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METHODOLOGY FOR COKEMAKING TECHNOLOGY SELECTION FOR OPERATING CONDITIONS AND EXPANSION OF IRON AND STEEL WORKS

Abstract

Selection of cokemaking technology within an Iron & Steel Works (I&SW) setting is a complicated problem, involving analysis of coal quality, coke demand and supply, environmental regulations, and the plant energy balance. The methodology involves coal blend selection, preparation, charging, cokemaking and quenching technology selection to meet the blast furnaces' coke quality requirements and the I&SW energy balance. Hatch's mass and energy balance, OPEX, CAPEX, Energy/CO2 and Financial Models provide the client with NPV/IRR ranking and sensitivity analysis to assist in selecting the best strategy amongst by-product or heat recovery ovens, charging and quenching systems for replacement or expansion programs.

Keywords: By-product cokemaking, heat recovery cokemaking, energy balance, financial analysis.

INTRODUCTION

Anticipated growth in various sectors of the global steel industry for the next 20 years, coupled with changing raw material quality and availability, industry structure, pricing and environmental issues will impact the preferred ironmaking route in different regions of the world. Cokemaking will face increasing environmental pressure, a shortage of good coking coals, and the need to renew old cokemaking facilities. As the availability of high quality coking coal decreases, new technologies that can use greater amounts of low grade coking coals or even non-coking coals and yet maintain/increase coke quality are being developed.

Hatch has developed a methodology for cokemaking technology selection that evaluates current coal blends against future coke quality requirements, considers future coke demand versus supply to determine the projected coke deficit, considers energy and environmental implications and, evaluates new capacity options using financial analysis models and provides strategic recommendations for the Iron & Steel Works (I&SW).

The methodology above uses Hatch's proprietary Mass and Energy Balance Models to take into account all major utility systems that can have an impact on the process. Options for new or replacement cokemaking capacity include both By-Product Coke Plant (BPCP) and Heat Recovery Coke Plant (HRCP) processes, as well as modern technologies to improve coke quality through increased coal bulk density, as well as various energy and environmental improvement technologies. Techno-economic analysis of the various cokemaking technologies is performed using OPEX and

CAPEX models and a Financial Model which includes Discounted Cash Flow (DCF) to calculate Internal Rate of Return (IRR) and Net present Value (NPV) data. An Energy /CO_2 environmental model based on carbon and hydrogen balances, various emission factors, and equipment capacities is used to provide a comparison between various technologies and provides an insight into the relationship between the technologies and environmental outcomes. The detailed financial evaluation and comparison ranking of cokemaking technology options by OPEX, CAPEX, IRR and payback period and the resultant environmental impacts assist the client in developing the best cokemaking strategy for their unique requirements.

METHODOLOGY

A multi stage approach for cokemaking technology selection has been developed to assist Hatch's clients to select the best strategy based on their I&SW site and company specific needs, and is illustrated in the flowsheet Figure 1. The methodology involves a holistic approach for the I&SW where the quality requirements of the blast furnaces and the coke oven gas and energy users downstream are balanced with the requisite cokemaking technologies after a complete and thorough analysis.

COKE DEMAND ANALYSIS

The coke demand analysis involves both the quantity as well as the quality requirements for present and future blast furnace operations. The opportunities for the blast furnace to reduce coke rate, increase productivity and reduce cost is dependent on receiving consistent high quality coke. Analysis of existing coal blends through modeling and pilot oven testing can be performed. A review of existing cokemaking technologies and identification of opportunities to introduce technology changes or new technologies are evaluated during facility audits.

COKE SUPPLY ANALYSIS

The coke supply analysis involves establishing for each coke facility the battery design, nameplate capacity, current and historical production, reline dates, service life, number of ovens out of service and on extended coking cycles, number of ovens with end flue or through wall repairs, and delays. Projected battery end of service life requires detailed inspections using an approach similar to ArcelorMittal's Coke Plant Age Determination Technology as shown in Figure 2.

A program of inspections and repairs can extend battery life by many years and can improve productive capability for a period of time before further declines occur. Once productive capability declines to about 50%, then repairs are not likely economical.

PROJECTED COKE DEFICIT

The projected coke deficit is simply the difference between the future coke demand and the future coke supply over the time horizon of interest. Barring any merger and acquisitions of cokemaking capacity, the projected coke deficit becomes the basis for study in selecting the best cokemaking technologies for the I&SW and company.

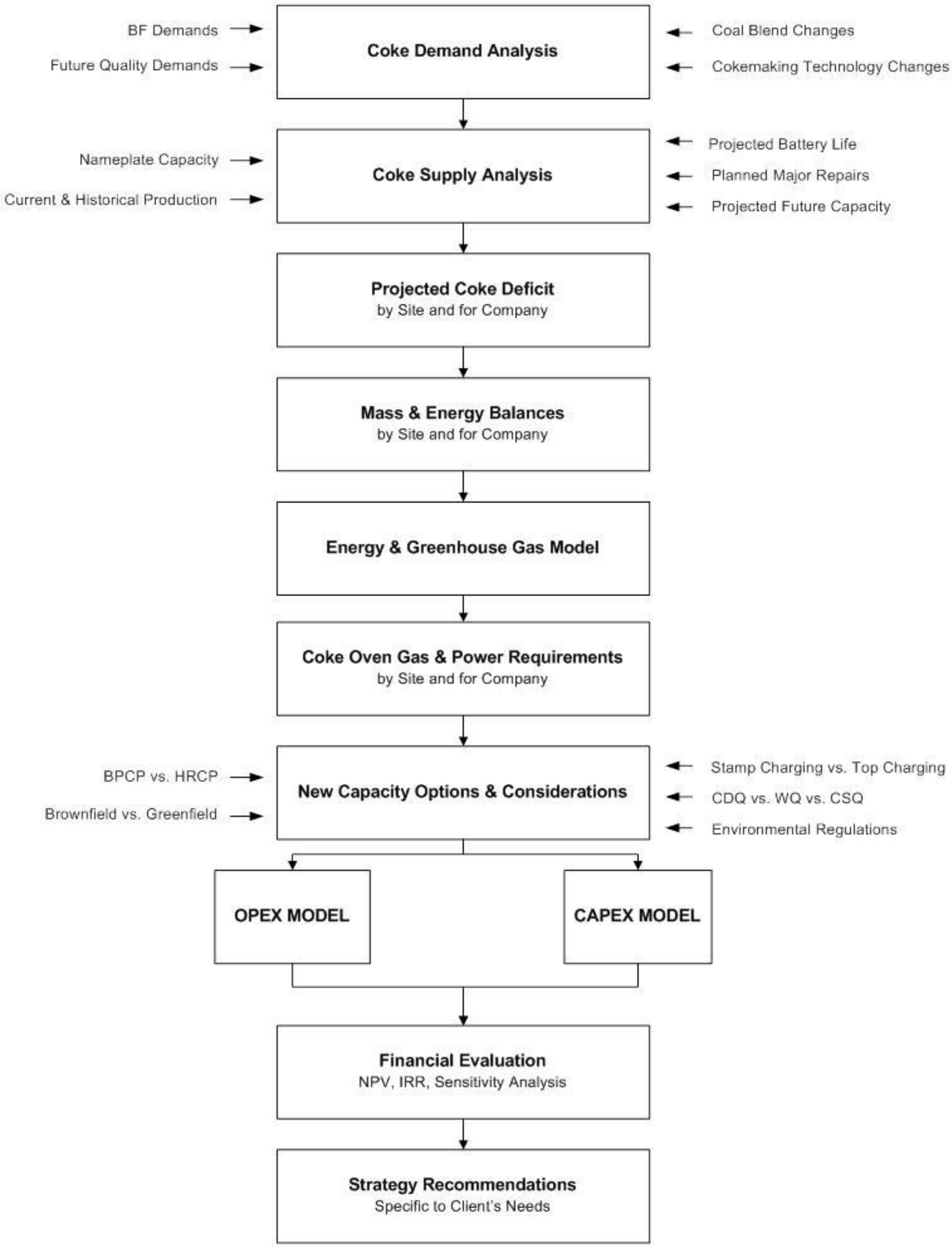


Figure 1. Hatch methodology for cokemaking technology selection and strategy

MASS AND ENERGY BALANCES FOR I&SW

A baseline mass and energy balance considering all process gases such as coke oven gas, blast furnace gas and LD convertor process gas generation and consumption in the I&SW is modeled and then used as a basis for comparison with the new capacity options. Power generation versus heating requirements for the process gases are also evaluated for the I&SW.

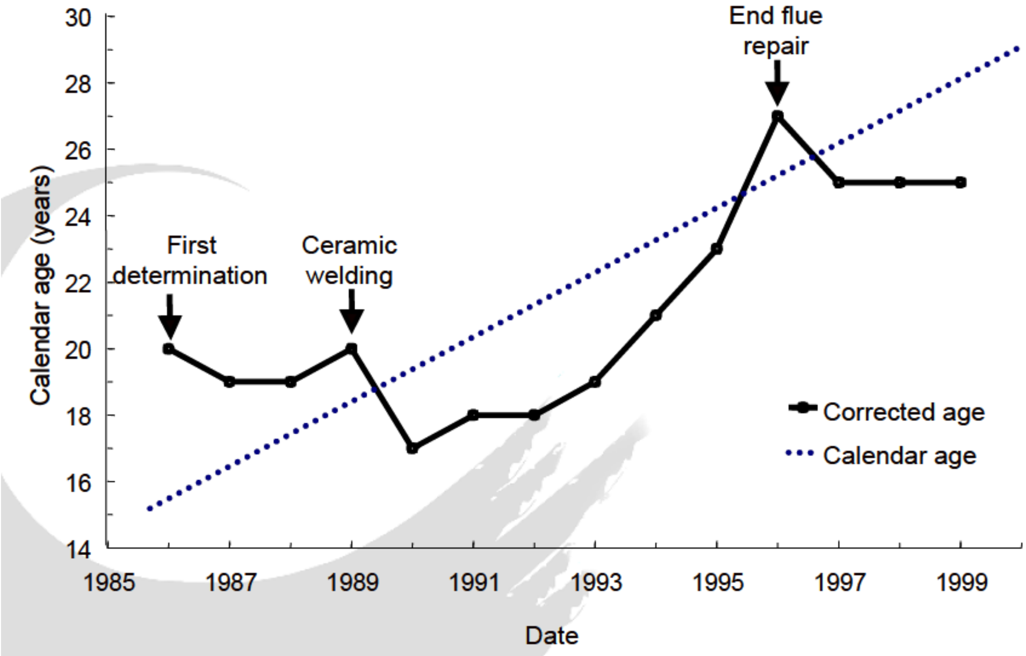


Figure 2. Arcelor theoretical chart of annual age determination data [1]

ENERGY AND CO2 (GHG) ENVIRONMENTAL MODEL

The Energy and CO_2 (GHG) Environmental Model [2] is based on hydrogen and carbon balances, various emission factors, consumptions and capacities at each process stage starting with cokemaking, and includes ironmaking, steelmaking, casting, hot rolling, and the conversion of surplus process gases to electricity for Power Plant and/or Oxygen Plant use.

NEW CAPACITY OPTIONS AND CONSIDERATIONS

New capacity options considered are the conventional By-Product Coke Plant and heat Recovery Coke Plants, both horizontal and vertical, for brownfield and greenfield sites. Coke quality improvement technologies such as coal blend improvements, or technologies that increase coal bulk density through oil additions, partial briquetting and stamp charging are evaluated. Coal Moisture Control (CMC) and coal preheating technology are also considered. Additionally coke quenching technologies – Coke Stabilized Quench (CSQ) and Coke Dry Quenching (CDQ) which produce higher quality coke then Wet Quenching (WQ), as well as power from CDQ are assessed. Air and water environmental regulations for the cokemaking facilities are reviewed and compared to current and future cokemaking emissions for compliance so that environmental improvement technologies are selected accordingly.

OPEX AND CAPEX MODELS

Hatch OPEX and CAPEX Models have been developed and refined through use in various cokemaking projects and studies [3]. The OPEX model consumption inputs are provided from the Mass and Energy Balance Models for the selected cokemaking technologies, from plant accounting data, and from Hatch's Key Performance Indicators (KPIs) database. The CAPEX Model costs the

Cokemaking Core Plant separately from the selected technologies as shown in Table 1 to arrive at a total Coke Plant cost. These models are tailored to the geographic region or country using specific raw materials, utility prices, labor rates, etc.

Table 1

Cokemaking CAPEX selection

	Coke Plant A	Coke Plant B	Coke Plant C	Coke Plant D	Coke Plant E
	Conventional BPCP+ Wet Quench	Conventional BPCP+ CDQ	Conventional BPCP+ CDQ + CMC	Stamp Charge Conventional BPCP+ Wet Quench	Stamp Charge Conventional BPCP + CDQ
Technology Cost					
Coal Drying (CMC)	x	x	√	x	x
Coal Stamping	x	x	x	√	√
Coke Wet Quenching	√	x	x	√	x
Coke Dry Quenching (CDQ)	x	√	√	x	√
Coke Stabilizing Quenching (CSQ)	x	x	x	x	x
By-Product Plant	√	√	√	√	√
Heat Recovery Power Generation Plant	x	x	x	x	x
Subtotal Technology Cost					
Cokemaking Core Plant					
Material	√	√	√	√	√
Labor	√	√	√	√	√
Infrastructure	√	√	√	√	√
Indirects	√	√	√	√	√
Total Cokemaking Core Plant					
Grand Total Coke Plant Cost (Core+Technology)					

Continue Table 1

	Coke Plant F	Coke Plant G	Coke Plant H	Coke Plant I	Coke Plant J
	Stamp Charge Conventional BPCP + CDQ + CMC	Wide Slot PROVEN + Wet Quench	Non Stamp Charge Horizontal Heat Recovery + Wet Quench	Stamp Charge Horizontal Heat Recovery + Wet Quench	Stamp Charge Vertical Heat Recovery + Wet Quench
Technology Cost					
Coal Drying (CMC)	√	x	X	x	x
Coal Stamping	√	x	X	√	√
Coke Wet Quenching	x	x	√	√	√
Coke Dry Quenching (CDQ)	√	x	x	x	x
Coke Stabilizing Quenching (CSQ)	x	√	x	x	x
By-Product Plant	√	√	x	x	x
Heat Recovery Power Generation Plant	x	x	√	√	√
Subtotal Technology Cost					
Cokemaking Core Plant					
Equipment (after repeated/multiple unit discount)	√	√	√	√	√
Material	√	√	√	√	√
Labor	√	√	√	√	√
Infrastructure	√	√	√	√	√
Indirects	√	√	√	√	√
Total Cokemaking Core Plant					
Grand Total Coke Plant Cost (Core+Technology)					

Notes: √ = Applicable x = Not Applicable

FINANCIAL EVALUATION AND STRATEGY RECOMMENDATIONS

The objective of compiling the OPEX, CAPEX and Repair and Maintenance estimates and providing a Cash Flow Model is to conduct analysis that will support the selection of strategy recommendations based on financial considerations. Figure 3 illustrates the Financial Analysis Model.

Figure 3. Financial analysis model

The OPEX Model provides production capacities, consumption of coal, utilities and their prices, labor, recoveries of gas and by-product credits and key performance assumptions as inputs to the Financial Model. The CAPEX Model provides project capital, sustaining capital and working capital estimates. The Financial Model includes a Discounted Cash Flow Model to calculate IRR Payback and NPV and provides financial evaluation and comparison ranking of cokemaking technology options by CAPEX, OPEX and IRR. Sensitivity analysis on NPV and IRR is based on impact of changes to pricing of coal, electricity, natural gas, capital and operating costs and any other key parameters as requested by the client.

CASE STUDY

The client's business strategy is to increase steel production by 20% over the next 10 years. The coke division is developing a technology strategy to satisfy the quality and quantity demands to meet the forecasted iron and steel production. Coke quality demands and quantity demands are forecasted to change with implementation of Pulverized Coal Injection (PCI) at all the blast furnaces. Hatch was retained to conduct a study to assist the client in developing a strategy with respect to:

- Coke production requirements.
- Predicted coke quality attainable with future coal blend compositions.

Assess current operation of over 20 coke oven batteries at different plant sites. Consider predicted end of life, repair to extend life, and battery replacement with new construction on existing sites and a greenfield site.

Report findings and recommend priorities for new and replacement cokemaking capacity.

OBJECTIVES

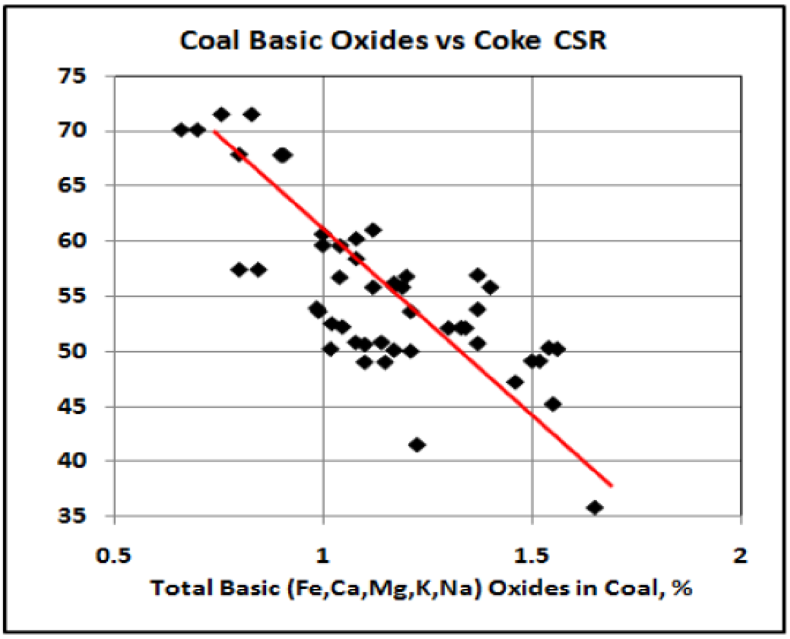
The main goal of the study was to develop a technology strategy to meet the future coke requirements with regard to production level and coke quality. The secondary goals were to recommend technologies to improve productivity, quality, energy efficiency and environmental performance of the existing coke oven batteries.

FUTURE COKE QUALITY DEMANDS AND STRATEGY

The client plans to introduce high PCI rates on the blast furnaces which will ultimately reduce specific coke consumption (kg/t hot metal). High PCI rates require significant coke quality improvements, in particular a 50 % increase in coke strength after reaction (from 40 to 60 CSR). These new coke quality improvements can be achieved by a combination of coal blend changes and technology improvements.

There are over 25 coal sources available in various tonnages. Selective use of the existing coals can improve CSR by 5–10%, and the import and blending of superior hard coking coals can increase CSR by a further 5–10 %.

Coal chemistry has the biggest impact on CSR[4]. High strength coke requires coals with suitable thermal softening properties and blend fluidity. Increased basic oxides make coke more reactive and reduces CSR as shown in Figure 4. Higher rank coal blends produce denser coke and higher CSR.



	Basic Oxides in Coal
Reject	2.01 and greater
Avoid	1.51 to 2.00
Minimize	1.01 to 1.50
Accept	1.00 and less

Figure 4. Coal chemistry's impact on CSR

Technology changes involving increased coal bulk density at the existing operations such as using oil additions can raise the CSR by up to 5 %. An even higher bulk density can be accomplished through capital investments in stamp charging which can increase CSR by up to 10 %, or partial coal briquetting which can increase CSR by up to 3 % on any new or rebuilt batteries.

Coke demand analysis for each I&SW over the next 10 years based on projected PCI implementation at all blast furnaces was provided by the client.

Coke supply analysis for each I&SW was conducted by a combination of detailed survey responses by coke battery and site which included nameplate capacity, historical and current production, coking times, various design information, coke quality and by coke battery facility audits and discussions with managers to gain first hand understanding and insights into facility conditions, inspection, delays, ovens out of service, repairs and end of life predictions, and to assess opportunities for technology improvements.

FUTURE COKE CAPACITY DEMAND AND SUPPLY ANALYSIS

From this information mass and energy balances were developed for each plant site as well as the coke oven gas generation and power capabilities and opportunities.

The projected dry metallurgical coke production and consumption for each I&SW and for the company for the next 10 years was calculated in order to project the coke deficit. Figure 5 shows that the projected coke deficit will begin in 2015 and grow by 2018 to 40% of current production, resulting from shutdown of existing batteries due to age and condition plus the increased coke demand to meet increased iron and steel production.

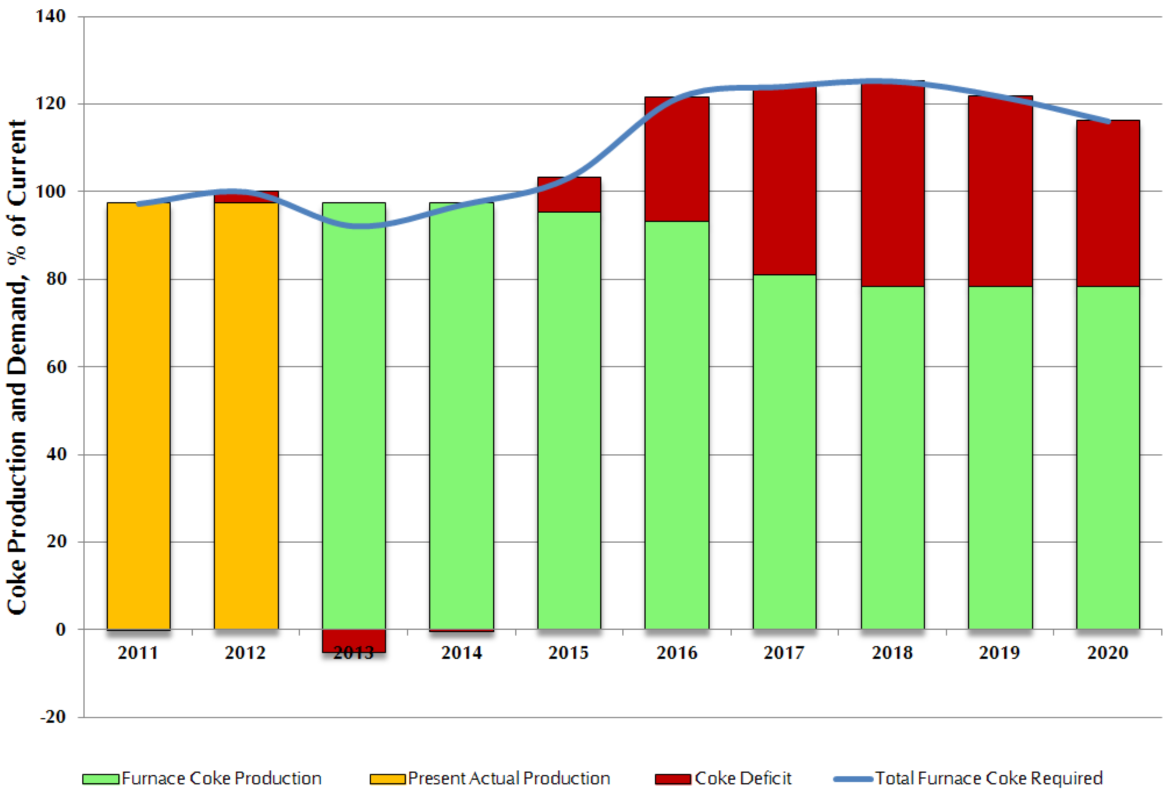


Figure 5. Furnace coke production versus consumption

NEW CAPACITY OPTIONS

To address the shortfall in coke capacity, options for increasing capacity were developed. Capital costs (CAPEX) and operating costs (OPEX) were estimated based on Hatch's project database. Financial results were calculated in order to rank the options in order of attractiveness. The following factors were considered in the analysis:

- By-Product Coke Plant and Heat Recovery Coke Plant technologies for new capacity.
- Coke Oven Gas (COG) usage based on historic and projected site usage.
- Power generation based on historic and projected site usage.

New capacity included the latest technologies shown in Table 2 such as stamp charging and partial briquetting of coals, with consideration of coal handling systems and space availability. Environmental improvements included High Pressure Ammonia Liquor Aspiration System, Leak Proof Doors and Land Based Pushing Emission Control.

Table 2

Modern technologies recommended for new or rebuilt batteries

Technology	Benefit	Result
Stamp Charging	Improves bulk density and coke CSR	Increases bulk density by $200 kg/m^3$ Up to 10 point increase in CSR
Coal Partial (30%) Briquetting	Improves bulk density and coke CSR	Increases bulk density by $70 kg/m^3$ 3 point increase in CSR
High Pressure Ammonia Liquor Aspiration System	Reduces steam consumption & emissions	Improves environmental situation
Leak Proof Doors	Reduces emissions	Improves environmental situation
Land Based Pushing Emission Control	Reduces emissions	Improves environmental situation
One-Spot Pushing/Charging Equipment and One Spot Wet Quench Car Operation	More accurate car spotting	Improves productivity, avoids refractory damage and more uniform coke quenching

FINANCIAL EVALUATION

Net Present Value (NPV) and Internal Rate of Return (IRR) were used to assess the investment options. The most cost effective addition of new capacity is to rebuild on the location of existing batteries to re-use as much as possible the existing equipment.

To meet the increased coke demand four batteries were recommended to be rebuilt and two new batteries were recommended for construction at specific sites based on NPV and IRR. For all new capacity, standard By-Product Coke Batteries were recommended based on the coke oven gas energy needs of the I&SW.

A list of potential improvement projects and estimated capital costs are given in Table 3. These improvements would increase coke plant productivity, improve coke quality, reduce energy consumption and improve the environmental performance of the batteries.

CONCLUSIONS

The optimum selection of cokemaking technologies requires a careful analysis of the I&SW and company specific requirements in order to develop a techno-economic analysis that will provide the optimum strategy to get the most from existing assets and to ensure competitive future coke production.

Table 3

Improvement projects

Project	Indicative Capital Cost $US/t annual capacity	Benefit
Oil addition to coal charge	0.30	Increases bulk density
Battery Heating Optimization	Nil	Energy reduction
Process Control System	5/battery	Improves heating control
Battery Heating Optimization	Nil	Energy reduction
Computerized Maintenance Management System	0.1-0.5/plant	Reduces maintenance cost
Gas Holder to improve recovery of COG by reducing flare/bleed	10-15	Reduces flared gas
COG Desulphurization	9-14	Increases usage of coke oven gas in steel plants
Wet Quenching Tower Upgraded Louvered Baffles	0.5	Reduces dust emissions
Use of Fresh Water for Wet Quenching	1	Reduces harmful emissions
CDQ Process Control	1	Improves coke yield
Coke Dry Quenching (CDQ)	70	CSR increase and power generation
Stabilized Quenching	30	Improves CSR
Main boiler House Replacement at Site A	50-100	Reduction of energy consumption

The Hatch methodology has been developed based on a variety of projects for various clients with different requirements and country and company specific situations. The methodology can include coal blending evaluation to improve coke quality as well as opportunities to reduce blast furnace coke rates. The projected coke deficit and time horizon is estimated based on a coke demand and supply analysis and future coal requirements are established through the use of blending, and mass and energy balance models. The I&SW process gas generation and consumption balance determines the efficient gas/power energy balance which includes cokemaking, ironmaking, steelmaking and hot rolling for existing and future scenarios involving replacement and new cokemaking capacity. Cokemaking technology selection includes conventional By-Product and Heat Recovery ovens for brownfield and greenfield sites, as well as modern technologies for coal densification, coke quenching, automation and environmental improvement. The financial evaluation includes, OPEX, CAPEX, Energy & GHG and Discounted Cash Flow Models to evaluate NPV and rank technologies by IRR and sensitivity analysis to assist the client in planning a competitive I&SW.

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NON-DESTRUCTIVE TESTING (NDT) AND INSPECTION OF THE BLAST FURNACE REFRACTORY LINING BY STRESS WAVE PROPAGATION TECHNIQUE

Abstract

Generally speaking, a blast furnace is the main equipment in Ironmaking and the campaign life of a blast furnace depends on its remaining hearth refractory lining [1]. The Acousto Ultrasonic-Echo (AU-E) is a stress wave propagation technique that uses time and frequency data analysis to determine coarse-grained material thicknesses, such as refractory and stave materials in operating blast furnaces. A mechanical impact on the surface of the structure (via a hammer or a mechanical impactor) generates a stress pulse, propagating into the furnace layers. The wave is partially reflected by the change in refractory layer properties, but the main pulse propagates through the solid refractory layers until its energy dissipates. The signal is mainly reflected by the refractory/molten metal interface, or alternatively by the build up/air or molten metal interfaces that are formed between internal layers or at external boundaries. In this paper, we describe the AU-E technique in details and demonstrate a few results that are indicative of the technique reliability and accuracy.