Use of Z-BOP Technologies at the Newcastle Steelworks of BHP Long Products

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The Newcastle Steelworks of BHP Steel rebuilt one of its two blast furnaces during a 68-day outage in 1996. The expected hot metal production and, consequently, steel production, was projected to drop to about less than half of the normal production level of about 5,000 metric tons per day. To offset some or all of the production shortfall, the plant decided to use Z-BOP technology, since it permits more scrap to be used in the BOF charge. The decision was made to use Z-BOP technology before, during and after the blast furnace outage. Later, the short-term contract was extended to a long-term agreement.

BHP Newcastle uses Z-BOP technologies to meet hot metal shortages and surpluses, as well as to enable use of cheaper materials in the charge.

BOF SHOP DESCRIPTION

The BOF shop at BHP operates two 215 metric ton nominal capacity vessels. Table I shows the specifications of the hot metal used in the conventional BOF practice. The waste gas system permits use of only one vessel in the blow mode.

Table I *BHP Hot Metal (in percent)*

C	Mn	P	S	Si	Temp. (°C)
4.5	0.62	0.09	0.012	0.71	1,360

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Steel typically is tapped from the BOF at a temperature between 1,610°C and 1,700°C. The aim tap temperature depends on the tap carbon, which ranges from 0.35 to 0.2 percent, and other factors, such as alloy additions and ladle condition.

Tapped steel normally is treated in a ladle metallurgy facility and then cast through a four strand, 630 mm × 400 mm, bloom caster. Cast blooms are transported directly to the bloom mill reheat furnace and hot charged.

About 40 percent of the steel grades produced by the Newcastle Steelworks require a sulfur content of less than 0.015 percent. High carbon steels as well as low carbon steels are produced. The most significant issues regarding steel quality are hydrogen, phosphorus and oxygen control.

The traditional BOF practice used about 20 percent solid metallic materials in the charge. These solid charges are weighed at the scrap yard, one to two heats in advance, and delivered to the shop by truck.

The Newcastle BOF shop has a unique bin system for overhead feeding of fluxes and other bulk materials. These materials are delivered to the weigh bins above the vessel by a Larry Car. The weigh bins consist of one larger bin for the main fluxes and five small bins for additions of ore, raw dolomite, ferrosilicon, burnt lime and slop suppressant material. Coke has replaced the slop suppressant with the use of Z-BOP. Both steelmaking vessels are equipped with sublance systems.

The shop does not have facilities for desulfurization or any devices for skimming slag from the hot metal.

ADAPTING Z-BOP TECHNOLOGIES TO MATCH BOF SHOP LOGISTICS

The optimization of Z-BOP at BHP began at the end of June 1996. Newcastle wanted to achieve the following goals in this phase:

- Increase steel production before the blast furnace shutdown.
- Reduce flux consumption.
- Use up stocks of low cost iron-containing materials.
- Decrease the prime cost of the steel produced.
- Increase lining life.
- Train personnel to use the Z-BOP method.

Since purchased scrap was restricted in availability and high in cost, the decision was made to increase steel production by increasing consumption of in-house solid metallic stocks. An estimation of the existing pit scrap and cold pig iron storage showed they could be consumed within several months. The question was, how should these scrap stores be used? Should the solid metallics in the BOF charge be increased to 45 to 60 percent for the period of the blast furnace shutdown? Or, should they be increased by a smaller amount for a longer time frame?

Newcastle opted for a smaller increase in solid metallics charged over a longer time period. The following factors formed the basis for this decision:

- The caster permitted an increase in steel production of as much as 5 or 6 percent.
- Only one fuel was required – coke as the carbonaceous material for input of additional heat energy in the bath.
- The Z-BOP technology did not require difficult changes, permitting a short training period for shop personnel.
- The longer time period permitted operators to increase their experience in working with the technology before the blast furnace outage.
- The demands on the process and people were less during the blast furnace outage than they would have been if a more intense solid metallics charge was used.
- Savings began immediately.

Thus, the decision was made to increase the solid charge ratio by 4 to 5 percent before the blast furnace outage. This increase corresponded with the capabilities of the recovery facilities.

The increased use of solid metallics required changing the procedure to load the charge. The bucket volume and truck capacity prohibited the use of one bucket for the total scrap charge. Therefore, a two-bucket charge was employed.

The solid charge was increased using the cheapest, but dirtier and more oxidized, metallic materials.

BOF Shop Operation During the Blast Furnace Shutdown

Understandably, the BOF shop logistics during the blast furnace shutdown differed from those during normal shop operation. During the shutdown, the portion of solid metallics charged was increased to 38 percent. Although cold charges could have been increased further, many reasons existed for restricting them. Bucket volume, truck capacity for scrap delivery and caster cycle time were some of the considerations. However, the main restriction was the planned refurbishment of BOF equipment.

The amount of solid metallics in the charge was restricted so that the BOF shop produced 16 to 17 heats per day. Also, only one BOF vessel was operated. This permitted the lining temperature to remain reasonably high between heats as well as between delays. The second vessel was held in reserve or in maintenance.

Operation Immediately Following Blast Furnace Repair

Hot metal production increased significantly after the blast furnace repair. The Z-BOP technology was used to help the BOF shop to achieve an increase in steel production at the higher hot metal ratios. This strategy was expected to prevent the dumping of hot metal on the ground.

However, Newcastle had a significant problem – more hot metal was produced than could be consumed. Hence, it was dumped into a pool area.

One component of the problem was the instability of the BOF shop operation. Sometimes the shop could not accept all the hot metal because of internal reasons. However, at times, unstable blast furnace operation also contributed to the problem. The productivity of blast furnaces sometimes exceeded BOF shop productivity. Also, the hot metal chemistry did not always permit its use in the BOF. For instance, the heat may have had a higher-than-specified silicon content.

Despite the excess in hot metal production, the cold pig iron as well as pit scrap storage disappeared.

Z-BOP Operation Today

Standard solid charges were used and are being used in the BOF operation.

Standard charging was performed in accordance with the Z-BOP concept. The Z-BOP technology assumes the use of a standard solid charge from heat to heat. Standard charging does not mean the amount of solid metallics cannot be or was not changed. The standard charge is changeable, but changes are made less often.

Changes are made one time per long sequence of heats. The main criteria that determines the amount of solid metallics in the charge is the amount of hot metal available to the BOF shop. The available hot metal determines the amount of hot metal used per heat. The hot metal per heat is not determined by steel grade produced or hot metal heat capacity.

The standard charge simplifies the preparation of metallics before the heat. This is especially important, considering all solid metallics are delivered by truck in the charge aisle.

METALLURGICAL RESULTS

This section will discuss BOF shop operation with and without Z-BOP use. It covers periods of sharp hot metal shortages and periods of excessive hot metal supply.

The hot metal used during shortages had a heat content significantly lower than that used during periods of excess. And, the hot metal temperature was significantly lower during the blast furnace reline. This was because the metal was held for long periods of time in the torpedo car and, as a result, lost heat. The hot metal silicon also was lower by an average of 0.18 percent and the hot metal carbon was reduced by an average of 0.2 percent.

Solid Charge Use

Figure 1 shows the changing of solid metallics in the charge before, during and after the blast furnace shutdown.

The figure shows a reduction in purchased steel scrap consumption before and after the blast furnace outage. Meanwhile, the amount of internal steel scrap consumed was virtually unchanged. As planned, consumption of pit scrap and cold pig iron increased drastically, especially during the blast furnace outage.

Steelmaking procedures had to be altered to accommodate the higher use of these dirty and often heavy materials in the BOF vessel. The benefit was that money could be recovered by using scrap that lay in the field for years. Pit scrap and cold pig iron consumption decreased following the blast furnace outage (Figure 1).

Flux Consumption

Figure 2 shows the consumption of flux materials. It does not include data from the blast furnace outage. During the outage, hot metal silicon was significantly lower, while pit scrap and cold pig iron consumption were much higher. Data shown in Figure 2 are for hot metal with a silicon content of 0.5 to 0.7 percent. The hot metal silicon content dropped after the blast furnace rebuild.

Although not indicated by the figure, use of Z-BOP technology reduced overall flux consumption. This decrease was not achieved at the expense of slag basicity or, worse, steel refining. It was achieved through segregation of flux additions.

Traditionally, flux use depends on the silicon content in the hot metal and the silica content of other charge materials. However, Z-BOP segregates flux additions depending on the required tap indexes.

Of course, the segregation of flux consumption would be impossible without an accurate prediction of the refining properties of the slag and final steel composition. Also, the process must be controllable.

The Z-BOP concept of slag formation assumes flexibility. Changes are required to the current and final slag properties, depending on numerous input and output factors.

Phosphorus – The first flux savings were achieved through improved accuracy in predicting phosphorus content. Many factors were taken into account to achieve the highly accurate predictions. The optimization accounted for input phosphorus with charge materials, phosphorus solubility in the final slag, temperature conditions of the liquid bath, some kinetic parameters and more.

Magnesium oxide – Another significant flux consideration was the magnesium oxide content of the slag provided through dolomitic lime and raw dolomite additions.

The Z-BOP concept brings a new idea into consumption calculation of these fluxes. According to the Z-BOP concept, consumption of these materials depends on vessel condition, method of lining maintenance before the heat being calculated, duration of delays before the heat and other factors. The effects of the calculated magnesium oxide requirements of the slag on flux consumption can be seen in Figure 2.

The far right portion of Figure 2 shows the results from changes made in early 1997. Some of the dolomitic lime was replaced with raw dolomite. The kiln operation did not provide enough fluxes at these production levels. Additional fluxes in the form of burnt lime had to be purchased. This burnt lime was very expensive. Adding the increased quantities of raw dolomite did not affect the hot metal ratio. An energy increase from the hot metal was not required. However, hot metal consumption increased because hot metal silicon decreased.

Raw dolomite requires significant energy when used as a flux addition in steelmaking. Therefore, steelmakers typically use this material only as a coolant. And, it rarely is used as an inexpensive source of magnesium oxide. With the Z-BOP concept, raw dolomite is considered only as an additional source of magnesium oxide. This way, its use is not determined by the lack or excess of heat energy in the bath. The quantity of

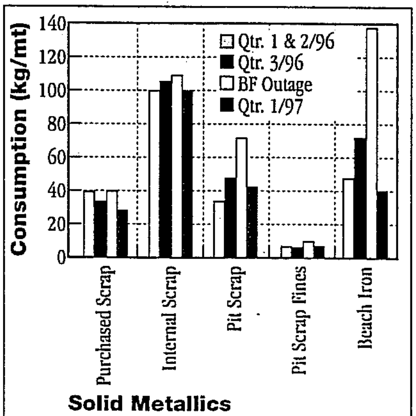

Figure 1 *The solid metallics used at BHP, Newcastle, are shown before, during and after the blast furnace shutdown.*

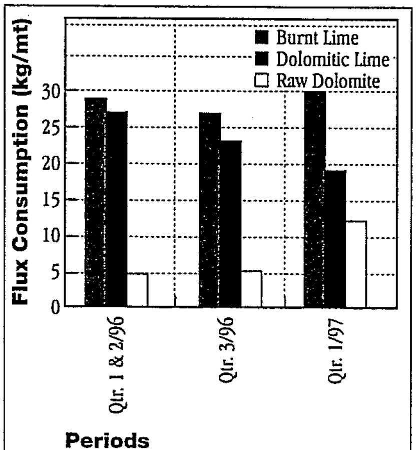

Figure 2 *The flux consumption is displayed for hot metal with a silicon content of 0.5 to 0.7 percent.*

raw dolomite used depends on the magnesium oxide content required in the final slag.

At Newcastle, a proportion of raw dolomite was added to compensate for the kiln capacity constraints. In the beginning, shop personnel were concerned that increased use of raw dolomite would increase slopping, reduce the refining capabilities of the slag, cause high carbon monoxide contents in the waste gases, etc. However, these concerns gradually were dismissed. The Z-BOP method of adding raw dolomite provides a smooth pace for the process, without increased slopping or reduced refining from the slag. Full replacement of dolomitic lime with raw dolomite was achieved.

Note that the raw dolomite used with Z-BOP can be added in combination with iron ore and coke in a large range of proportions. The segregation of flux additions depends on aims and indexes. This philosophy has permitted significant reductions in flux consumption and cost.

Coke Use

The Z-BOP technologies implemented at the Newcastle Steelworks of BHP do not require a scrap preheating stage in the vessel. As stated previously, one carbonaceous material (coke) is used as a fuel. Use of coke alone did not require remodeling the bin system or significant changes to the traditional technology. It also simplified personnel training and permitted faster implementation of Z-BOP technology.

When carbonaceous material is used as the main fuel, the question usually is – How can the fuel be used effectively? To estimate the fuel efficiency of the carbonaceous material, an index, "the additional solid charge melted per unit addition of coke," is used (Figure 3).

Z-BOP technologies permit as much as an additional 10 metric tons of solid charge/metric ton of coke for small additions and an average of 6 to 8 metric tons of solid charge/metric ton of coke for larger additions.

The index of energy use from coke burning for Z-BOP technologies is 2 to 3 times higher than that for conventional practices. The high indexes are achieved through the use of special methods of coke additions and slag formation. For small increases in scrap consumption, Z-BOP technologies can add as much as 10 times the scrap/unit of coke used. As more scrap is added, some of the energy provided by the coke has to be used for other purposes.

Obviously, the estimation of thermal coke efficiency to melt additional scrap in the BOF is not the complete indication of heat energy use with Z-BOP. For larger coke additions, the thermal energy provided by coke is less predictable (Figure 3). And, sometimes heat energy recovered from the coke is spent for other purposes besides scrap melting. For example, it can be used for forming additional slag volume to improve refining or to increase consumption of raw materials (i.e., raw dolomite, limestone, or iron oxide containing materials). At times, the energy is used to compensate for hot metal with low heat content.

For the Z-BOP concept, melting large quantities of solid metallic charge in the BOF is not the end in and of itself. The goal is to achieve the desired cold charge level with the desired refining for all desired conditions.

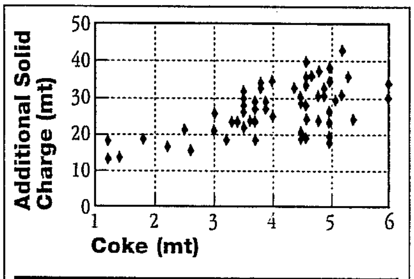

Figure 3 *This index is used to estimate the fuel efficiency of carbonaceous material.*

Several aspects of coke consumption will be discussed:

- Effect on sulfur content
- Use of coke energy
- Effect on the amount of solid metallics charged

Effect on sulfur content—An important or popular theme concerning the use of coke as a fuel is the influence of coke consumption on the final sulfur content of the steel. Coke is an additional source of sulfur. Separating the influence of coke from other sources is difficult. To avoid the influence of such factors as hot metal sulfur, an estimation of the sulfur input with coke, or the relative "sulfur pickup" index, will be discussed. As shown in Figure 4, the influence of coke as a sulfur source is not clear.

In practice, when large quantities of coke are used, large quantities of solid charge also are used. The problem is the sulfur content in cold metallics is not constant and can significantly exceed the figure accepted for calculations.

At times, other sources of sulfur, such as hot metal slag, play more significant roles. As already stated, the hot metal at Newcastle is not desulfurized or skimmed. Figure 5 shows the influence of the hot metal slag on sulfur pickup for coke consumption equaling 15 to 25 kg/metric ton, when the hot metal sulfur is 0.011 percent.

In this case, the tie between these parameters is more clear. Of course, the examples discussed are specific for the Newcastle Steelworks. However,

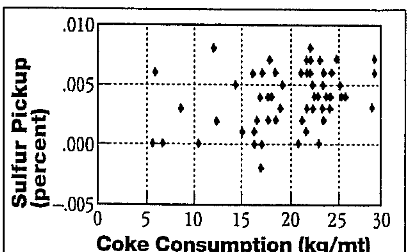

Figure 4 *The influence of coke as a sulfur source is not clear from this graph.*

the influence of coke on tap sulfur must be considered.

One more Z-BOP concept connected with sulfur holds that "if the sulfur input is increased, the sulfur output should be proportionally increased."

The sulfur output occurs in two phases – slag and gas. The removal of sulfur into the slag phase can be achieved by two means – increase the sulfur solubility in the final slag or increase slag volume.

Experience teaches that to achieve the desired goal, all accessible methods should be used. First, coke additions should provide the maximum sulfur removal into the gas phase. Second, the methods used for slag formation should provide maximum sulfur removal into the slag phase.

Figure 6 shows the results of the sulfur balance calculations.

Some simplifications are used in the calculations. For example, sulfur content in the solid charge and hot metal slag are assumed to be constant. Analysis shows increasing sulfur removal into the slag and gas phases promotes the reduction of sulfur in the steel before tap.

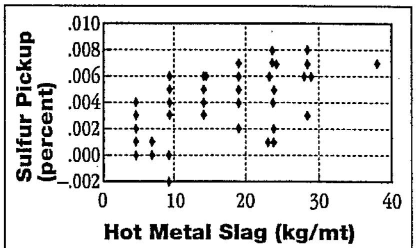

Figure 5 *The influence of hot metal slag on sulfur pickup is shown (coke consumption is 15 to 25 kg/metric ton, hot metal sulfur is 0.011 percent).*

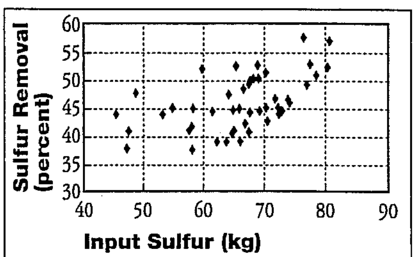

Figure 6 *The results of the sulfur removal calculations are shown.*

Use of coke energy – This section discusses one more concept of Z-BOP as it relates to use of carbonaceous material in the BOF. Traditionally, energy recovered from the carbonaceous material, in this case, coke, is spent for scrap melting. However, many other raw materials require heat energy when used as part of BOF steel production. These raw materials are burnt and raw fluxes, iron and iron oxide materials (e.g., ore, sinter, pellets, DRI, HBI, etc.).

The Z-BOP concept assumes the amount of energy recovered from the carbonaceous fuel depends on the circumstances. Sometimes the energy is used for additional scrap melting, sometimes for additional fluxes and iron oxide materials, and sometimes for increasing slag volume. Most important, Z-BOP assumes coke use for the complicated circumstances of additional scrap and raw or burnt flux materials and iron oxide materials.

Effect on the amount of solid metallics charged – One aspect of coke use can help answer two important questions. They are:

(1) How much solid metallics can be melted in the BOF vessel without preliminary preheating?
(2) How much coke must be consumed to achieve this?

Figure 7 answers these questions. The data are specific for the period of the blast furnace outage. During this period, coke was used basically for two purposes. The first was to increase the solid charge. The second was to increase the slag volume to improve steel refining. The old blast furnace had some operational problems that caused the hot metal consumed in the BOF to have some bad indexes (i.e., low carbon, temperature and increased quantities of hot metal slag).

Anyone who has used carbonaceous material in the BOF knows that using more than 12 to 15 kg of coke/metric ton of steel is difficult. Conventional methods of adding large volumes of coke create problems with slopping, unburned coke, high phosphorus, high sulfur and other negative phenomena. However, the Z-BOP technologies permitted use of as much as 40 kg of coke/metric ton of steel without these negative results. Of course, if the Z-BOP option with preliminary preheating was implemented, the amount of carbonaceous fuel used would increase.

Note that coke use also does not increase the nitrogen content of the steel.

Final Liquid Bath Indexes

This section discusses some indexes of the liquid bath with Z-BOP use. Although the scrap ratio does not influence the condition of the liquid bath with the Z-BOP technology, some results achieved during the blast furnace outage should be discussed. This period of shop work occurred under unusual conditions. Therefore, this data is interesting. Figure 8 shows the actual data and equilibrium between the carbon and bath oxygen.

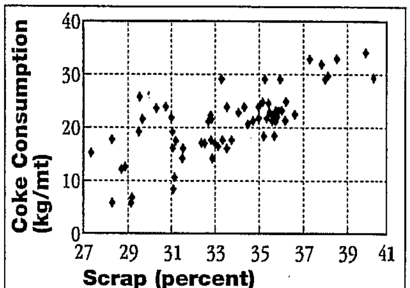

Figure 7 *Coke consumption is compared with the percentage of scrap used in the charge during the blast furnace outage.*

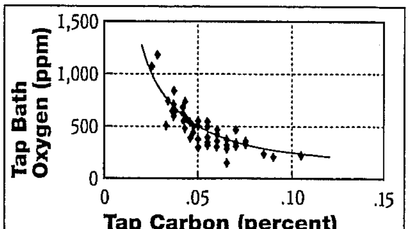

Figure 8 *The actual data and equilibrium between carbon and bath oxygen are shown.*

The solid charge was not increased at the expense of over-oxidation of the metallic melt. Figure 9 shows the oxygen distribution between slag and metallic phases. The actual condition of the liquid bath at blow end was not significantly different than theoretical equilibrium conditions. Note that the data shown in Figure 9 are for data in the range of slag basicity (CaO/SiO_2) from 2.5 to 2.7. In conclusion, the condition of the liquid bath before tap was in good control with Z-BOP.

Figures 10 and 11 show the influence of iron content in the final slag on the manganese content of the steel before tapping and the manganese distribution between slag and metal.

Tap manganese depends on the iron oxide content in the final slag. However, Figure 12 shows the basicity of the final slag also influences the manganese distribution. These data are for heats in the temperature range of 1,660°C to 1,693°C.

The explanation for this relationship is a quasi-constant for the manganese oxidation reaction and its dependence on basicity. Also, this may be related to a changing relation between the activity coefficient of iron oxide and the activity coefficient of manganese oxide.

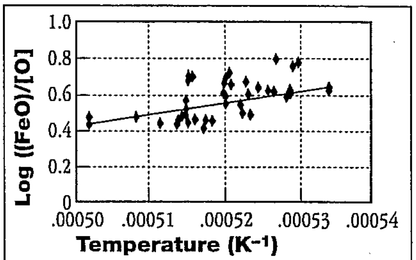

Figure 9 *The oxygen distribution between slag and steel is displayed.*

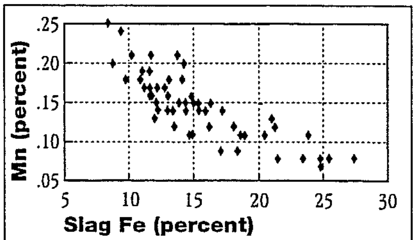

Figure 10 *Iron content in the final slag influences tap manganese.*

REFRACTORY

The final indexes of liquid bath, as well as methods of lining maintenance, play important roles in lining life. Z-BOP technologies offer proprietary slag coating and treatment technologies for effectively coating the vessel with slag.

As mentioned previously, the Z-BOP concept assumes the final basicity depends on indexes of the liquid bath before tapping. Also, Z-BOP controls the MgO level in the final slag. As a rule, this level is a function of vessel conditions. The Z-BOP concept assumes the final MgO content has to vary from 8 to 12 percent. With the use of Z-BOP technologies, the lining life increased significantly. The vessel in operation at this time also was used during the blast furnace outage period. To date, no full lining campaign has been completed with full Z-BOP practice. However, refractory consumption for the first full

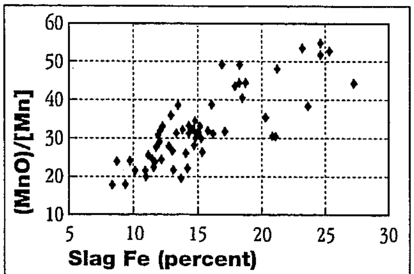

Figure 11 *Manganese distribution is shown between the slag and the metal.*

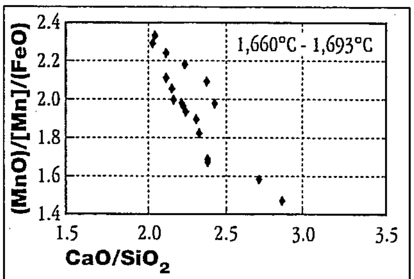

Figure 12 *The basicity of the final slag also influences the manganese distribution.*

Z-BOP campaign is predicted to be increased to greater than 4,000 heats from 3,300 heats. Modifications to gunning practices also are a part of the plan for the least-cost approach to increasing lining life.

STEEL PRODUCTION

Adoption of Z-BOP use at the Newcastle Steelworks has made a major contribution to increased steel production. During the first three months of Z-BOP application (June to August 1996), approximately 44,000 metric tons of additional steel were to be produced compared with planned production without the Z-BOP. However, blast furnace operation problems during September 1996 reduced the overall margin by some 30,000 metric tons.

In spite of this, the application of Z-BOP considerably lessened the impact of the substantially reduced iron. During the blast furnace reline, October 1996 through early December 1996, approximately 12,000 metric tons of additional steel were produced compared with what would have been produced without the Z-BOP.

During the first quarter of 1997, new records for steel production were achieved for post-bloom caster commissioning. Additional production, as compared with the traditional BOF practice was 59,000 metric tons. Increasing the solid metallic charge was a part of the increased production. The cold metallic charges were maintained at a higher level. However, stable production at the BOF shop was the primary source of production improvement. At the end of April 1997, the production level was 104,000 metric tons ahead of the original plan.

Contributing to the stable shop performance were accurate predictions of the final indexes, reduced reblows, increased lining life and well-trained personnel. Other improvements to equipment reliability also helped to enable the production rate capability to be improved on the order of 10 percent.

Another benefit of stable operation was the reduced prime cost of the product. This reduction was achieved by increasing pit scrap consumption, reducing flux consumption and replacing more expensive flux materials with cheaper ones. The impact of fixed costs was diluted by the increased productivity.

CONCLUSION

The BOF shop of the Newcastle Steelworks of BHP began producing steel using Z-BOP technologies starting in June 1996. Initially, Z-BOP technologies were used to offset a production shortfall created by the relining of one of two blast furnaces.

To compensate for this lost steel production, BHP decided to use high scrap melting versions of Z-BOP technologies. These versions of Z-BOP increased the solid metallic charge to 38 percent and were used before and during the blast furnace shutdown.

After the blast furnace repair, the hot metal production increased. In these new conditions, Z-BOP technologies provided significant advantages other than scrap melting.

BOF shop operations became more stable and hot metal being poured on the ground was eliminated. A new operational logistic was introduced into shop operation – the weight of the solid metallic charge was constant (or stable) during long sequences of heats.

Inventories of pit scrap and cold pig iron, as well as iron ore, were used as additional sources of solid metallics. Coke was the main source of additional energy to the steelmaking bath, when shortages of energy occurred. The quantity of fluxes and other materials were reduced. Expensive materials were replaced with cheaper ones.

The high predictability of the final results with Z-BOP technologies permits reliable production of more complicated (and, consequently, more profitable) steel grades. The endpoint conditions (i.e., carbon, manganese, phosphorus, nitrogen, bath oxygen and the slag Fe) of the liquid bath after the oxygen blow were similar to the traditional process results.

More than 110,000 metric tons of additional steel were produced during the first nine months of Z-BOP use. Some records for steel production were achieved with the use of Z-BOP technologies. Pollution control and furnace lining life also were improved.

Thus, with the use of Z-BOP technologies, the BOF shop gained not only the flexibility required for the hot metal shortages and surpluses, but the flexibility to use cheaper materials while improving productivity and process capability.

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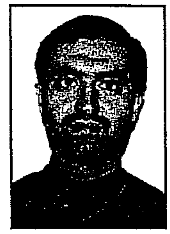
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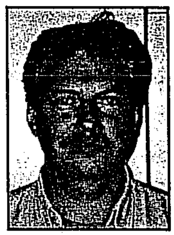
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Environmental Self-Audits and Enforcement in Steel Minimills – An EPA Initiative

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