APPLICATION OF Z-BOP TECHNOLOGY AT VARIOUS BOF SHOPS

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ABSTRACT

This paper describes several applications of a new high solid metallic charge ratio basic oxygen process (Z-BOP) and its performance under operating conditions of different integrated mills.

Z-BOP was developed and initially implemented at West Siberian Steel Works (Zapsib), Russia. In 1992, the technology became available for commercialization and was successfully implemented at Bethlehem Steel (BSC), Bethlehem, Pennsylvania, and at Iscor, Limited, Newcastle Works Newcastle, Republic of South Africa. Performance of Z-BOP technology modifications utilizing solid metallic charge ratios varying from 30% to 100% are described in this paper.

The data presented confirms Z-BOP technology as essentially a no-capital expense solution to reduce the cost of BOF shop operation, to increase steel production for hot metal limited shops and to produce steel during blast furnace relines and short outages.

GENERAL OBJECTIVES OF Z-BOP DEVELOPMENT

One of the major deficiencies of the basic oxygen process arises from its limited flexibility due to its high dependency on hot metal supply and the overall scale of the operation found in the majority of modern facilities. Furthermore, higher tap temperatures caused by the broad implementation of continuous casting technology has reduced the potential share of applicable solid metallic charge thereby potentially limiting capacity of the steelmaking operation.

Currently in process of being introduced to the Western market is a modification to the basic oxygen process which is designed to address the deficiencies outlined above. The tradename for this new process is Z-BOP.

Z-BOP is applicable when increased steel production is desired in hot metal limited shops. The majority of shops have maintained a scrap handling capacity which would allow an increased production rate with a 30-35% (or more) share of scrap in the charge. Z-BOP also facilitates reduced operating costs by reducing the consumption of slag forming materials and by increasing the flexibility of the quantity and type of the solid metallic charge that can be used.

HISTORY OF THE DEVELOPMENT OF THE PROCESS

Z-BOP originated at the Western Siberian Steelworks (Zapsib) which is located in Novokuznetsk, Russia. This integrated steel mill has an annual production capacity in excess of 7 million tons of raw steel produced in two BOP shops. The imbalance between the production of hot metal and government imposed plans for production of raw steel forced Zapsib to continually innovate its BOP technologies. They had to develop new BOP modifications which could allow an increase in the ratio of scrap and other solid metallics.

In the 1980's, one of Zapsib's BOF vessels was used for industrial scale implementation of the new Russian BOP process modification called the "Tula Process." The process was based on the utilization of oxygen and natural gas injected into the vessel from the bottom and side tuyeres as well as on the introduction of coals through the top of the vessel. In spite of significant time and costs spent by the Soviet government and Zapsib to implement the Tula Process on the industrial scale, this implementation program failed.

However, the motivation behind the Tula Process along with the results and the industrial experience gained during its attempted implementation made it possible to create a more economical and operationally friendly concept to provide for BOF operation with an increased scrap ratio in the charge. This concept served as a basis for the creation of a family of BOP processes which are very flexible and could meet the wide spectrum of requirements of modern integrated mills. Those requirements were identified and established as a set of objectives for development of the family of Z-BOP processes.

1. The technology should be capable of providing for a gradual increase in solid metallic charge without increasing the cost of steel production.

2. The technology is to be realizable with traditional BOF equipment and without additional capital modifications.

3. The technology should efficiently utilize as much of the heat available in the BOF bath as possible.

4. Any deficiency of heat caused by the increased scrap ratio which could not be compensated by improved efficiency of available heat utilization should be compensated through the effective use of heat being released by combustion of inexpensive auxiliary fuel.

5. The metallic charge should include a wide variety of materials to make the technology less dependent on scrap market prices.

6. Practice of the processes should not create additional burden on the critically loaded equipment in the BOF shop or on shop logistics.

7. The technology should satisfy existing environmental requirements.

8. The quality of the steel produced should not be hurt or reduced by the use of new modifications.

9. The production rate of the BOF shops should be less dependent on the pace of the blast furnace operation (including during periods of blast furnace outages).

It took a decade of continuous development effort at the Western Siberian Steel Works before a commercially feasible technology emerged. The major process breakthrough was development of a new concept for providing thermal energy to an increased mass of solid metallic charge rapidly and efficiently. The concept involved a combination of the following basic components.

1. More complete utilization of the heat available from the oxidation of melt impurities.

2. Combustion of carbonaceous fuel with top blown oxygen to make auxiliary heat available for rapid and efficient preheating of solid metallic charge.

3. Localized burning of a small part of solid steel scrap in order to release additional heat for processes utilizing more than 45% solid metallic charge without local overheating of the convertor's refractory lining.

A complete re-evaluation of the slag forming practice of the conventional basic oxygen process was required in light of the above new processes affecting the basic oxygen process heat and mass balance. Changes in oxygen blow practices and revisions in the dynamics of the oxidation of the molten bath also became necessary in order to realize the above process concept.

The R & D effort has led to the creation of several proprietary modifications of Z-BOP technology (broad U.S. and Russian patents allowed) consisting of several innovative features. These provide for enhancement in utilization of heat available in the basic oxygen process and also provide for effective additional auxiliary heat introduction and utilization. These features include:

- A distinct slag forming practice

- A different mode of oxidation of impurities in the molten bath.

- An innovative method of combustion of lump carbonaceous material which effectively transfers the auxiliary heat to the metallics charged in the vessel.

- Efficient utilization of a small portion of steel scrap as additional fuel when the solid metallic portion of the charge is in excess of 45%.

CLASSIFICATIONS OF THE PROCESS

The family of Z-BOP processes can be split into major categories:

Category	Processes
1. Z-BOP W/O Use of Carbonaceous Materials (Such as Coal or Coke)	Z-BOP/NC
2. Z-BOP With Use of Carbonaceous Materials	Z-BOP/30 Z-BOP/50 Z-BOP/75 Z-BOP/100

Z-BOP/NC

The processes within this category do not utilize an auxiliary heat source. They fully rely on providing additional available heat through utilization of the heat traditionally wasted in the basic oxygen process. This higher efficiency of heat utilization for heating and melting of increased solid metallic charge mass is primarily provided through the use of more energy efficient slag practices and more effective use of heat released from hot iron component oxidation.

The Z-BOP/NC processes provide the opportunity to efficiently operate with a metallic charge containing up to 40% scrap or up to 15% iron oxides like iron ore pellets or sinter. The use of such iron oxides reduces the cost of the metallic charge and benefits the production of steel grades which are extremely sensitive to residual elements included with steel scrap. The achievable share of scrap and/or iron oxides is a function of a number of parameters including the silicon content and temperature of the available hot metal and the aim steel chemistry and temperature.

The Z-BOP/NC processes not only perform well with the use of optimum hot metal chemistry but are capable of achieving significant benefits in cases when hot metal is utilized with relatively high silicon content (0.9-1.5%) and with low silicon content (0.2 - 0.5%). High silicon content facilitates a scrap ratio up to 40% with a corresponding decrease in lime consumption (up to 70%) and significant increase in the metallic yield. In low Si content hot metal cases, the scrap ratio increase is limited to 30%, the metallic yield can be significantly increased. Other benefits that utilization of these processes can provide to a BOF shop include improved metallic yield and prolonged vessel lining life when low and optimum Si content hot metal is utilized.

The Z-BOP/NC processes also provide for significant quality improvements due to increased sulphur and phosphorous removal efficiency. This allows a significant reduction in consumption of slag forming materials.

The primary limitation of the Z-BOP/NC processes is a potential increase in charge to tap time. The use of a conventional charging cycle with increased solid charge weight could increase charge to tap time up to 4 minutes. An increase in the solid metallic charge to a level requiring the use of additional scrap charges would increase charge to tap time accordingly. It is possible that the effect on production capacity due to the increase in charge to tap time can be mitigated or eliminated by changing the logistics of the shop.

Z-BOP/30

The processes in the second category of Z-BOP utilize auxiliary heat provided by combustion of coal. Implementation of the first process in this category, designated "Z-BOP/30", provides an adequate amount of available process heat to increase the solid charge ratio up to 35% by using less than 20 pounds of coal per ton of steel produced. Utilization of auxiliary fuel combustion for solid charge heating results in a 1-2 minute increase in oxygen blowing time as well as an increase of oxygen consumed per ton of steel produced (up to 13 scf of oxygen per pound of charged solid carbonaceous fuel). Z-BOP/30 also provides an improvement in slag forming practices, reduction in consumption of fluxing materials and improvements in the efficiency of sulphur and phosphorus removal in the basic oxygen process similar to the effects provided with Z-BOP/NC.

Z-BOP/30 allows the scrap ratio to rise approximately 5 percentage points above the scrap ratio for a given BOF shop utilizing Z-BOP/NC. Metallic yield and BOF lining life for this modification are similar to the metallic yield and lining life which existed prior to the implementation of Z-BOP technology.

Z-BOP/50

This process utilizes multiple solid metallic charge preheating cycles inside of BOF vessel and is designed to bring the solid metallic charge ratio to the level of 50%. This process is designated "Z-BOP/50" and, compared to Z-BOP/30, uses a greater charge of coal (approximately an additional 50 lb/ton) and accordingly greater oxygen consumption. Multiple charging of solid metallics prolongs charging time and therefore tap-to-tap time. The amount of time increase depends on the number of additional scrap boxes needed to charge a 50% solid metallic charge into the BOF vessel.

An additional 5 to 15 minutes of charge to tap time duration can be tolerated in the majority of BOF shops without a reduction in the average tap to tap time through reduction of idle time of the involved BOF vessel. It is possible this idle time could be used to charge additional scrap and perform a scrap preheating cycle during the time when an adjacent converter is turned down for sampling or is occupied with an operating step which does not involve the scrap crane or the main oxygen blow. It is also possible Z-BOP/50 with its increased tap-to-tap time could be used to stretch production in shops with extremely short cycle times. This could be achieved by using the process at the start of a continuous casting sequence when there is typically additional BOF time available.

Z-BOP/50 is designed for shops having a deficiency in the supply of hot iron to support the desired BOF shop production rate. However, because of the increased amount of residuals introduced with steel scrap, the use of the process is limited to shops producing steel grades less sensitive to residuals.

The outage of a blast furnace in an integrated mill with multiple blast furnaces is an opportunity for Z-BOP/50 utilization. Another suitable case is the possible shut down of a small expensive blast furnace while maintaining the same level of steel production. Use of solid pig iron, cast iron scrap and DRI is possible for this process and could be used to reduce the input of residuals.

The sulphur content of steel produced with the use of Z-BOP/50 is case specific and for the majority of steel grades does not constitute an unsolvable problem. This process, as in all Z-BOP processes utilizing up to a 50% scrap ratio, has an essential feature of low nitrogen content in the heat. Metallic yield is slightly reduced (less than 0.7% for the 50% scrap case) due to unrecoverable oxidation of a small fraction of the metallic charge.

Z-BOP/75 & Z-BOP/100

Another process in the category of Z-BOP technology that utilizes auxiliary heat is designed for use during temporary blast furnace outages in single blast furnace shops when hot metal becomes temporarily or permanently unavailable. The process capable of increasing the solid metallic charge ratio to 100% is known as Z-BOP/100. Another process supporting approximately 75% solid metallics is designated Z-BOP/75.

The key feature of these processes is they provide the ability to maintain a substantial production level in the BOP shop when the supply of hot iron is reduced to 20-25% of the normal supply level, or when the supply of hot iron is completely eliminated. It therefore provides BOF shops with significant economical advantages and the capability to maintain an uninterrupted steel supply to the most critical and profitable customers.

These processes utilize a significant amount of additional heat released by controlled localized steel scrap combustion. The extremely high temperature combustion process responsible for the additional heat release consumes up to 5% of steel scrap when 80% of the charge is solid metallics. A substantial increase in tap to tap time occurs when practicing this process. The increase is caused by the additional solid metallic charging cycles required and the additional oxygen blowing time that is necessary to release the heat by combustion of carbonaceous fuel and a small fraction of steel scrap. Production of steel utilizing 100% scrap consumes up to 10% of the steel scrap (in addition to carbonaceous fuel) to provide necessary auxiliary heat in the BOF vessel.

It is typical that some decrease in the production rate of the shop is experienced when Z-BOP processes are used to achieve solid metallic ratios in the charge higher than 65%. This limitation is related to the logistics of scrap preparation and to the potential increase in charge to tap time. As the portion of scrap in the charge increases the time required for scrap charging and the time required for preliminary scrap preheating also increase. The specific nature of the charging and preheating time periods depends to a significant extent on the type of scrap use, the existing system for hot metal charging, and the limitations of the waste gas systems of the BOF shop.

The implementation of the Z-BOP processes that use coal does not usually require any significant changes in the BOF hardware. The most likely change involves making modifications to facilitate controlled charging of coal in batches. Also it is possible that equipment devoted to measurement of process characteristics like waste gas temperature and composition should be installed.

It is of note that although the use of a proprietary ZapTech oxygen lance is required for 100% scrap, no change to the conventional lance design is needed or recommended by ZapTech for implementation of other Z-BOP processes.

In order to provide for normal or higher lining life of the vessel, proprietary ZapTech slag coating practices should be utilized. These practices do not require any significant additional costs. For Z-BOP utilization with 100% solid charge, it is recommended that ZapTech flame gunning hot refractory repair technology be utilized. This technology requires installation of special equipment.

Z-BOP PROCESS CHARACTERISTICS

Solid Metallic Charge

Z-BOP processes utilize traditional solid metallic charge components such as internally generated light scrap, heavy pit scrap, tundish skulls, purchased scrap and recovered slag metallics, etc. Solid iron in the form of solid pig iron, pool (beach) iron, broken molds, and cast iron scrap can also be effectively utilized by Z-BOP processes to reduce the input of residuals with solid metallics.

The flexibility of Z-BOP technology allows for expansion of the range of suitable solid metallic charge components in the area of low cost metallic oxide materials such as ore pellets and sinter. DRI can also be used where economically feasible.

An increased solid metallic charge ratio results in changes in the logistics of material handling. The degree of change in the solid metallic charging practices increases with the solid metallic charge ratio.

The logistic of solid metallic charging is aimed at maximizing the use of the volume of the charging boxes in order to increase the weight of each charge. When two converters operate without the ability to blow oxygen simultaneously, the charging of one converter is preferably completed before the second converter has been turned down for sampling. Such a charging sequence allows for a scrap preheating cycle to be conducted in the first convertor when the second one is waiting for sampling.

In BOP shops producing low residual steel grades, solid metallic charge logistics can be adjusted to allow an increase in hot iron and internally generated scrap charged for use on low residual steel grades while increasing the quantity of lower grade purchased scrap for less sensitive steel grades.

Slag Forming Materials

Slag forming materials used by Z-BOP process are similar to the ones utilized in traditional basic oxygen process. They include burnt lime, dolomitic lime and raw dolomite. However, due to changes in slag forming practices, this process eliminates the need for expensive fluxing enhancers such as spar.

Carbonaceous Materials

Carbonaceous materials used in the process as auxiliary fuel should consist of low sulphur (preferably ≤0.75%) lump coals preferably bituminous coal and anthracite. Coal is fed to the process through the existing flux bin system. In some cases, coke can be substituted for anthracite. The size of lump coal can be varied, but the preferred size is ½ to 1 inch. Typical variation in calorific value, hydrocarbon content and other energy related characteristics of the above materials are acceptable for use in the Z-BOP process.

Hot Metal

Dependence of BOP performance on hot metal temperature and chemistry variation (Si, Mn and C content) is essentially eliminated with the use of Z-BOP technology due to process capability to add auxiliary heat to make up for the reduction of the heat available with the hot metal charge. This results in an improvement of BOF performance by eliminating the need to increase the hot metal charge for the heats supplied with lower energy containing iron. The requirement for additional hot metal has a particularly negative impact on hot metal limited shops because of the loss of production.

HISTORY OF IMPLEMENTATION

Outside of the implementation at Zapsib the performance of Z-BOP implementations can be demonstrated through two case histories:

1. Bethlehem Structural Products Corporation (A subsidiary of Bethlehem Steel)

2. Iscor, Limited - Newcastle Works

BETHLEHEM STRUCTURAL PRODUCTS CORPORATION

The first application of Z-BOP technology outside of Zapsib was carried out at Bethlehem Structural Products Corporation (BSPC) in Bethlehem, Pennsylvania. The BOF shop at BSPC has two 270 ton converters. All the steel produced is cast to ingots for production of a wide range of structural products and some ingots that are converted into flat rolled products at other divisions of Bethlehem. The shop has limited ladle treatment capability. The BOP shop is equipped with a full combustion hood and electrostatic precipitator system.

The initial investigation focused on the technical and economic feasibility of Z-BOP to utilize 100% solid scrap in the charge. This operating mode was considered as a low capital investment alternative to construction of a new electric arc furnace shop.

Following a visit to Zapsib by operating and technical personnel from Bethlehem Steel in order to observe the process, a series of trials were conducted utilizing 100% solid scrap with no hot metal in the charge. In total 52 trial heats were produced.

The general process steps followed for the trial heats were as follows:

1. Prepare furnace
2. Charge and preheat
3. Main blow
4. Turndown & sample
5. Tap

The procedures within steps 1 through 3 differed the most from "normal" BOP practices. The other key area of difference was the materials used. There were particular requirements for either the quantity and/or type of scrap, coal, flux and alloys used. Scrap selection was a compromise based on residual content, density, non-metallic contaminants, cost and availability. The combustion of 136 lbs (average) of coal per net ton of liquid steel and the oxidation of about 10% of the scrap charge provided the necessary heat for the process.

The description of the process and materials used along with the results of the 100% scrap charge trials have been documented in other papers[1,2]. The general conclusion from the trials was that Z-BOP/100, as with any steelmaking process, has its advantages and disadvantages; they should be carefully analyzed prior to implementing the process.

From the trials it was concluded that the key advantages of the Z-BOP/100 process are that it:

- Reduces, or eliminates, dependency on hot metal and coke.
- Involves low capital costs to convert an existing BOF to an all scrap-charge process.
- Can provide steelmakers with hour by hour flexibility in the choice of scrap/hot metal ratio.
- Can provide reduced operating costs.

The key disadvantages were concluded to be:

- The tramp residuals present are similar to those found in an EAF production route.
- The process is not proven for every-heat use.
- It decreases steel yield and increases slag FeO.
- There are detrimental effects on lining life and for best results ZapTech flame gunning refractory repair technology should be utilized.
- Utilization of the process reduces shop capacity by 1/2 compared to a steelmaking facility that is not hot metal limited in any way.

The Z-BOP/100 trials at BSPC represented the most extreme form of Z-BOP technologies.

Operating factors such as yield, FeO in slag, heat time, scrap handling and environment were in their "worst case" because of 100% scrap being used in the charge. Even then, with the scrap prices available at the time of the trials there were positive economic results.

BSPC has, for many years, actively worked at reducing hot metal consumption. The overall results are shown in Figure A. The progress from a "normal" hot metal percentage of 75% in 1982 to the 65.7% achieved in 1988 came about through the evolution of plant-developed practices such as:

- conserving hot metal temperature
- post-combustion lances
- anthracite additions

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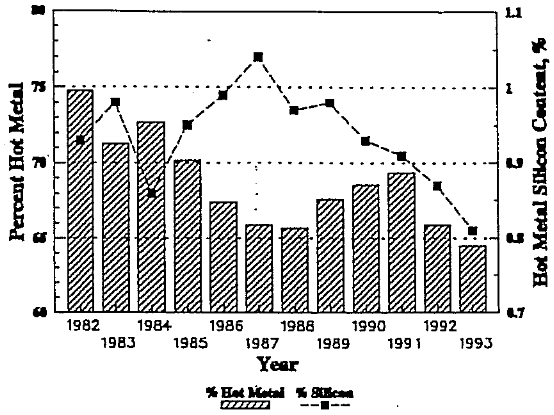
[1] Bethlehem Steel Corporation & West Siberian Steel Works, *BOF Steelmaking Without Hot Metal*, as Presented at ISS 76th Steelmaking Conference, March 1993, Dallas, Texas.

[2] Bethlehem Steel Corporation & West Siberian Steel Works, *BOF Steelmaking Without Hot Metal*, as Presented at the 1st European Oxygen Steelmaking Congress, June 1993, Dusseldorf, Germany

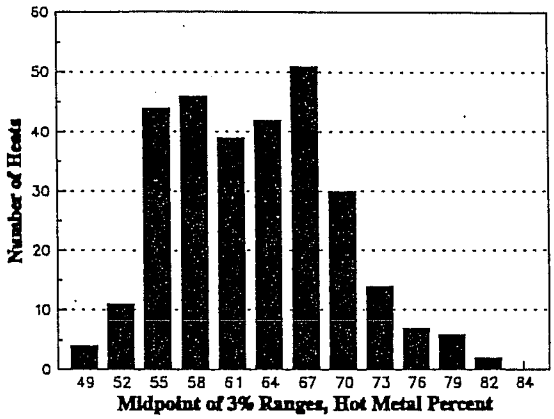
Figure A. Hot Metal Use



The higher hot metal use in 1989 through 1991 was because in much of that period BSPC did not want to maximize scrap consumption because of economic and production considerations. In addition hot metal silicon content, cold iron use and steel production levels all were dropping which increased hot metal consumption.

In 1991, through their exposure to the ZapTech techniques employed in the Z-BOP/100 trials, BSPC recognized that some of these practices particularly scrap preheating, could benefit their normal production. The ZapTech preheating practice clearly was a more thermally efficient way of using coal to add energy to the BOF. Since then BSPC, aided by ZapTech, has evolved a customized high scrap ratio process that uses BSPC's post-combustion and supplemental fuel practices coupled with the licensed proprietary scrap preheating practices from ZapTech. This process is used routinely and is responsible for the record low hot metal use (64.6%) in 1993. This is three to four percent lower than it would have been without the ZapTech contribution. Note that the annual overall hot metal use is a composite of all heats ranging from less than 50% to over 80% hot metal. The distribution for a typical recent month is shown in Figure B. The charge for each heat is dictated by scrap and hot metal availability as well as logistics, metallurgical constraints and a wide variety of other factors. BSPC expects to get to 61% hot metal by further tuning the process and minimizing the external factors that prevent using the process.

Figure B. Typical Monthly Distribution of Hot Metal, %



This customized high scrap ratio process has proven to be an effective tool to produce heats with hot metal use in the 50-55% range. Some details of the process follow:

Material Consumption

By integrating the process into the Bethlehem process control computer in early 1992, the operators were able to make this a routine practice. Table 1 represents the current typical normal materials consumption for a 54% hot metal, 270 ton heat with a turndown aim of 0.08% C and 2960°F using hot metal at 0.85% Si, 0.025% S and temperature of 2440°F.

Table 1. Typical Consumption of Materials

Material	Consumption, Pounds Charged	
	Per Heat	Per Liquid Steel Ton
Hot Metal (54%)	327,000	1211
Scrap (44.8%)	271,000	1004
Burnt Lime	25,600	95
Dolomitic Lime	16,500	61
Bituminous Coal	10,800	40
Anthracite	10,800	40
Alloys (1.2%)	7,000	26
Oxygen, scf	570,700	2114

The current scrap blend is shown in Table 2.

Table 2. Typical Scrap Charge

Purchased Scrap Percentage	
Tin Can Bundles	28.0
#1 Heavy Melt	5.0
#2 Bundles	3.0
Total Purchased Scrap Percentage	36.0
Home Scrap Percentage	
Beam End Scrap	28.0
Bloom Crops	20.0
Iron Scrap	6.0
Misc. Steel Scrap	10.0
Total Home Scrap Percentage	64.0

Operation Logistics

A 45% (or higher) scrap heat resembles a normal BOF heat at BSPC except for the following:

1. Three boxes of scrap instead of two.
2. Scrap preheating; at least once and as many as three times.
3. Modified conventional BSPC anthracite addition practice during the main blow.
4. Optional use of post combustion oxygen lance.

Relative Technical and Economic Performance

In general this process could be characterized as follows:

a. Ninety-nine percent of all structural grades have been produced.

b. The technology can be successfully used to produce plate grades.

c. Residual elements reflect scrap use and can prohibit production of certain grades.

d. The heat time additions are:

Preheating one scrap box	4 min
Charging & Preheating each add'l scrap box	8 min/box
Anthracite coal on main blow (optional)	4 min
Post combustion lance (optional)	4 min

Currently, a typical blend of these items increases charge to tap time about 21 minutes. In the Bethlehem shop the increase in heat time is not the limiting factor. BSPC would like to reduce this time, but erratic hot metal delivery coupled with their desire to keep only one BOF hot tend to negate these efforts.

e. The process is still less automated and requires greater effort and attention from the crew.

f. Correlating meltshop yield data with anything is difficult, but it is the operators' consensus that at 55% hot metal BSPC loses about 1/2% yield compared to normal hot metal practice.

g. It was necessary to carefully plan the logistics of material flow into the shop. The ability of the BOF and scrap yard to handle the extra scrap and the flux systems' ability to properly store and feed coal to the furnace were the main areas of concern.

h. Characteristic slag chemistries are:

Chemical Components	Normal, %	Z-BOP-50, %
FeO	16.8	20.0
MnO	7.7	6.8
MgO	7.2	6.1
CaO	45.0	43.3
SiO_2	17.5	16.8
P_2O_5	1.2	0.9
Al_2O_3	1.9	3.5

Note that FeO + MnO are only 2.3% higher than for a normal 75% hot metal practice.

i. As BSPC has gained experience with this process, refractory performance has improved to where it is now back to near normal. Earlier problems with wear in the barrel-bottom junction and to a lesser degree in the tap pad have largely been overcome.

BSPC Summary

BSPC's operating experience in the past two years show that this process is a practical way to increase steel production from their limited hot metal supply. Economic performance is quite specific to the plant and depends heavily on current scrap and hot metal costs. Under the conditions that have existed for most of this period the economic benefit has been substantial.

ISCOR NEWCASTLE

The facilities at Iscor Newcastle include a single 5000 MT per day blast furnace, a 1500 MT induction furnace, and a BOF shop with 3, 170 MT, converter vessels feeding 3 continuous casters. The shop produces approximately 2 million MT of raw steel per year. The product mix of the Newcastle facility consists of section products like channel, bar, wire rod, rails and I&H sections. The melt shop produces a wide variety of steel grades including conventional low carbon steel, low alloy steels and high carbon steels.

Objectives During Blast Furnace Shutdown

Based upon the experience gained during the previous reline of the NS blast furnace, Newcastle works could, with the aid of the induction furnace, produce ~22,000 tons of liquid steel per month. The main objectives for implementing the Z-BOP technology using approximately 75% scrap during the last reline period were as follows:

- Increase the monthly production from ~22,000 to 80,000 tons per month.
- Minimize the loss of customers.
- Decrease the amount of steel to be laid in for standing orders.
- Reduce old scrap stocks at Newcastle works.

In brief, the implementation of the Z-BOP process during the blast furnace shut down had the major technological goal of increasing the production rate within the limitations of hot metal consumption produced in the induction furnace. This goal had to be accomplished while providing the tap chemistries, temperatures and frequencies required to support the traditional pace of the continuous casting operation. Also ZapTech hot repair practices needed to be introduced to enhance BOF lining longevity.

BOF Charge Composition

An auxiliary objective during the shut down was to optimize the utilization of solid metallic charge components that already existed at Newcastle or were readily available from Iscor's Vanderbijlpark Works. During the blast furnace shut down period the iron bearing materials used to produce steel in the BOF were as follows:

a. light weight steel scrap
b. heavy weight steel scrap
c. solid iron
d. hot metal produced in induction furnace
e. liquid semi product produced in the BOF vessel.

a. Light Steel Scrap - The ratios between the different components of solid metallic charge were influenced by the greater availability and presence of significant amounts of light scrap at Iscor. This light steel scrap is characterized by low bulk weight (.4-.6 tons/cubic meter) and high level of oxide content (10-15%). Much of the scrap had been stored at the plant for more than 15 years. Also included in the light weight scrap was internally generated steel scrap produced at the rolling mills and solid metallics extracted from the BOF slag (iron content 70-75%). The combined share of the light weight scrap in the metallic charge was 18-32%.

b. Heavy Scrap- The heavy scrap component consisted of caster crops, crop ends from the roughing stands, ingot scrap, butts, pit scrap and what is referred to as Hecketts B scrap. Hecketts B scrap consisted of reclaimed steel skulls from the ladles and tundishes and had a Fe content of ≈80%. The bulk weight of heavy scrap ranged from 3.0 to 4.5 tons per cubic meter. The share of heavy weight scrap in the charge did not exceed 18%.

c. Solid Iron. Two types of solid iron were used, pool (beach) iron and broken molds. Pool iron is not produced in special casters but produced in specifically designed pits or pools. This method of solid iron production, leads to a very high dirt content (15-25%). Pool iron has a high sulphur content (.1-.3%) due to absence of hot metal desulphurizing prior to casting of pool iron. The average Fe content of the pool iron is only 85%.

These two types of solid iron were utilized in different ways. The broken molds were used primarily in the induction furnace because of their relatively low sulphur content and higher cleanliness. The pool iron on the other hand was primarily used as part of the charge to the BOF vessel. Dedicated use of cleaner iron in the induction furnace allowed its production rate to be maximized at the level of 1000 tons per day.

d. Hot Metal - Hot metal produced in the induction furnace had the following chemical composition:

Carbon	3.2 - 4.1%
Silicon	0.5 - 0.9%
Manganese	0.5 - 0.7%
Sulphur	0.04-0.08%
Phosphorus	≈.1%

The temperature of hot metal before tapping from the induction furnace was 1220-1250°C. On average the induction furnace provided 56.9 tons of hot metal per charge.

e. In addition to the "raw" iron bearing materials there was limited use of a liquid semi-product produced in the BOF. This semi-product was treated and returned to the BOF. The use of semi-product is reviewed more extensively with the discussion of logistics.

Carbonaceous Materials

In addition to the iron-bearing materials other non-metallic materials were used. The bituminous and anthracite that were used at Newcastle Works for scrap preheating had a low percentage of fines and the size range was 6 to 10mm. The composition of the bituminous and anthracite is shown in Table 3.

Table 3. Coal Components

Coal Components	Bituminous	Anthracite
Fixed Carbon	75	80
Ash	13.7	12.5
Sulphur	0.5	0.7
Volatiles	26.2	8
Moisture	1.6	8

Fluxes

The normal type of fluxes were used with the exception that no CaF_2 was utilizing by Z-BOP/75 technology.

The average consumption of non-ferrous materials is presented in Table 4.

Table 4. Consumption Characteristics

Materials	Consumption, per ton steel*
Bituminous Coal	26-32 kg
Anthracite	24-40 kg
Burnt Lime	31-43 kg
Burnt Dolomite	33-41 kg
Raw Dolomite	10-20 kg
Oxygen	125-145 m^3

*Calculated per ton of liquid steel actually produced in BOP vessels.

Compared to the expected level of consumption using Z-BOP at this share of solid metallics in the charge there was a relatively high level of consumption of slag forming materials. This was caused by a high dirt content in the metallic charge and especially in its pool iron component.

The basicity of the final BOF slag was maintained at about 2.5 to 2.8 in spite of the significant pool iron consumption. This is shown in Figure C.

Figure C. Slag Basicity vs Pool Iron Share

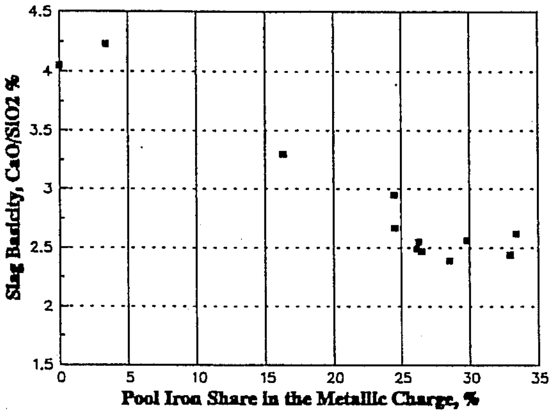
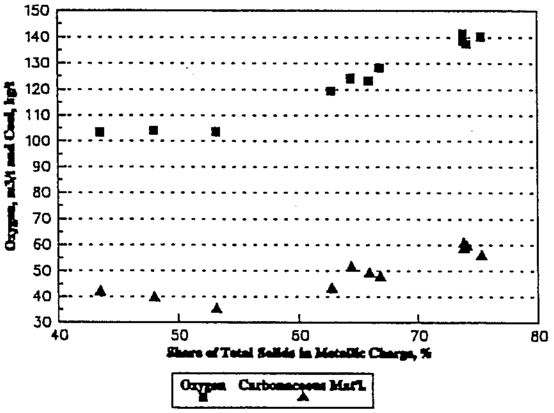


Figure D illustrates total carbonaceous materials and oxygen consumptions vs. solids share in metallic charge.

Figure D. Carbonaceous Materials and Oxygen Consumption



Operation Logistics

In addition to accommodating material issues at Newcastle there were considerations that had to be made for the logistics specific to the plant. In particular the utilization of the induction furnace, the use of a semi-product, and the added level of scrap preparation and handling were optimized during the implementation of Z-BOP/75 for the duration of the blast furnace outage.

Induction Furnace

The first logistical issue was related to effectively integrating the induction furnace into the BOF process. The induction furnace at Newcastle Works has a capacity of 1500 MT with a total possible power input of 15 Mwatt (6 x 2.5 MW inductors). During normal operation, this furnace is used as a mixer, for melting scrap and to control the maximum power demand at the works.

During the blast furnace reline, the induction furnace played a very important role. Broken mold scrap and pool iron were melted in the induction furnace to provide the hot metal charged to the BOF's. During the reline period, it was used to melt 100,055 MT of solid iron scrap.

The hot metal temperature inside the furnace was held at 1220°C. If the temperature dropped below 1200°C , the scrap charging was halted to raise the temperature. The molten metal mass during furnace operation was maintained at above 700 MT. If the level dropped below 700 MT, production was slowed down or stopped to increase the level.

The method of operation of the induction furnace allowed for tapping a full heat of 165 MT so that efficient deslagging of the iron ladle could take place. After charging 50 - 60 MT back to the BOF, the rest of the liquid iron was then poured back into the induction furnace. This caused some heat loss, but ensured that there was no slag build up in the induction furnace.

Semi-Product

The second major logistical consideration was the use of a semi-product. To increase the amount of share of liquid metal in the BOF metallic charge a liquid semi-product was produced periodically in BOF vessels. To produce semi-product the furnace was charged and operated similar to the production of a normal heat. The only difference occurred during the killing of the heat and the carburizing of the heat in the ladle. The result was in production of an iron melt with high carbon content which was used later on in three ways:

- As a charge to the induction furnace
- As multiple liquid charges for several BOP heats.
- Partially used for direct charging to the induction furnace and partially mixed with liquid iron in the ladle prior to charge to the BOF.

The use of the semi-product in these ways allowed:

- An increased liquid weight of the BOF charge when availability of hot metal was constrained.
- An increase in induction furnace productivity.
- More efficient burning of vessel lining during its start-up period after repair.
- An increase in the share of solid metallics in shop operation.
- An increase in the efficiency of steelmaking equipment and an overall improvement in the flexibility of operations logistics.

Although semi-product was useful for the reasons noted above, its use as a main production operating practice was limited for several reasons. Large amounts of alloys (FeSi and SiMn) and recarburizers were needed to kill and recarburize the steel. Also, due to low carbon content and low temperature of the semi-product, skulls formed in the ladles and the induction furnace. These skulls tended to reduce the life of the limited number of available ladles thereby hampering production to a degree.

Scrap Handling

The third major logistical issue was that of scrap handling. The BOF shop at Newcastle began its operation in 1974 and up to the implementation of Z-BOP used a range of 9 to 15% scrap in the charge. Due to the high amount of scrap that had to be handled on a daily basis to support a scrap ratio of approximately 75% it was necessary to make some significant changes in the preparation, handling and charging.

First of all it proved necessary to purchase the following additional equipment:

4 scrap transport vehicles
1 second hand grab crane
1 second hand magnet crane
2 additional scrap buckets

As an aside, the purchase of other additional equipment in order to support Z-BOP was minimal. The only other equipment modifications that were made were:

- Modification of a screw conveyor that supplied coal to the furnace so the supply rate could be increased from 800 to 1000 kg/min.
- A burner for the hot metal ladles to reduce skulling.

In order to produce 18 heats per day it was very important that the scrap transport vehicles were well synchronized and kept in good working condition. For this to happen it was necessary to keep breakdown assistance on the plant for a 24 hour period for the complete reline period.

Scrap was brought in from two areas:

- Light scrap was mainly transported in by lorry (truck) from the outside scrap yard. This was charged into small scrap buckets by grab crane and weighed on a weigh bridge. The final mass adjustments were done with a mobile magnet crane next to the weigh bridge.

- The heavy scrap with some light scrap and pool iron were charged from the gantry scrap yard into large scrap buckets using the two overhead magnet cranes.

Operational Steps

Considerations were made regarding the charging of scrap. The charging boxes at Newcastle have a capacity of 20 cubic meters. The low capacity of the boxes affected the logistics of the Z-BOP process. In order to charge larger amounts of scrap four charging boxes were used.

The charging and heating of scrap had a dominant influence on the process steps utilized. The sequence and typical duration of the operating steps are outlined in Table 5.

Table 5. Duration of Operating Steps

Technological Steps	Duration, min.
Charging of first portion of solid metallic charge	1-2
Charging of second portion of solid metallic charge	3-4
Charging of hot metal	3
Scrap preheating	9-10
Charging of the third portion of solid metallic charge	2-3
Scrap preheating	7-8
Charging of fourth portion of solid metallic charge	2
Blowing	32-35
Turndown	3
Tap	4-10
Total	66-80

Almost all the heats tapped at the BOF plant were sent to the continuous casting plant via the single ladle furnace. The idea was to save on BOF lining and reduce consumption of thermal energy by tapping the heat at a lower than normal temperature and then heating it up to casting temperature at the ladle furnace. Because of the relatively long travel time between the BOF and casters the normal BOF practice had relatively high tap temperatures. Normal ladle furnace treatment with slag conditioner was done on all of the heats produced.

The ladle furnace was further utilized as a buffer for the heats to be sent to the continuous caster. Even with simultaneous utilization of two BOF vessels the BOF tap-to-tap time tended to be longer than the continuous casting time. In order to facilitate longer casting sequences, the 1st ladle of the sequence was held at the ladle furnace and only sent to the casters once the 2nd ladle had arrived at the ladle furnace. Using this logistic up to a 6 ladle casting sequence was obtained.

Results Achieved During Outage

Using the materials and logistics described above a total of 248,618 tons of liquid steel was produced during the blast furnace shut down period. Without the Z-BOP technology Newcastle Works would have been able to produce approximately 60,000 tons of liquid steel utilizing the induction furnace and normal steelmaking practice.

Liquid Steel Yield

In total 329,732 tons of solid metallics were melted in the BOF and induction furnace. The average yield was computed to be 84-86%. This yield was defined as total liquid steel produced divided by the total metallic fraction of scrap plus hot metal charge weight.

The relatively low yield was due to two primary reasons. First, some portion of the scrap was burned as is typical for Z-BOP processes for solid metallic shares in excess of 50%. Secondly, substantial additional loss of metallic yield occurred at Newcastle because of the excessive slag volume resulting from the use of pool iron with high (≈20%) dirt content and light rusty scrap with metallics content of approximately 95%.

Steel Analysis

During the above mentioned period 111 heats were made out of aim specification. This was 6.8% of the total production during the reline period.

Most of the heats regraded were for Si and Mn being out of specification. The main reason for Si and Mn being out of specification was slag carry over to the steel ladle and problems that arose on a fairly regular basis with the deslagging equipment at the ladle furnace. Reversion of Mn back to the steel occurred when trying to adjust the Si specification without deslagging at the ladle furnace The main cause of the large amount of slag in the furnace was the high dirt content in the pool iron scrap.

The process caused no problems in the production of conventional steels. It was not used to produce such products as rope wire and rail steel grades which are limited by specification to a nitrogen level below 0.010% and sulphur below 0.025%.

Another key quality consideration was sulphur content and the sulphur removal efficiency of the process. During the blast furnace shut down charged materials with high sulphur content were used for the heats. Table 6 represents the data related to sulphur content of the charged materials.

Table 6. Sulphur Content of Charged Materials

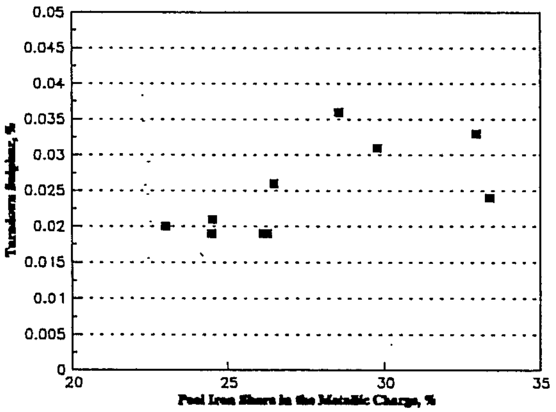
Materials	Sulphur Content, %
Induction furnace hot metal*	0.04 - 0.08
Pool Iron	0.1 - 0.3
Bituminous Coal	0.8 - 1.1
Anthracite	0.7 - 1.2
Induction Furnace Slag	0.9 - 1.3

*Induction furnace hot metal was not desulphurized.

Due to the high sulphur input obtaining a low tap sulphur of the BOF heat was a challenging goal. This goal was achieved due to the high sulphur removal efficiency of Z-BOP process. Figure E illustrates turndown sulphur data vs. pool iron share in the charge.

High sulphur removal efficiency was provided by forming final BOF slag with optimum basicity for Newcastle operation conditions.

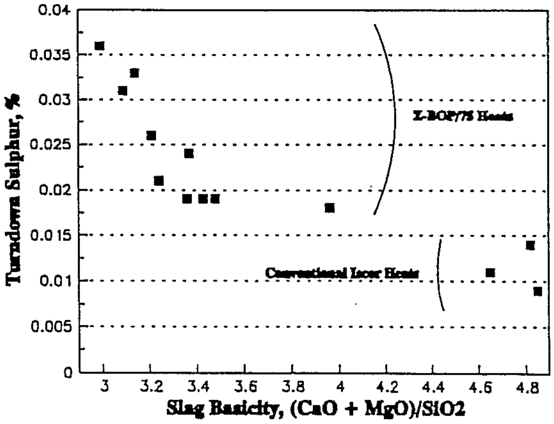
Figure E. Turndown Sulphur Dependency vs Pool Iron Share in the Metallic Charge



Flux Consumption

The use of the Z-BOP process allowed a reduction in relative total lime consumption The basicity of conventional Newcastle practices [calculated as (CaO + MgO)/SiO2] equalled 4.6-4.9 and was reduced to a 3.3 - 3.9 level as shown in Figure F.

Figure F. Turndown Sulphur Dependency vs. Slag Basicity



BOF Refractories

Another key concern was refractory consumption not only because of cost but because vessel availability was key to maintaining production. The Z-BOP/75 process can be harsh on the refractory linings in the BOFs because of the relatively high FeO values of the slag and the longer processing time.

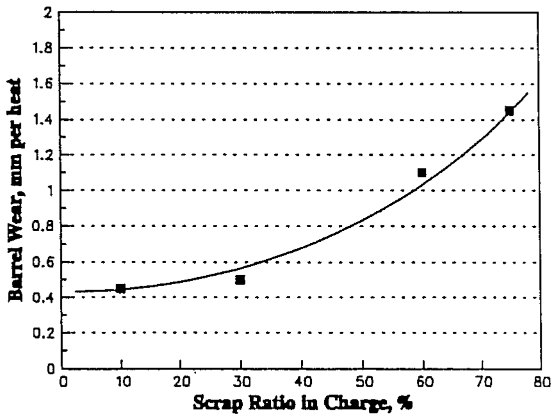
The level of lining wear in areas such as the furnace cone and in the slag metal zone was close to the typically observed level of wear during normal Newcastle practices. Excessive wear was observed on the barrel surface. Additional wear on the bottom was effectively compensated by proprietary ZapTech slag repair practices.

The characteristics of the lining wear indicates the regular use of ZapTech proprietary slag coating practices in combination with wet gunning was able to counteract the effects of longer process time and high FeO in the slag. However those practices were not able to counteract the effects of mechanical impact.

Converter campaigns were ended due to local wear caused by impacts during charging of large pieces of heavy scrap (some pieces were up to 2.5 tons in weight). Compounding the heavy weight of these pieces was the configuration of the charging boxes at Newcastle. They are rather long and facilitated greater acceleration of the pieces during charging.

The refractory wear for conditions at Iscor's Newcastle plant is illustrated in Figure G.

Figure G. Refractory Wear Pattern



As an aside, at Zapsib BOP vessels are maintained with the use of proprietary flame gunning technology. That technology provides a substantially thicker deposit layer than wet gunning and allows Zapsib to maintain a conventional lining wear pattern. It is also worth noting that elimination of heavy scrap pieces from the Newcastle charge would significantly increase lining life.

Summary of Operation During Blast Furnace Outage

Summarizing the experience during the outage using the Z-BOP/75 technology, Newcastle Works was able to increase steel production from approximately 60,000 tons to 248,618 tons. With only the induction furnace available Newcastle would have been able to produce an average of 4.5 heats per day compared to the average of 16 heats per day that were produced. This increase in the relative production rate of about 50,000 tons per month was key to minimizing the loss of customers and the negative financial impacts of a blast furnace reline. According to our internal financial study, it was estimated profitability was increased by over 600% and cashflow by 460% compared to the values that were anticipated if operations had utilized the induction furnace without Z-BOP.

Use of Z-BOP After Blast Furnace Re-Start

After the start-up of the blast furnace another Z-BOP process was introduced to the Newcastle Works in order to facilitate increased output at the hot metal limited shop and lower costs of production.

Objectives After Outage

The objectives for Z-BOP utilization during the post blast furnace relining period were shaped by the limited availability of economically priced scrap at the Newcastle Works. Specifically those objectives were:

- To increase shop productivity by improved utilization of the continuous casters. The improved utilization would be created through increased flexibility at the BOF provided by the ability to utilize increased scrap during period of time when the blast furnace output is temporarily reduced or interrupted. Increased throughput would also be generated by use of a marginally higher share of solid metallic charge consisting of available materials such as pool iron, internally generated scrap, sinter, etc.

- To reduce the operating costs of steel production. Reduced operating costs would be achieved by decreased consumption of slag forming materials, increased metallic yield, the opportunity to utilize a larger portion of inexpensive sinter in the charge, and improved refractory lining life with reduced costs of hot repair by gunning.

Operation Logistics with Z-BOP/30

The operating conditions of the Newcastle BOF shop presented a challenge in implementing a Z-BOP/30 process to address the objectives and achieve an increased ratio of solid metallics in the charge. The equipment and logistics were designed in anticipation of a relatively low scrap ratio (10-15%). The BOF vessel volume per ton of liquid steel tapped is relatively small. The charging boxes have a relatively small volume and the scrap yard has a low throughput capacity.

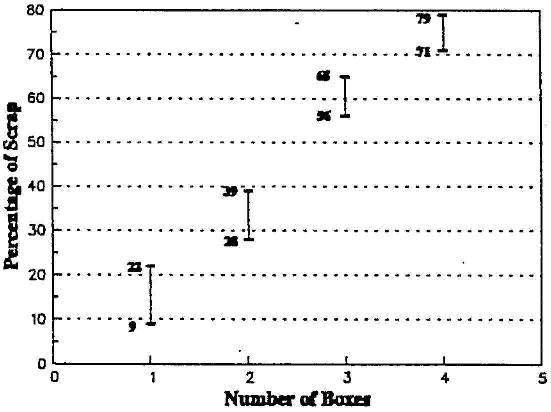
In addition to the limitations of adding more scrap there are process requirements that make a lower scrap charge attractive. Specifically the tap temperature is high (≈1700°C). This high tap temperature is required because of the excessive heat losses that occur downstream as steel is processed and transported to the continuous caster and large alloy additions that are made at the ladle stations.

The limited volume of scrap charging boxes create a condition of increased charging time in order to achieve a 30% solid metallic charge ratio because two boxes are required. Due to an operating preference to maintain a simple single box charge the share of solid metallic charge has been limited for the majority of heats to 20% to 22% of the total metallic weight. Those heats are produced with the use of Z-BOP process technology without coal.

A minority of the heats are produced using two scrap charging boxes and utilize carbonaceous fuels. Those heats are produced during periods of time when increases in charge to tap time can be accommodated (first two heats of new casting sequence) or when temporary hot metal limitation necessitates the use of a higher scrap ratio.

The relationship between the number of charged boxes and the utilized scrap ratio is illustrated in Figure H.

Figure H. Relationship Between the Number of Charging Boxes and Scrap Ratio



Flexibility of Operation

The accommodation to the characteristics of the Newcastle BOP shop spotlight the main advantage that Z-BOP technology provides -- operating flexibility. The flexibility the technology provides is demonstrated further by the plant operation during periods when the blast furnace is producing slowly. At those times the scrap percentage per heat is high. As the rate of furnace production improves the scrap ratio can be decreased without big changes to the overall steelmaking/casting process. In this way better production levels can be achieved than were possible under the before outage (normal) operating practices.

Table 7 below summarizes several of the key factors indicating the flexibility provided by Z-BOP.

Table 7. Table 5. Z-BOP Areas of Flexibility

BOF Shop	Newcastle
Scrap Charge Weight (t)	15-150
Number of Preheatings	0-2
Liquid Steel Weight (t)	145-165
Heat Time (min.)	50-80
Steel Production (heats/day)	15-38

Heat times vary between 50 and 80 minutes depending on the amount of scrap charged to the BOF. For a 30% scrap charge the typical heat time is 55 minutes with an average liquid steel weight of 160.0 tons.

Flux Consumption

Routine utilization of Z-BOP technology during normal shop operation also leads to substantial reduction in slag forming materials as illustrated in Table 8.

Table 8. Slag Forming Materials Consumption

Materials	Z-BOP,kg/t	Normal, kg/t
Lime	33.3	45.3
Burnt Dolomite	9.8	13.8
CaF_2	0	1.5
Raw Dolomite	9.7	2.8
Gunning Mix	1.28	2.58

The above reduction in consumption of slag forming materials has not resulted in deterioration of refining capability due to the inherent increase in desulphurizing and dephosphorizing capacity of Z-BOP processes.

The chemical composition of a typical steel chemistry at turndown is presented in Table 9.

Table 9. Chemical Composition of BOF Steel

Process Characteristics	Z-BOP, %	Conventional, %
Scrap Ratio	10-22	9.0-15
C	0.05-0.12	0.05-0.12
Mn	0.12-0.20	0.14-0.24
S	0.004-0.013	0.005-0.018
P	0.004-0.010	0.004-0.010

Slag Coating in BOF

Utilization of proprietary hot repair slag coating techniques has been incorporated for continuous use as part of the Z-BOP technology. This slag coating practice protects converter refractory lining under conditions of increased scrap utilization. Also gunning mix consumption has been reduced from the traditional amount for Newcastle of 2.58 kg/ton to 1.28 kg/ton. Statistical assessment of converter lining longevity is difficult at this time due to relatively short history of the technology utilization. Preliminary assessments indicate improvement trends in refractory lining life.

Liquid Steel Yield

The metallic yield is calculated at Newcastle as the weight of liquid steel divided by the weight of metallic charge. The corrected average yield has been reported equal to 91.5% with Z-BOP technology implementation. This is the same metallic yield which was achieved with the prior use of conventional BOF practices in spite of the use of a higher share of Hecketts B scrap containing ~80% Fe.

Costs

The impact Z-BOP utilization has on several key indicators of operating cost is summarized in Table 10.

Table 10 Z-BOP Performance Parameters

August 1993	Z-BOP	Normal	Difference
Average Hot Metal	160.5	165	-5.5
Average Scrap Charge (MT)	22.5	12	+10.5
Burnt Lime (kg/MT)	33.3	45.31	-12.0
Burnt Dolomite (kg/MT)	9.8	13.8	-4.0
Raw Dolomite (kg/MT)	9.7	2.8	+6.9
CaF_2(kg/MT)	0	1.5	-1.5
Sinter (kg/MT)	5.2	1.5	+3.7
FeSi (kg/MT)	1.56	1.4	+0.16
FeMn (kg/MT)	1.1	1.0	+.1
Liquid Steel (MT)	165.7	162	+3.7
Corrected Yield (%)	91.5	91.5	0
Gunning Mix (lb/MT)	1.28	2.58	-1.2

Iscor Summary

The process has provided cost savings while increasing the flexibility of plant operation and resultant throughput capability. The use of Z-BOP processes at Iscor's Newcastle Works after their blast furnace reline is also very economically attractive.

SUMMARY

Site specific operating experience gained by three BOF shops utilizing various processes of Z-BOP technology under different market and material price conditions existing in Russia, the United States and the Republic of South Africa has led to the following common conclusions.

- The enhanced flexibility of the new technology significantly reduces the dependency of BOF shops production rate on blast furnace throughput rate. The use of this technology may increase productivity of shops which are constrained by hot metal output, including during blast furnace reline periods.

- The ability of the new Z-BOP process to use an increased solid metallic charge ratio and/or reduced volume of fluxing materials may provide integrated steel mills with significant operating savings. Savings may also be possible from the utilization of an increased share of less expensive solid metallics including steel scrap, solid iron scrap, sinter and pellets.

- A consistent throughput rate of the BOP process is substantially less affected by variation in the chemistry and temperature of hot iron and variation in solid metallic charge density and weight.

- A broad variety of low, medium and high carbon steel grades can be successfully produced in BOP shops of different design with the use of Z-BOP technology without any significant capital expenses for the process implementation.

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