with integrated heat recovery at pilot-scale*. Following the proof of concept through series of pilot scale tests using iron blast furnace slags, the fast quenched granulated slags were characterised and their suitability with respect to substitute material for Portland cement was confirmed. An advanced CFD model of the dry granulation reactor was developed as a tool for process optimisation and for designing of semi-commercial and commercial reactors. More recently, a semi-commercial scale dry granulation pilot plant has been designed and constructed at CSIRO. Future work includes commissioning of this new pilot plant, validation and use of the CFD model for scaling up the process to a commercial scale and demonstration of the technology through plant trials.

Greener Steelmaking by Direct Reduction Process

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Steel production requires iron ore and coal, and is accompanied by greenhouse gas emissions. The annual production of the world crude steel increased from 900 million tonnes to 1.3 billion tonnes since 2002, and is anticipated to increase due to the continuous economic growth in developing countries. The adoption of iron and steel making processes with superior raw material flexibility and environmental friendliness to the conventional processes is highly required.

Approximately 5% of the world CO_2 emissions are due to the iron and steel production. The BF-BOF route is the major iron and steel making process, producing about two thirds of the world steel. About 2 tonnes of CO_2 is generated per tonne of steel produced by the BF-BOF process. The CO_2 emissions in the steel industry have largely increased as the steel production increased in the last decade, in spite of the increased concern in global warming.

The BF requires high grade iron ore and coking coal, since sintered ore with high Fe content and coke with high strength is needed in order to guarantee consistent flow patterns of the burdens as well as the process gas flow through the burdens. Continuous supply of the high grade iron ore and coal has also become a major concern in the steel industry due to the increase in steel production. Scrap, on the other hand, is an important iron unit that has accumulated consistently as steel products were consumed during the decade.

In this presentation, two direct reduction technologies “Midrex®” and “ITmk3®” are considered as ironmaking processes followed by EAF to produce steel, and are compared with the BF-BOF route.

The Midrex process uses natural gas as a reductant to remove oxygen from iron ore and as a fuel to provide heat. Natural gas can also be used to produce electricity required for the EAF. The combination of the Midrex process and the EAF can lower the CO_2 emissions per tonne of steel significantly, when compared with the BF-BOF process.

The ITmk3 process uses coal as a reductant. Iron ore fines are mixed with coal fines, agglomerated into green pellets and processed in the RHF to produce “Iron Nuggets” which are equivalent to pig iron in terms of chemical composition. Since high strength is not required for the green pellets in the RHF, non-coking coal can be used as a reductant. Lower CO_2 emissions can be achieved by the ITmk3 process, when compared to the BF-BOF process.

Steelmaking by feeding either the Midrex DRI or ITmk3 Iron Nuggets to the EAF together with scrap can significantly decrease the CO2 emissions while satisfying the steel quality by diluting the impurities containing in the scrap, as well as conserving the natural resources of high grade iron ore and coal. Steel production by using the direct reduction processes together with scrap is a suitable and reasonable solution for the increasing demand in sustainable iron and steel making.

Introduction of the Research Projects of ISIJ for the Flexible and Low Carbon Iron Ore Sintering Technology

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The properties of iron ores used in ironmaking process have been drastically changed in the past couple of decades. Especially, the change has become significant in the last few years because of the considerable increase in the world steel production. The property change of the iron ore is mainly caused by the depletion of the hard and high-grade lump hematite ores. It has led to the increasing use of ores containing a larger amount of goethite/limonite, *i.e.*, hydro-oxides of iron. Typically, the proportion of pisolitic ores, which are course limonitic ores, has remarkably increased by several times in Japan. Further, large deposits of the fine goethite ores called Marra Mamba have been developed in Australia and exported to Asian countries. Such trends will be continued in future. Since the change of the ore properties affects not only to the productivity and yield of the sinter but also its metallurgical properties in the blast furnace, further improvement in the sintering technology/process is required including the preliminary treatment process of raw materials.

In order to make wide researches concerning the above issues, the research project *"New Sintering Process through Designing of Composite Granulation & Bed Structure"* was formed in the ISIJ, which was the collaborative project between Japanese steel companies and several universities. The project was started in 2005 and carried on the wide range of studies for three and half years. Its main objects are the characterization of pisolitic/goethitic ores and the understanding the behavior during the iron ore sintering process. Further, considering the ore characteristics, some basic researches on the optimum designs of raw material blending, granulation, bed structure, and the metallurgical properties of the produced sinter were performed. The project have invented the technical principle of a new sintering process, namely MEBIOS (Mosaic EmBedding Iron Ore Sintering Process), characterized by the composite granulation and bed-structure, aiming to cope with the drastic shift of the ore properties.

Another big issue fallen on the steel industry is the global warming. CO_2 emission from steelmaking industry occupies about 15% of the total value of the artificial emissions in Japan and therefore its reduction is urgently required.

In order examine the possibility to minimize or to reduce further the CO_2 emission from the iron ore sintering process, the research project "*Technological Principle for Low-Carbon Sintering*" has been formed since 2009 in the ISIJ. In this project, the analyses of the combustion rates of carbonaceous materials and heat transfer in the sintering bed are first examined by referring the previous studies. Further, experimental works will be conducted on the combustion/oxidation characteristics of biomass charcoal, some organic wastes, steel can scraps, mill scale and partially reduced iron ores as alternative agglomeration reagents of coke and anthracite coal. The effect of their use on the sintering process will be evaluated systematically. It is expected that the structural changes of the sintering bed is considerably different between carbonaceous materials, which disappear during combustion leaving a little amount of ash components and metallic iron bearing materials, which increase the mass and volume during its oxidation. Previous studies showed that the use of metallic iron bearing materials such as steel can scrap and mill scale led to significant decreases in the production rate.

This project examines the characteristics of such changes of the sintering bed structure and mineral phases and main process parameters, which govern such phenomena. Further, it searches for a new process principle to overcome the demerits and realize the significant reduction of CO_2 emissions from the iron ore sintering process.

In the symposium, summary of activities and the major results and progresses of the above two research projects will be introduced.

Use of Process Integration methods for evaluation of energy and GHG emission strategies in ironmaking and steelmaking

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Profitability is one of the foundations for industrial sustainable development. In general, cost and performance have to be balanced in an industrial system. This is one of the incentives for developing systematic and all-embracing methods to analyze the trade-offs between two or more objectives, i.e. emissions and costs, energy utilization, material efficiency, and other resources.

Climate change, energy efficiency and management of CO_2 are definite issues for the steel industry. Much of the research and development within the CO_2 area take place internationally, often in co-operation between academic and applied research groups at universities, institutes and the industry. The research comes up with general conclusions. New or improved technology options will be presented. The best solution for each company or production site will depend on the local conditions, the existing technologies, the availability of energy carriers and raw materials, the legislation, and a lot of other factors.

The Process Integration approaches can be used to optimize energy efficiency and/or for CO_2 minimization at site level in integrated steelmaking systems. It can also be used to evaluate different technology options or operational strategies. In our case, a method based on mixed integer linear programming (MILP) and the MIND method has proved to be particularly useful for optimization and/or simulation of integrated iron- and steelmaking systems. The MIND method (Method for analysis of INDustrial energy systems) represents the industrial system as a network of process nodes, connected by energy and material flows. This type of optimization models for an industrial system can therefore be used to manage complexity, to manage changes, to facilitate faster decisions, and is a powerful complement to other modeling and simulation tools.

The presentation will include a Process Integration method overview and some examples on studies covering costs, energy and CO_2 aspects of ironmaking and steelmaking.

Value of Coal Beneficiation Development

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Coal beneficiation has gone through several periods of evolution in the past where research and development (R&D) has provided breakthroughs in significant areas of technology that have improved efficiency, reduced costs, increased recovery and enhanced product quality. Some very simple ideas have led to significant improvements and some complex solutions have become possible via sophisticated control technologies borrowed from other engineering disciplines.

The past decade has been a period of significant progress in technology development and with it has come a more holistic approach to coal treatment. It is now more common for a “whole of supply chain” approach to be adopted in determining the processing needs of an end user. This has in turn encouraged more R&D in specific applications.

The continuing contributions from Industry that provide research funds like ACARP in Australia and CoalTech 21 in South Africa have enabled producers to maintain a clear focus on relevant issues and have identified urgent problems needing solutions. This paper covers some aspects and examples of the contribution that R&D has provided in the development of coal preparation technologies in the last 10 years and raises some potential opportunities for sharing knowledge and innovation in the future.

Understanding Coke Behavior in a Blast Furnace

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Coke quality is critical to blast furnace process which is the predominant route for ironmaking from virgin iron ore. Currently, a range of coke quality tests are used to assess suitability of coals to make a high quality coke. Most of these coke quality parameters including cold strength (e.g. DI/Micum test) or hot strength (e.g. CSR) are empirically associated with coke performance in BF as well as with conventional coal properties including oxide ash analysis of parent coals. Due to limited understanding of coke properties in a working blast furnace, operators have to rely on these coke quality parameters. This paper provides some of the recent results of an ACARP sponsored study to improve understanding of coke characteristics in lower zone of a working blast furnace with emphasis on high temperature mineral chemistry of cokes. Mineral matter of coals and lower zone cokes were characterized using SIROQUANT/XRD and SEM and related to coke fines. Implications of lower zone coke chemistry on the coal properties are also discussed.