McMaster University | ENGINEERING

27TH McMASTER UNIVERSITY

BLAST FURNACE IRONMAKING COURSE

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BOOK OF ABSTRACTS

Blast Furnace Control Measurement Data and Strategy

Bob Nightingale, University of Wolongon/Retired from Bluescope Steel

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.

Blast Furnace Design I

Brian Black, SMS group Americas

Today’s efficient blast furnace (BF) 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; the application of automation and control technology.

This paper, which is complementary to others presented in this 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

Blast Furnace Design II

Guilherme Guidugli, Primetals Technologies

Blast Furnace Design II covers air (blast) and gas system designs for modern blast furnace operations. Increases in hot blast pressure and temperature during the past fifty years, together with the need to improve operating and maintenance efficiencies, and corresponding cost reductions, have resulted in design improvements in the air and gas system designs.

The subject will be covered in the following areas:

- Importance of Hot Blast to the Blast Furnace Operation
- Functional Layout and Design of Hot and Cold Blast Systems
- Hot Blast Stove Design and Operation
- Stove Operating Parameters
- Energy Recovery from Stove Waste Gas
- New Stove Operating Concepts
- Interesting Stove Design Options
- Blast Furnace Gas Cleaning Systems
- Gas Cleaning Performance and Economic Comparisons
- Top Pressure Control and Energy Recovery Turbines

Blast Furnace Design III, Campaign Extension

Salustiano Martins Pinto Junior, Consultant

Before a Blast Furnace reaches the end of lifespan would be interest perform a campaign extension plan to postpone the reline like Blast Furnaces references with long campaign that achieves more than 25 years with high productivity and lower cost.

A Blast Furnace campaign extension also allow more time to study solutions to CO2 emission still in development in the Steel industry due to the urgent issue of climate change putting more pressure on significantly reducing emissions.

A suggestion of best practices of Blast Furnace Campaign Extension will be presented and explained in detail:

1. Dedicated work team (Operation + Maintenance + Engineering);
2. Separated and specific budget;
3. Constant hearth and tap hole residual thickness assessment;
4. Shotcrete every 2 to 4 years to protect older refractory lining and cooling members;
5. Constant staves wear assessment;
6. Constant shell temperature control;
7. Immediately eliminate any water leaking from cooling system;
8. Keep water quality at cooling system to avoid dirt and clogged;
9. Purchase of critical scope (long time to delivery): Hearth refractory, staves, top charging system, etc.;
10. Benchmarking and synergy programs;

Blast Furnace Campaign Extension and Reline experiences will be presented and at the end of lecture leave an opportunity for questions from audience members.

Keywords: Blast Furnace, Reline, Campaign Extension, CO2 emission

Blast Furnace Energy Balance and Recovery: Rules of Thumb, Game

John Busser and Mitren Sukhram, Hatch

Simplified mass and energy balances are outlined for the purpose of optimising 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 importance of chemical reaction equilibria with respect to temperature are discussed. 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.

Blast Furnace Reactions

Bob Nightingale, University of Wolongon/Retired from Bluescope Steel

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.

Burden Distribution and Aerodynamics

Joseph J. Poveromo, Raw Materials & Ironmaking Global Consulting
Presented by: Joseph Morey, Consultant

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.

Casthouse Design and Blast Furnace Casthouse Optimization

Floris van Laar, Allied Minerals

This paper will focus on the fundamentals of the casthouse in ironmaking. The casthouse system must be able to sustain an uninterrupted production of iron The casthouse design, lay-out and maintenance strategy will be discussed. It will be followed by the differences between trough designs, refractory materials, and the impact of how the implementation will affect the planned system life span and efficiency.

Challenging Blast Furnace Operations

Frederick 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 blowdown, blow-in, 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 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 empty furnace 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.

Chinese Blast Furnace Practice

Dennis D. Lu, ArcelorMittal USA

Exponential growth in the Chinese ironmaking industry in the last 2 decades has resulted in over 1,500 blast furnaces, large and small, being built, and now producing about 61% of the world's pig iron. Following in the footsteps of European and Japanese iron makers, the Chinese have 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. This presentation describes 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 on the record (1315 0C) hot blast temperature achieved at three modern 5,500 m3 blast furnaces at Jingtang Steel and the very high (265 kg/thm) PCI rate once practiced at Baosteel. The largest blast furnace (5,800 m3) ever built at Shagang is briefly described. Recent development and future challenges for the Chinese blast furnaces and practices are also presented.

Coke Production for Blast Furnace Ironmaking

Hardarshan S. Valia, Inland Steel Company Research Laboratories
Presented by Ka Wing Ng, NRCAN

The cokemaker has to understand the definition of coke from consumers' perspective who demands high quality coke with certain specifications that reflect coke behavior both inside and outside the blast furnace. Similarly, the consumer, the ironmaker, has to understand how the coke producer is trying to achieve a balance between the competing sets of requirements such as throughput/high quality/battery life/cost efficiencies. Hence, there needs to be a better understanding on both cokemaker and ironmaker's part as regards to each others requirements. Keeping this in mind, the lecture is divided into four sections that cover: 1) Coke Properties and Coke Behavior, 2) Coke Production, 3) Factors Affecting Coke Quality, and 4) Coal Quality Monitoring and Reserve Evaluation. The emphasis is on understanding the needs of both cokemaker and iron maker.

Comprehensive Numerical Modelling of the Blast Furnace Ironmaking Process

Tyamo Okosun and Chenn Zhou, Purdue University Northwest
Presented by Sam Neilsen, Purdue University Northwest

Blast furnaces are counter-current chemical reactors, widely utilized in the ironmaking industry. Hot reduction gases injected from lower regions of the furnace ascend, reacting with the descending burden. Through this reaction process, iron ore is reduced into liquid iron that is tapped from the furnace hearth. Due to the extremely harsh environment inside the blast furnace, it is difficult to measure or observe internal phenomena during operation. Despite the age of the process, the blast furnace remains critical to industrial ironmaking. With advances in analysis technologies and control systems, and pressure from new steelmaking techniques, modern blast furnace operation has become more efficient. Further development requires better understanding of phenomena within the blast furnace, including heat transfer, mass transfer, chemical reactions, and multiphase flow in the three regions of the furnace, the shaft, the raceway, and the hearth. To that end, computational simulation and visualization have been applied to explore blast furnace phenomena. This paper discusses recent current state-of-the-art techniques for simulation and visualization of the blast furnace using Computational Fluid Dynamics (CFD) models developed by the Center for Innovation through Visualization and Simulation (CIVS) at Purdue University Northwest (PNW), as well as an overview of their applications for troubleshooting and optimization of blast furnace operations. In addition, PNW is working to expand the application of these models to the development of a combined CFD-machine learning approach to real-time, what-if, and guidance predictions called the Integrated Virtual Blast Furnace (IVBF).

Keywords: Blast Furnace, Hearth, Shaft, Pulverized Coal Injection, Modeling, CFD, Virtual Reality

Day-to-Day Blast Furnace Operation

Arthur Cheng, National Steel Corp.
presented by Katie McCourt, US Steel

A good day to day blast furnace operation is essential in the attempt to achieve a world class performance. This lecture discusses two main points. First it will discuss how different management objectives can be achieved. Some of these objectives are cost reduction, customer satisfaction in terms of production and delivery, and product quality. Key operating parameters for each objective will be identified, and the control of these operating parameters necessary to achieve the desired results will be reviewed. Second, we will concentrate on the basic ingredients required for the day to day control of an operation, such as burdening, standard operating procedures, key process parameters for monitoring and statistical process control.

Fuel Injection in the Blast Furnace

Frederick W. Hyle, Manager Ironmaking Technology
Presented by Donald Zuke, Cleveland-Cliffs

In this lecture I will begin with a history of blast modifications and then we will discuss combustion reactions and raceway phenomena. The concept of replacement ratio will be introduced and illustrated with an example. The effect of fuel injection on burden and gas distribution will be outlined. The key aspects of natural gas, oil, tar and coal injection will be presented.

Fundamental Principles Applied to Blast Furnace Environment

E. Cocchiarella, Vale Inco, Ltd
Presented by Fred Post, Algoma Steel

In this paper and the accompanying presentation, environmental issues will be addressed from the perspective of management systems, technologies to prevent and control emissions and operating practices. The management system addresses issues such as planning, organizing, controlling, and human resources. Control technologies include air and water treatment systems. Operating practices are reviewed in light of the effect that abnormal operating conditions have on the natural environment.

Fundamental Principles Applied to Blast Furnace Safety

Shawn C. Tilbury, ArcelorMittal Dofasco

The Ironmaking Blast Furnace can be a very dangerous machine. However, much has been done to manage the hazards associated with making iron. Although there are countless hazards associated with this heavy industrial process, three hazards unique to the process will be discussed specifically. These include, heat (Hot Metal and Gases), Carbon Monoxide and water. Specific events and corrective actions associated with these hazards will be reviewed. Through continuous improvement and advancements in technology and legislation, the three conditions have been controlled to reduce the risk to humans working in Ironmaking. Although in many advanced blast furnaces, human interaction has been minimized or eliminated from day-to-day operations, extreme injuries are still a risk. Today, the biggest hazard to human safety is humans themselves in the form of poor behaviours. Today, each accident in the blast furnace is a repeat of a historical event. The critical decision matrix will be reviewed and tested against recent accidents within the industry. The next quantum leap forward in safety will be from instilling good behaviour and reducing risk tolerance in the workforces.

Future Trends in Ironmaking

Ian Cameron and Mitren Sukhram, Hatch

Accounting for 6-7% of global greenhouse gas (GHG) emissions, the steel industry and its supply chain emits more CO_2 than any other metal produced. Deemed a 'hard-to-abate' industry due its reliance on carbon to reduce iron ore to iron in blast furnaces, the steel industry will require new innovative technologies to reach net zero GHG emissions. Steel demand will grow due to population growth, implementation of renewable energy systems, and a need for resilient infrastructure. The steel industry and ironmakers must reduce GHG emissions while increasing steel output by more than 30% by 2050. Ironmaking GHG emissions will reduce in stages, first with the optimization of blast furnace ironmaking to world-class performance followed by blast furnace transformation. New ironmaking processes will grow in importance as an alternative to the blast furnace and to reduce GHG emissions and meet steel industry's aspirations for carbon neutrality by 2050. This paper describes the expected ironmaking technology changes and their related challenges.

Historical Development and Principles of the Iron Blast Furnace

Johan van Ikelen, ret. Tata Steel, consultant Danieli-Corus

The evolution of ironmaking raw materials, equipment and practices will be reviewed from ancient to the present.

In a chronologic way the historical development of all issues around ironmaking will introduced in which material handling, furnace, process and installation development will be discussed, from a simple clay furnace till the pulverized coal injection.

Knowing the history is a first step for a basic understanding of the ironmaking process and the roots of the modern blast furnace facilities and operation.

Iron-Bearing Burden Materials

Marcelo Andrade, John Ricketts, Harold Kokal, and Pinakin C. Chaubal, ArcelorMittal
Presented by Renard Chaigneau, Baffinland Iron Mines Corp.

Iron ore is one of the key ingredients for iron & steelmaking. Especially the interaction between the iron ore and the blast furnace process is key for an efficient operation. For that we dive deeper into what an iron ore is, including its origin and how various iron ores are preprocessed by beneficiation and agglomeration techniques like sintering and pelletizing but also briquetting to create the best ferrous burden for the blast furnace process. Characterization of these agglomerates, their quality control and the effect of their properties on blast furnace performance are also key aspects to be covered.

Ironmaking in Western Europe

Jan van der Stel, Tata Steel

This presentation introduces the evolution of iron making in Western Europe as compared to the development of iron making in other parts of the world. This highlights several aspects of iron making practices, such as: introduction into the development of hot metal production, progress of the structure of reductants and ore burden materials, sintering of iron ores, evaluation of constructional features and equipment of the blast furnace. This also provides an outlook for the current and future European iron making scenario.

The integrated steel works in Western Europe operate modern plants to produce a wide variety of high-grade steel products. Currently, the blast furnace-basic oxygen furnace (BF-BOF) route for steel production is the dominant production route within Europe.

However, this scenario will undergo a transition toward iron making process with the use of "Green and Blue" H_2 in the direct reduction shaft, together with application of electricals furnaces like EAF and REF, or with the integration of deep CO_2 capture, utilisation, and storage (CCUS) to meet the challenges of net-zero emissions steel production by 2050. Thus, the other focus of this paper is to provide an insight to the development of the CO_2 emissions reduction programme based on past and on-going projects, and the impact of the EU emissions trading system together with the introduction of any form of carbon border adjustment mechanisms.

Ironmaking Refractories

Floris van Laar, Allied Mineral Technical Services, Inc.

The blast furnace is one of the most efficient iron making facilities in existence and must be protected by refractory systems in each high temperature process areas. The refractory systems in the iron making process must be reliable to sustain its operation.

This paper focuses on the basics of refractory materials and systems that are used in the ironmaking process. Components of iron making equipment that are lined with refractory are reviewed in detail. New materials and repair techniques, which are displacing traditional designs, are also included in this paper.

Ironmaking/Steelmaking Interface

M. Price, D. Liao, M. Pomeroy, ArcelorMittal Dofasco
Presented by Mike Pomeroy, 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, process capability and raw material inputs along with the internal customer requirements (Steelmaking).

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.

Maintenance Reliability Strategies in an Ironmaking Facility

Johan van Ikelen, ret. Tata Steel, consultant Danieli-Corus

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". That starts with recognition of the critical installation parts, combined with a simple inspection system, which provides knowhow over the condition and signals 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!

Which means here: do not overact such measuring and preventive maintenance actions, otherwise your maintenance will be very costly.

Extra concerns are the essentials for campaign extension and contingency measures which may be prepared.

This presentation is intended to explain this program and factors required that influence its success.

Overview of the DRI process

Kevin Persad, Nucor

This is a new lecture. Abstract will be available soon.

Transitioning The Iron and Steel Industry Towards a Low-Carbon Future: Climate Change Policies and Approaches

Katie Chan, Stelco

In 2021, almost 200 countries around the world made commitments to adopt the Glasgow Climate Pact which includes commitments to reduce greenhouse gas (GHG) emissions to prevent planetary warming from exceeding 1.5 degrees above pre-industrial temperatures. As the world continues to seek solutions to address climate change, the steel sector is recognized as an essential part of global sustainable development. Meanwhile, it is important to note that the steel industry is an energy-intensive and trade-exposed sector. According to the International Energy Agency, the global steel industry is responsible for about 8% of global final energy demand and 7% of energy sector carbon dioxide (CO2) emissions1. Approximately 70% of CO2 emissions in integrated steel mills comes from blast furnace ironmaking2. This lecture will provide an overview of climate change policies related to steel industry GHG emissions from multiple regions around the world. Further, it will explore the key groupings of iron and steelmaking decarbonization pathways.