3.0 Basic Oxygen Furnace Steelmaking

Basic Oxygen Furnace (BOF) steelmaking accounts for just under 40% of the liquid steel output in North America. While this figure may decline with the growth of Electric Arc Furnace (EAF) use, the BOF will continue to be a major source of steel for many years. BOFs include conventional top-blown furnaces, Q-BOP (bottom blown) furnaces, and various mixed blowing configurations and inert gas bottom stirring modifications.

Because significantly higher new blast furnace capacity is not expected, steel plants must find ways to meet demand by extending steel production with available liquid pig iron (hot metal). Achieving the lowest possible production costs has become the highest priority for many steel plants. Given the high fluctuation in raw materials prices, procedures are being developed to consume high amounts of hot metal in the BOF or, on the contrary, to stretch hot metal by using other fuels (mainly carbon or silicon based) to allow high scrap rates when economically beneficial. The flexibility this provides to the blast furnace amounts to significant overall cost savings for the plant. One way to extend production and lower cost is to optimize both blast furnaces and BOFs in terms of production planning and logistics, but technological challenges remain. Steelmakers are applying or experimenting with new and emerging technologies that, with more R & D, could overcome these challenges.

3.1 BOF Furnace

The predominant advantages of the BOF are very high production rates and low-residual-element, low-nitrogen liquid steel tapping. The BOF is fed liquid pig iron, almost always from blast furnaces, in amounts ranging from 65 to 90% of the total metallic charge. The average pig iron is approximately 74% of the charge; the balance is recycled scrap.

Efforts to improve BOF productivity and annual production capacity in recent years have included various automation technologies to optimize the blast furnace and the BOF relationship, improvement in oxygen blowing technology, development of automatic process controls, more reliable equipment and refractory maintenance techniques, better use of secondary refining processes (driven both by productivity and by new steel grades), and improved coordination with downstream facilities.

Trends and Drivers. Steel plants must reduce production losses (materials consumption, processing times, yield losses, reprocessing, etc) in order to stay competitive. Advanced process monitoring (intelligent camera systems) and automatic control of key processes utilizing process control models must be rapidly deployed in order to take advantage of currently available low-cost advanced digital and instrumentation technologies.

Advances in slag splashing, laser scanning of the furnace interior, and use of post-combustion lances have improved furnace availability. The frequency of refractory relining BOF vessels is down to one per year per furnace or less for conventional top blown vessels; lining life is in the range of 8,000 to 25,000 heats for these vessels with a record of 64,000 heats. However, in plants with phosphorous greater than 0.1% in hot metal (as in many European plants), BOF vessels equipped with bottom stirring are common. For these vessels, relines are performed 3 to 5 times per year per furnace and lining life is in the range of 1,500 to 6,000 heats without slag splashing. The choice of BOF blowing technology depends on which technology provides the lowest total cost for the given shop and is driven by two opposing factors of phosphorous refining and refractories maintenance needs.

Use of the post-combustion lance has reduced the time and effort involved in controlling BOF mouth and lance skulls (a build-up of slag and steel that occurs with use). Current R&D efforts to develop new post-combustion lance designs are targeting improved energy efficiency while reducing lance and mouth skulling.

Increasing demand for ultra-low-carbon (ULC) steels, ultra-low-sulfur steels, and advanced high strength steels (AHSS) with higher alloy content has made secondary processes more important. Many shops have focused on coordination between BOF and one or more secondary steelmaking stations to achieve temperature and chemistry control and timely delivery of the heat to the caster. Common secondary steelmaking facilities utilized in North America include a Ladle Metallurgical Furnace (LMF), a degasser, an argon stir station, and possibly a Composition Adjustment by Sealed argon bubbling and Oxygen Blowing station (CAS-OB). Some shops have found that optimizing secondary processes helps productivity by allowing the BOF to aim for a wider endpoint temperature and chemistry targets; but an overall tighter range of ordered chemistries pose additional challenges.

Another trend is hot metal desulfurization, usually done in the BOF transfer ladle. When 100% desulfurization can be attained, the blast furnace can operate at higher hot-metal sulfur and lower fuel rates, which may reduce hot metal costs and thus overall manufacturing cost.

Meanwhile, steelmakers constantly experiment with BOF oxygen lance configurations, oxygen blowing, lance height, and flux addition practices to achieve better slag making and chemistry performance, better control of refractory wear, and higher production rates. With improving knowledge of the BOF process kinetics, it is becoming more and more possible to optimize lance designs (number of holes, port angles, nozzle throat diameters, etc.), oxygen blowing and flux batching practices to achieve these objectives while mitigating adverse consequences such as severe emissions, slopping and skulling. Given the increasing specification for lower phosphorous in the ordered steel chemistries, there is a gradual trend toward softer blowing, or blowing at a lower velocity, with more oxygen nozzles (holes in the lance) in order to improve refining slag formation in the BOF furnace.

Technological Challenges. Environmental standards are getting tougher, requiring better air-cleaning technologies for fugitive emission control and in-shop work environments. In several BOF shops in Western Europe and South America, off-gas collection and reuse for energy production has become part of normal steel plant operations thanks to incentives from local environmental policies. In addition, a significant increase in oxygen blowing rates which is directly responsible for lowering process times is currently not possible partly because of inadequate equipment capabilities but also because of strict environmental standards. Achieving significant increase in oxygen flow rates and thus increasing BOF productivity will require a coordinated effort to develop a high performance BOF technology involving a combination of optimum lance and tuyere designs, blowing practices and off-gas emission control systems.

In top blown vessels, slag splashing has increased furnace life to well beyond the life of the lower hoods. To cope with this incompatibility, shops must consider new maintenance schedules for hoods, environmental control equipment, and new hood materials. On the contrary, increasing the refractory life in vessels equipped with bottom stirring continues to be a big challenge. These vessels stand to benefit from advances in vessel lining wear management including slag splashing and improved tuyere designs.

Furnace vessel shell distortion and destruction during a long campaign must be overcome with use of improved alloys. Slag entrainment or carryover from furnace to ladle, a key to clean steel, should be controlled using electromagnetic sensors, IR camera systems and other currently available techniques. This will improve the control and consistency of secondary treatment.

North American BOF shops generally are still enjoying low phosphorus in hot metal thanks to the low phosphorus content in iron ore available domestically. However, many shops are beginning to feel the pinch of lower phosphorus specifications. Reducing the recycle of BOF slag to sinter plants and blast furnaces is a way to reduce phosphorus content in hot metal. This has some benefits but also poses some problems: While lowering the recycle reduces steel phosphorus, it also increases the amount of slag for landfills and may increase hot metal costs by increasing the cost of replacing blast furnace charge materials. Even with low phosphorous, lowering the BOF slag recycle to ironmaking also reduces the manganese content in hot metal. Many BOF shops today struggle to reach low turndown phosphorous aims because of high phosphorous contribution from scrap, necessitating stringent scrap segregation and restrictive loading practices that has a negative impact on slag formation in the BOF furnace. Using separate dephosphorization stations, as in some Japanese shops, or double slag practices or even retained slag practices, the low aim phosphorous can be achieved; but this increases the liquid steel costs and adds another major source of emissions. Further control of phosphorous in the steel ladle is generally not possible; thus the need for reliable slag carryover control to limit phosphorus available for reversion from slag to steel.

The increase in the production of AHSS steel which generally has higher alloy content (and often with narrower range in the specification) is also a challenge to many BOF shops that traditionally produce low alloy steel. This is especially true for some North American shops that have older and inadequate alloy addition systems. Moreover, the need to reduce production cost has placed blast furnace (BF) operations under pressure to reduce fuel rates resulting in the production of hot metal with low Si and lower temperatures. This impacts slag formation in the BOF vessel in addition to causing BOF operating issues. Accordingly, new procedures need to be developed in order to cope with the technical challenges associated with use of sub-standard hot metal quality.

New and Emerging Technologies. Work is being conducted to improve chemistry, temperature, and process control in the BOF and to virtually conduct the BOF process from start of blow to tapping in a fully automatic mode. The use of in-blow sensors, either in the form of drop-in ("bomb") unit or sublance head, is widely adapted to measure the bath temperature and oxygen to improve end-point control. More recently, early development work has been conducted to develop a drop-in sensor that is capable of measuring the carbon content in the steel bath. If successful, it has the potential to be used on many North American BOF furnaces that are not equipped with a sublance. Another recent development for BOF end-point control is the utilization of off-gas composition and/or temperature for carbon prediction near the end of the blow.

Sensors and techniques are also being developed to measure lance height and to detect the advent of slopping. Improved techniques of adding alloys, usually with the aid of secondary processing, will improve control over the range of chemistries to meet new grade demands and allow consolidation of grades. Upgrading computer and expert systems will also help operators achieve consistent process control.

Using inert gas bottom stirring in BOF achieves better phosphorus removal, improved iron yields, and alloy recovery through reduction of furnace slag iron oxide. However, it is difficult to maintain effective stirring currently in use. New improved tuyere designs, refractory monitoring techniques and improved process control procedures are being developed while slag splashing is used to achieve efficient long furnace lining. Some recent developments in Asia and Europe appear to have overcome the obstacle: furnace lining life of around 10,000 heats with effective bottom stirring while increasing lining life during the entire campaign was achieved.

Many shops need techniques that enable the aggressive use of post-combustion lances or supplemental fuels to extend the use of hot metal. These techniques will increase BOF shop capacity without requiring investment in new hot metal capacity. These techniques would also minimize production losses during periods of blast furnace relines.

3.2 Other Related Technologies

Other technologies that support oxygen steelmaking also require development. These include scrap preparation and handling, fluxes and methods of additions, recycling of waste oxides, and process sensors with feedback capability (for example, light meter, lasers and infrared temperature detectors).

Trends and Drivers. Scrap handling is unique in each plant. Use of home scrap usually requires preparation before recharging into the BOF. Use of outside or purchased scrap is subject to the same demands and problems experienced by EAF operators. In addition, the trend in scrap prices (especially for premium scrap) in recent years has been upward due to competitive buying pressures from EAF shops and export.

Some integrated plants aggressively maximize lower-grade, higher-residual (and thus cheaper) scrap in the purchased scrap mix because it can be diluted by low-residual hot metal and home scrap.

Flux quality, size, and method of introduction are becoming more important because of increased demands on slagmaking, both for refractory maintenance and for control of sulfur and phosphorus. Investigations of flux batching and related oxygen blow profile are contributing to ongoing improvements in charge recipe calculations and the consistency of slagmaking.

Increasingly, recycling in-plant waste oxides in the BOF is addressing environmental pressures and presenting opportunities for low-cost sources of iron and/or coolants in the furnaces.

The use of industrial gases is also increasing. Many shops have nitrogen circuits tied into the main lance circuit for slag splashing as well as to replace argon for bottom stirring, when not in the heat. Nitrogen gas can be used for nitrogen chemical control when required on certain grades to replace expensive nitrided ferro-manganese.

Technological Challenges. BOF steelmaking improvements must overcome many technological challenges. One area that requires technological development is scrap systems. Scrap delivery and analysis systems now-in-use are complicated, unreliable, and inefficient. Without better systems, the amount of scrap used and effect on quality is limited.

The difficulty of maintaining reliable sensors and automated systems is also a challenge. The lack of fully developed, reliable automatic flux batching systems, particularly bin level detectors for dusty environments, limits slag making consistency. Variation in the fraction of fines in the flux that may be lost into the gas cleaning system is another factor contributing to the deviation of slag chemistry from the intended. Although some technologies, such as BOF vessel and ladle scan with laser, are available for this purpose, better and more reliable technologies are needed.

Another technological challenge that must be overcome is slag analysis. A speedy, reliable slag oxide analysis technique is not available, particularly for iron oxides that enables controlling lance height, making slag, or calculating alloy efficiencies. In addition, slag analysis is expensive and slow and involves sampling separation problems related to the use of iron versus iron oxides. Techniques have been developed for quick sampling and analysis of ladle slag. However, for the inhomogeneous BOF furnace slag that contains significant amount of solid, fast slag analysis remains to be a challenge. There are shops that manage~~d~~ to have slag chemistry available before the charge of the next heat so that flux addition can be adjusted if necessary.

New and Emerging Technologies. Recent and developing BOF process improvements primarily affect scrap and process sensors. Additionally, development is ongoing in burners and nozzles for the BOF process. This work could improve post-combustion performance.

Preheating techniques and quality improvements lead the emerging scrap technologies. A number of investigations are looking for economical ways to remove residual elements from scrap to replace expensive but successful techniques, such as detinning of bundles. Also, effective scrap preheating techniques are being developed. Smelt-refining processes and EAFs have developed submerged dust injection and scrap preheating technologies, but their application to BOF steelmaking remains unexplored.

Light meters, lasers and infrared cameras and sensors are being studied to control carbon, temperature, slopping, waste gas composition, and lance height above the bath. Improved sensors, instrumentation, computer power, and process models are used to provide data that enable an operator to consistently optimize production processes. Industry-sponsored work on various sensors in BOFs that apply laser measurement and in-lance cameras are presently undergoing commercialization tests.

3.3 BOF Steelmaking Research and Development Needs and Opportunities

Despite all the ongoing research to improve BOF performance, numerous other research opportunities exist.

Big Data. It is necessary to develop models to utilize vast business and process data to optimize steelmaking processes including BOF steelmaking. Modern computing capability made the collecting of vast data and fast processing of such data possible. Such technology should be utilized to reduce material and energy consumption, improve productivity and product quality.

Long-life refractories. Investigate ways to increase use of long-life refractories to improve stirring elements for furnaces or ladles and use in BOF tap holes. A significant opportunity in refractory savings exists if techniques to ensure more even lining wear, for example using fixed laser scanners for heat-by-heat refractory monitoring, are broadly implemented along with development of new erosion prevention techniques such as using a rotating lance carriage. Also, the hood life should be extended to equal that of the refractory lining. Optimal BOF furnace lining life requires the consideration of costs on refractory and gunning material, other maintenance cost, and the productivity of the furnaces.

Process sensors. Develop various user-friendly, robust process sensors with feedback capability to detect bath carbon, temperature, and the advent of slopping, waste gas composition, dusty bin levels, and furnace shell temperatures. The temperature sensor should be able to measure continuously during the final minutes of the blow. Sensors for quick analysis of turndown manganese, sulfur, and other elements are also needed.

Lances. Develop a reliable sensor to detect lance- to-steel bath distance

- Reliable process solutions to achieve more uniform lining wear
- Reliable automatic oxygen blowing, sampling and tapping control solutions
- Increased blowing intensity for the BOF

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Heat-to-heat feedback or real time feedback of lance height will improve the consistency of the process reaction path. Also, a clear understanding of the hydrodynamics of the oxygen lances and its effect on splash generation and decarburization kinetics needs to be developed with a view to optimize lance designs and blowing practices

BOF steelmaking research needs and opportunities

- Robust process sensors for the BOF to measure process variables
- Reliable sensors to detect lance-to-steel bath distance
- Clear understanding of the hydrodynamics of the oxygen lances and BOF bath
- Reliable process solutions to achieve more uniform lining wear
- Reliable automatic oxygen blowing, sampling and tapping control solutions
- Longer lasting, easy-to-maintain hoods
- Economical and environmentally friendly methods of removing or controlling phosphorus
- Longer-life, efficient and easily replaceable stirring elements
- Environmental controls for primary and secondary emissions control systems
- Improved understanding of micro-alloying element recovery through the process
- Increased blowing intensity for the BOF

Flux and oxygen batching. Improved flux raw materials analysis and size with reliable computer controlled batching are needed for better slag making consistency. This research also applies to developing better oxygen batching methods for early slag making.

BOF hoods. Improved, easy-to-maintain hoods, possibly in conjunction with protective coating techniques and/or constant temperature/pressure control techniques need to be further researched.

Dephosphorization. Economical and environmentally friendly methods of removing or controlling phosphorus need to be developed. Alternatively, find other viable uses for BOF slag rather than recycling to the sinter plant. This will reduce the input phosphorus load from the hot metal.

Stirring elements. Longer lasting and more easily replaced stirring elements could make maintenance and bottom stirring more reliable. It is necessary to develop a robust technology/practice to maintain BOF bottom stirring while slag splash is used to extend the furnace lining life.

Environmental controls. Primary and secondary environmental control systems need to be developed and upgraded to Best Available Technology (BAT) in all areas of emission concern as well as higher capacity emission control systems need to be developed to support an increase in oxygen blowing rates. Constant technical review and upgrades are necessary to meet environmental standards of the future.

Other BOF steelmaking R&D needs include using models, maintenance procedures and new technologies to improve performance. One essential requirement is the development of scrap preheating techniques for stretching hot metal. Production pacing and coordination models are needed for BOFs trying to supply steel for multiple casters. These models should consider steel ladle requirements and "what-if" production alternatives.

Research into processes to remove residual elements, such as tin, copper, antimony, and others during the steelmaking process is needed. Maintenance techniques for mechanical and ancillary systems need to be developed to take advantage of increased BOF lining life from slag splashing.

Other BOF Steelmaking research and development needs

- Scrap preheating techniques for stretching hot metal
- Utilization of natural gas in BOF steelmaking
- Refining technology for low Mn/Si ratio metal
- Submerged dust injection for recycling
- Maintenance techniques to take advantage of increased BOF lining life from slag splashing
- Model to optimize blast furnace and BOF operations
- Improved raw materials preparation and analysis including scrap, hot metal and flux
- Use of low quality raw materials in BOF
- BOF off-gas recovery and its effects on process efficiency
- Intelligent cost-based process simulation and analysis logics