ABSTRACTS
2016 Blast Furnace Ironmaking Course

1. **Historical Development and Principles of the Iron Blast Furnace**
   John Ricketts, ArcelorMittal Steel USA
   The evolution of ironmaking raw materials, equipment and practices will be reviewed from ancient Egypt to the present. The basic principles of iron making will be introduced throughout the historical development chronology. The final result of this presentation should be a basic understanding of the iron making process and the roots of the modern blast furnace facilities and operation.

2. **Blast Furnace Reactions**
   Text by Wei-Kao Lu, McMaster University
   Updated by Bob Nightingale, Wollongong University,
   Blast furnace ironmaking involves many chemical reactions. This is only to be expected since a number of quite different raw materials are used and the furnace environment spans a very wide temperature range.
   A good grasp for a small number of these reactions is essential to any reasonable understanding of the process. These key reactions involve iron oxides, carbon and carbonaceous gases. Our time today will be spent mainly on these. However, some references will also be made to elements that present problems – either to the blast furnace process itself or to its steelmaking customers.
   The physical configuration within the furnace needs to be understood since the important reactions occur between gases and solids and the efficiency and continuity of these contacts must be assured for good operation. The physical structure of the Cohesive Zone and its role as a gas distributor will be examined.
   Topics such as raw material quality, burden distribution and tuyere practice are also of vital importance in the control of the chemical reactions upon which stable and efficient operations rely. These will be covered in detail in other lectures of this course.

3. **Environmental Issues in Blast Furnace Ironmaking**
   Frank Harrison, U. S. Steel Canada
   This paper will discuss aspects of the operation of a Blast Furnace that have the potential for adverse air, water or waste environmental impacts. These include the emission of air contaminants (such as particulate matter, sulfur dioxide and nitrogen oxides) and greenhouse gases (in particular carbon dioxide), and water contaminants (such as metals, cyanide, ammonia and suspended solids). Blast Furnace ironmaking also generates coproducts such as slag, dust and sludge. Although beneficial use of slag and dust is widespread, Blast Furnace sludge often requires disposal. In addition, the paper will discuss the use of Environmental Management Systems in managing the environmental risks associated with Blast Furnace ironmaking.

4. **Fundamental Principles Applied to Blast Furnace Safety**
   Fred Rorick, Rorick Inc.
   Not everyone can agree on just what "Blast Furnace Safety" actually is. A legal requirement? A company guiding principle? An environmental problem? Something else? All of the above? It is certain, however, that the Blast Furnace Manager will be held accountable for the results according to his company's program. There are many different types of safety programs available for the Manager to utilize, in addition to those mandated for him. This paper will provide a roadmap of how to define just what "Blast Furnace Safety" is, how to organize an effective safety program melding the options and mandates, and how to do it all in a simple and organized way, utilizing the fundamental principles provided in the lecture titled "Challenging Blast Furnace Operations."

5. **Blast Furnace Energy Balance and Optimization (Computer Game)**
   John Busser, Hatch
   Simplified mass and energy balances are outlined for the purpose of optimizing blast furnace operations. A summary of useful blast furnace related data from numerous sources is presented. Tuyere zone, stack and general blast furnace reactions are reviewed from an energy standpoint. The impact of variability in blast furnace input parameters is discussed. "Rules of Thumb" relating furnace raw material and practice changes to energy consumption are reviewed. These principles are demonstrated through a computer simulation model "The Blast furnace Game" that uses mass, energy, chemical and cost balances to assess means of improving the blast furnace process.

6. **Blast Furnace Design I**
   Dave Berdusco, Paul Wurth Inc.
   Today's efficient blast furnace operations have evolved through developments in raw materials preparation and quality; blast furnace design, including profile, cooling system, refractory configuration; cast house layout and operations; improvements in equipment and the application of automation, controls and Blast Furnace Expert Systems.

   This lecture which is complementary to others being presented on the course, reviews the following components and sub-systems which form the blast furnace iron making plant.

   » BF iron making materials flow sheet
   » Stockhouse
   » BF charging equipment
   » BF proper; design for efficient operation and long campaign life
   » Cast house; hot metal and slag handling with associated equipment

7. **Blast Furnace Design II**
   Peter M. Martin, PE, Primetals Technologies USA LLC
   Blast Furnace Design II covers the air (blast) and gas system designs for modern blast furnace operations. The desire to improve blast furnace operation and lower operating costs have led to significant increases in hot blast pressure and temperature during the past forty years. These changes have required considerable design and operating improvements to be made in the air and gas system designs. The subject will be covered in the following areas:

» Importance of Hot Blast Temperature
» Functional Layout and Design of Hot and Cold Blast Systems
» Hot Blast Stove and Ancillary Equipment Design
» Stove Firing and Operation
» Operation Optimization and Energy Recovery from Stove Waste Gas
» Importance of Blast Furnace Gas Cleanliness
» Gas Cleaning System Design
» Top Pressure Control and Energy Recovery Turbines

8. **Ironmaking Refractories: An Outlook Based on Daily Operation and Successful Maintenance**
   Floris van Laar, Integrated Steel Allied Minerals Products Inc.
   The blast furnace is one of the most efficient iron making facility in existence. The iron making process must have reliable refractory systems to sustain its operation. All high temperature process areas are protected by refractory systems.
   This paper focuses on refractories systems and materials with which operators have to cope with.
   Also equipment components, which depend on long-term stability of the refractory systems, like the furnace hearth and hot blast stoves, are reviewed.
   The criteria in taking the proper steps for iron making refractory materials selection and how to operate systems with-in predictable limits will be discussed.

9. **Iron-Bearing Burden Materials**
   Marcelo Andrade, ArcelorMittal USA
   Iron ore pellets, sinter, and lamp ore are the main iron-bearing burden materials used in the blast furnace. This lecture will cover how properties of pellets and sinter affect blast furnace performance in terms of fuel consumption, production, and campaign life. The choice between pellets and sinter is largely a matter of mineralogy of ore and geographic location of iron ore sources relative to the steel mill. Limestone and dolomite fluxed pellets are widely used in North America in view of their improved metallurgical properties which significantly improve blast furnace efficiency. Recycling of in-plant generated steel mill wastes has become an important function of the Sintering process. Briquetting is occasionally employed for the same purpose. Direct reduced iron (DRI) or hot briquetted iron (BBI) is used to improve productivity of the blast furnace. Handling, economic, and technical considerations in using these unconventional materials in the blast furnace will be covered. Pellet and sinter property needs are more stringent for high productivity

and low coke rate (due to high coal and/or natural gas injection rates at the tuyere) blast furnace operation. An integrated system perspective, including iron production priorities, blast furnace equipment, and raw materials, is essential for selecting optimum iron-bearing burden material composition for a specific blast furnace.

10. **Blast Furnace Control - Measurement Data and Strategy**

R. J. Nightingale, University of Wollongong, Formerly ; Bluescope Steel, Port Kembla, N.S.W., Australia

The competitive realities of modern blast furnace practice necessitate high standards of product delivery, quality, safety, environmental compliance and extended asset life. All need to be achieved consistently at an acceptable cost. The development of sound operating control strategies is a basic necessity.

Near term control of production rate and quality are strongly dependent on strategies to control thermal balance and gas distribution. These are increasingly based on complex models founded in basics of thermodynamics and fluid flow. Data from sophisticated sensors and probes is required for successful application. Proper calibration and maintenance standards are essential to operator confidence and interpretation.

In the longer term, decisions about raw materials sourcing and preparation set the foundations for process capability. Decision makers must be able to respond to variations in market pricing while respecting guidelines that define the boundaries for adequate operation.

In both the shortest and longest terms, diligent monitoring of asset status provides the key to maximising process safety and value extraction from any furnace asset. These data also provide the best basis for improvement decisions at reline time.

This paper will also discuss hearth dynamics and explain the formation, behaviour and influence of the deadman coke bed. The interpretation of hearth thermocouple data in relation to both refractory wear and liquid flow regimes will also be discussed.

11. **Maintenance Reliability Strategies in an Ironmaking Facility**

Johan van Ikelen, consultant, ret. Tata Steel,

In order to establish and maintain maximum output of the blast furnace, equipment reliability is paramount.

On a day to day, week to week and month to month basis the blast furnace is required to operate without interruption to allow downstream processes to function with a consistent supply of hot metal, liquid steel and semi-finished product. Only then can the integrated steel production facility maximize equipment assets to produce a quality product, on schedule and within set budgets.

At the blast furnace, there must be a proper maintenance strategy to ensure reliable, consistent operation, with provision for timely outages and possibilities to use unscheduled outages.

The key word is “installation condition knowhow”, which starts with knowhow of the built installation and recognition of the critical installation parts. That should be combined with a simple inspection system, which provides knowhow over the condition and signals of future breakdown treats of the working installation.

But remember this saying of Nelson Piquet, former World champion F1 auto racing:

When you measure it, you can control it. When you control it, you can improve it. But when you want to control everything, you are not driving fast enough!

That means to make the choice, based on skilled personal knowhow, of what you will measure and how to improve your installation performance. But do not overreact on such measurings and preventive maintenance actions; otherwise your maintenance will be very costly.
Supported by a maintenance information system, which must show trends in wear and degrading, so that maintenance actions can be planned on time, just before breakdown or performance quality loss resulting in a high installation availability and performance with the lowest maintenance costs.
This presentation is intended to explain this program and factors required that influence its success.

12. **Coke Production for Blast Furnace Ironmaking**
    Hope D. Huntington, Clark Testing
    This presentation will contrast the coke requirements for successful blast furnace operation with requirements for the cokemaking process. In many cases these requirements conflict with each other. Production of high quality coke necessary for efficient blast furnace operation is limited at the coke plant by coal cost and availability, coke production throughput, and coke battery life. The objective is to facilitate a better understanding between ironmakers and cokemakers with the ultimate purpose of producing the lowest cost, highest quality steel. The following topics will be covered: 1) coke properties and their importance to the iron making process, 2) coke production and the theory of carbonization, 3) factors affecting coke quality, battery productivity, and battery life.

13. **Day-to-Day Blast Furnace Operations**
    Art Cheng, Former SeverStal North America, Inc.
    A blast furnace involves significant capital and energy intensive processes. Due to complex phenomena and the difficulty of taking measurements, the knowledge needed for process optimization can be most readily obtained through the development of high fidelity computational fluid dynamics (CFD) modeling and simulations. Such modeling and simulations are powerful tools that can provide detailed information on hydrodynamics, heat transfer, and chemical kinetics for gaining fundamental insights, investigating the impact of key operation and design parameters, and developing strategies to optimize the blast. Recently, Virtual Reality (VR) technology has provided an efficient means of visualizing and analyzing huge amounts of CFD data in a virtual environment. It allows people "walk" inside a blast furnace and enables us to have more intuitive and comprehensive understanding of complex phenomena and better communication with people of various technical backgrounds, leading to more innovative and cost-effective solutions. The Center for Innovation through Visualization and Simulation (CIVS) at Purdue University Calumet has developed and validated several state-of-the-art 3-D blast furnace CFD models in collaboration with steel companies. These CFD models include the hearth model, PCI model, and shaft model. Blast Furnace Simulators and Virtual Blast Furnaces have been developed through the integration of CFD modeling and VR

visualization. The Blast Furnace Simulators have been used for the troubleshooting and optimization of blast furnace operation, resulting in the saving of multiple millions of dollars and significant reduction of furnace downtime. The Virtual Blast Furnaces have been used for training in steel companies and have received excellent feedback.

14. **Challenging Blast Furnace Operations**
Fred Rorick, Rorick Inc.
Day-to-day blast furnace operations have improved as the process has become more thoroughly investigated and understood, and as standardized practices and techniques have been rigorously implemented. There is a substantial body of opinion, however, which tends to believe that those standardized practices do not and cannot apply to the more challenging operations, such as blow-in, blowdown, and especially chilled hearth recovery, because those circumstances are always uniquely different from furnace to furnace, and even for the same furnace at different times. That opinion is wrong. It turns out that standardized approaches to the more challenging operation circumstances are both available and proven to be directly applicable. This paper will be specifically address some general rules to avoid getting into blast furnace difficulty in the first place, followed by more detailed explanation of four elements of furnace shutdown (bank, gravel bank for reline, salamander tap, and blowdown), two types of restart (from bank and from empty furnace condition), and an additional segment on recovery from a cold furnace or chilled hearth condition. In each case, fundamental principles, and their application, will be explained.

15. **Burden Distribution and Aerodynamics**
Steve Yaniga, U. S. Steel Corp.
The manner of charging raw materials to the blast furnace affects the distribution of gases that reduce and heat the descending burden materials. The distribution of burden and gases in the stack has a strong effect on the efficiency of gas-solid reactions and on shaft permeability. These in turn have a large influence on furnace performance as measured by fuel rate and productivity. In addition, burden and gas distribution have an effect on furnace lining life and hot metal chemistry.
In this lecture the effects of raw material characteristics, charging practices, charging equipment and furnace geometry on burden and gas distribution and furnace performance are presented. Fundamental concepts and techniques used to physically and mathematically model burden and gas distribution are reviewed. Practical applications of instrumentation to measure and control burden distribution are presented. Some examples are given concerning the use of various types of charging equipment to improve burden and gas distribution and furnace performance. Finally, some principles are outlined for the optimization of burden and gas distribution with respect to furnace fuel efficiency, productivity and lining wear.

16. **Ironmaking/Steelmaking Interface**
Mike Price, ArcelorMittal Dofasco
A healthy customer-supplier relationship between Ironmaking and Steelmaking is vital. Understanding the needs of each department will ensure an optimized

solution. Optimization of both Ironmaking and Steelmaking is dependent upon regular and consistent communication, working models and a fundamental understanding of each other's business.
The production planning process translates market demands into facility deliverables for each operation.
Hot metal specifications generally reflect a balance between the plant infrastructure and technology utilized, process capability, raw material inputs along with the internal customer requirements.
Management of hot metal inventory is a primary consideration for operational and process control which supports the monthly or annual production and cost targets.
Opportunities to lower costs are available through recycling of by-products and other wastes into the Blast Furnace.

17. **Fuel Injection in the Blast Furnace**
Donald Zuke, ArcelorMittal IH
This lecture will discuss the history of blast modification used in the blast furnace. Discussions on combustion reactions and raceway phenomena will provide the background to the concept of replacement ratio. Examples of the replacement ratio will be given. The impact of fuel injection on burden and gas distribution will be described. The injectants discussed will be natural gas, oil, tar and coal.

18. **The Science and Technology of Blast Furnace Slag**
John D'Alessio, U. S. Steel Canada
This paper addresses the fundamentals of blast furnace slag and its importance to the overall blast furnace operation efficiency, stability and cost. The properties of slag melting points, chemical composition, structure and temperature are reviewed. Slag control practices for sulfur and alkali removal, viscosity, slag volume and operating tolerances in composition and temperature are discussed.

19. **Casthouse Practice and Blast Furnace Casthouse Rebuild**
Barry Hyde, Hatch
This presentation will attempt to impart an understanding of the principles behind casting practice and their effect on Blast Furnace operation. The presentation will follow a path beginning with a review of technological limitations on pre 1970 designed casthouses and refractories. It will then be followed by explanations of present day furnace process requirements and Blast Furnace Operator's casthouse objectives. An example of modernizing a 1960's vintage two taphole furnace will be discussed. The discussion will follow the evolution of this modernization including installation of tilting runners and a fugitive emission collection system during operation, results of trough water modeling studies, and the complete revamp of both casthouses during a reline.

20. **Blast Furnace Modeling and Visualization**
Chenn Q. Zhou
Center for Innovation through Visualization and Simulation
Purdue University Calumet
A blast furnace involves significant capital and energy intensive processes. Due to complex phenomena and the difficulty of taking measurements, the knowledge needed

for process optimization can be most readily obtained through the development of high fidelity computational fluid dynamics (CFD) modeling and simulations. Such modeling and simulations are powerful tools that can provide detailed information on hydrodynamics, heat transfer, and chemical kinetics for gaining fundamental insights, investigating the impact of key operation and design parameters, and developing strategies to optimize the blast. Recently, Virtual Reality (VR) technology has provided an efficient means of visualizing and analyzing huge amounts of CFD data in a virtual environment. It allows people “walk” inside a blast furnace and enables us to have more intuitive and comprehensive understanding of complex phenomena and better communication with people of various technical backgrounds, leading to more innovative and cost-effective solutions. The Center for Innovation through Visualization and Simulation (CIVS) at Purdue University Calumet has developed and validated several state-of-the-art 3-D blast furnace CFD models in collaboration with steel companies. These CFD models include the hearth model, PCI model, and shaft model. Blast Furnace Simulators and Virtual Blast Furnaces have been developed through the integration of CFD modeling and VR visualization. The Blast Furnace Simulators have been used for the troubleshooting and optimization of blast furnace operation, resulting in the saving of multiple millions of dollars and significant reduction of furnace downtime. The Virtual Blast Furnaces have been used for training in steel companies and have received excellent feedback.

21. Ironmaking in Western European Blast Furnace Practice

Dr. Hans Bodo Luengen, Steel Institute VDEh, Dr. Michael Peters, ThyssenKrupp Steel Europe AG, Dr. Peter Schmoele, ThyssenKrupp Steel Europe AG, Germany

This presentation will focus on the evolution of iron making practice in Western Europe in the past and highlight some technological aspects, like: Introduction into the development in hot metal production, progress of the structure of reductants and ore burden materials, evaluation of constructional features and equipment of the blast furnaces, presentation of the largest European hot metal producing companies and further outlook for the European ironmaking scenario. The integrated steel works in EU 27 operate many modern plants for the production of a wide variety of high grade steel products. The blast furnace/converter route will remain dominant. Control of emissions is mainly related to concentration of dust, SO2, NOx, dioxins and other substances. Some developments in sinter plant waste gas cleaning or waste gas recycling are presented. One main focus is set on the emissions of CO2 and the CO2 emission trading system. New processes in ironmaking to reduce CO2 emissions are described. With respect to the international finance crisis which also affected the steel industry the question is answered “How flexibly can metallurgical plants be operated?“. The plunge in order intakes in late 2008 called for decisions which produce immediate effect, in order to adapt the entire chain to the requirements, beginning with logistics and warehousing of raw materials down to the linked production units of integrated works. Suitable measures realized at coke oven batteries and blast furnaces are described.

Results are based on basic hot metal only and do not consider foundry iron.

22. **Chinese Blast Furnace Practice**
Dennis Lu, ArcelorMittal USA
The exponential growth in the Chinese ironmaking industry in the last 20 years resulted in over 1,300 blast furnaces, large and small, producing more than 50% of world pig iron. Following the footsteps of European and Japanese iron makers, the Chinese has pushed the science and art of ironmaking to a new level garnered by vast numbers of trained professionals in ironmaking and steelmaking, supported by many universities and research institutes, and guided by various government agencies. The presentation covers the widely practiced top gas dry dedusting system, highly efficient top fired stoves and many new and innovative waste-reduction and energy-saving technologies such as waste heat recovery and zero blast furnace gas flaring at many blast furnaces in China. Details are given to the record (> 1300 ^{0}C) hot blast temperature achieved at two new 5,500 m^3 blast furnaces in Jingtang Steel and the very high (240 kg/thm) PCI rate practiced at Baosteel. The largest blast furnace (5,800 m^3) in the world built at Shagang is briefly described. Future challenges for the Chinese blast furnaces and practices are also presented.

23. **Japanese Blast Furnace Practice**
Taihei Nouchi, JFE Steel Corporation
The Japanese steel industry has a long history of introducing new and innovative technologies in the field of ironmaking. The new technologies introduced during the past ten years include technologies to use cheaper and lower-grade raw materials and fuels, measures to prolong the service life of blast furnaces and coke ovens, promotion of energy saving, use of wastes and solutions to environmental problems. The lecture outlines the condition of production, technological trends and technical development themes in ironmaking technologies.

24. **Future Trends in Ironmaking**
Joe Poveromo, Raw Materials & Ironmaking
The role of the blast furnace in steel production is discussed, followed by the trends in blast furnace performance. The issues facing the blast furnace process are: external such as coke supply and internal such as limitations on coal injection and hearth life, as influenced by phenomena in the various furnace zones. The challenges to the blast furnace process include both alternative steel production routes such as the integrated DRI/scrap/EAF mode and also alternative hot metal processes. These DRI and alternative hot metal processes will be listed with comments as to their future success.

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