MODERN DEVELOPMENTS IN ENGINEERING OF OXYGEN STEELMAKING SHOPS FOR BOTTOM AND COMBINED BLOWING

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INTRODUCTION

The bottom blown basic oxygen steelmaking process was introduced and tested on low phosphorus hot metal in North America during 1971. The OBM/Q-BOP process proved to be an improvement over the top blown basic oxygen process in many aspects - capital costs, operating costs, and process capabilities. Capital costs could be saved mainly because of much reduced space requirements and deletion (particularly in the case of open hearth conversion) of extensive overhead material storage and handling systems due to the absence of top lances and because pneumatic material handling and bottom injection permitted replacement of gravity fed top additions. Operating costs were reduced by a combination of high productivity due to the capability of greater specific oxygen blowing rates and better product yields, both from charged and additive materials. Process capabilities included inherently better control of the decarburization process with resultant better end-point consistency (carbon and temperature), improved sulphur removal and considerably less oxidation of the liquid steel. Significantly lower dissolved oxygen in the liquid steel resulted in improved surface and internal cleanliness of the final product. With the worldwide OBM/Q-BOP* steelmaking capacity at about 30 million tons per year, (Table I), information on all aspects of this process is becoming quite voluminous and summary reviews are published (1,2,3,4 and 5). The injection of inert gases or oxygen/inert gas

*The first North American user of the OBM process, U.S. Steel Corporation, chose to re-name the OBM process"Q-BOP", now a wide-spread synonym stressing the generic similarity to the basic oxygen process.

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TABLE I - PRESENT LIST OF OBM/Q-BOP LICENSEES

Country and Company	Location	No. & Size of Converter MT	Annual Capacity 10^6 MT/year
Belgium			
Forges de Thy-Marcinelle	Marcinelle	3 x 150	2.0
France			
Union Siderurgique du Nord et de l'est de la France (Usinor)	Longwy	2 x 40	0.5
Usinor Rehon	Rehon	2 x 85 1 x 85	.85 Start-up
Usinor Neuves-Maisons	Neuves-Maisons	2 x 125	1.0
Germany, Federal Republic			
Maxhuette	Sulzbach-Rosenberg	3 x 60	1.2
Neunkircher Eisenwerk AG	Neunkirchen	3 x 60	1.2
Stahlwerke Roechling-Burbach GmbH	Voelklingen-Saar	5 x 40	1.68
Italy			
Italsider SPA	Cornigliano	2 x 250	3.0
Japan			
Kawasaki Steel Corporation	Chiba	2 x 235	3.5
Luxembourg			
Miniere et Metallurgique Rodange-Athus	Rodange	---	---

TABLE I - PRESENT LIST OF OBM/Q-BOP LICENSEES (Continued)

Country and Company	Location	No. & Size of Converter MT	Annual Capacity 10^6 MT/year
Sweden			
Stora Kopparberg Bergslags AB	Domnarvet	---	---
Surahammars Bruks AB	Surahammar	1 x 35	.15
United States			
U. S. Steel Corporation	Gary	3 x 195	5.0
U. S. Steel Corporation	Fairfield	3 x 180	3.2
Republic Steel Corporation	Chicago	2 x 200	1.1
National Steel Corporation	Granite City	2 x 200	Start-up
Greece			
Larco	Larymna	2 x 50	---

mixtures into the liquid steel bath and the technological advances in the area of solids injection are expanding the OBM process capabilities at present into the fields of degassing, desulphurization and alloying. As more existing LD/BOF steelmelt shops are converted to take advantage of these OBM benefits, the engineering aspects of such conversions have led to incorporation of facilities which logically combine top and bottom blowing to maximize the utilization of existing top blown equipment. Thus, top lance oxygen is used for purposes of both post combustion of off-gases to increase scrap melting capabilities, and the introduction of a combination of top and bottom blown process oxygen to achieve specific metallurgical results.

INCREASED SCRAP MELTING DEVELOPMENTS

Technical developments in bottom blown steelmaking have logically followed the needs of the steel industry. In North America and Europe where high scrap charges in the oxygen process provide significant economies in operations through replacement of higher cost hot metal, it became clear that there was a need to increase scrap melting

TABLE II - IRON LOSS DATA FOR BOP AND OBM/Q-BOP

AS A PERCENTAGE OF CHARGED IRON

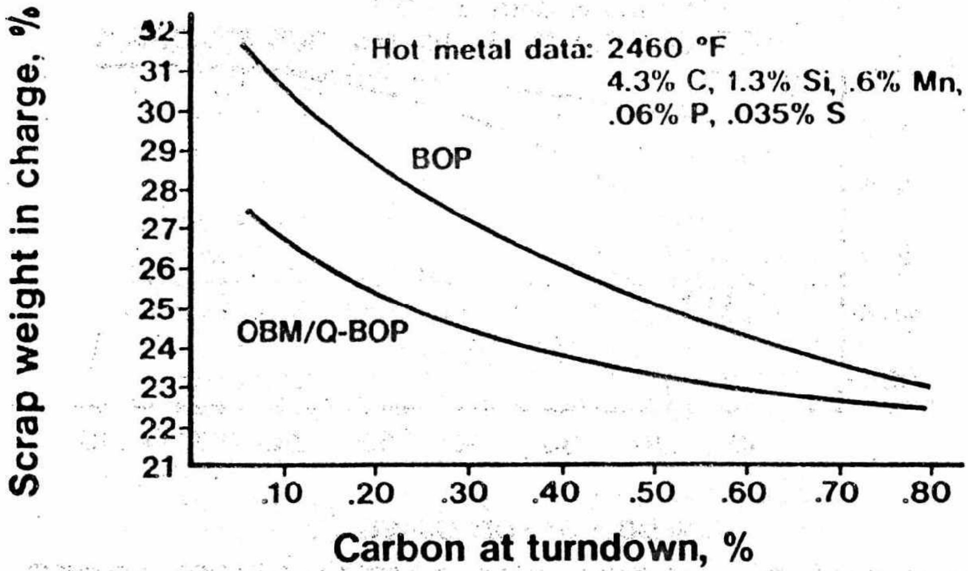
	BOP	OBM/Q-BOP
% Fe Loss as (FeO)	2.19	.74
% Fe Loss as ($Fe_{metallic}$)	1.49	1.87
% Fe Loss as iron oxides in waste gas	.91	.59
% Fe Loss* as iron in slopping, sparking, and nose and hood skulling	.67	.34
% Fe Loss, Total	5.26	3.54
Weight of emissions in primary off/gas lbs./ton liquid steel	25 - 50	8 - 18

* Estimated Combined Totals
Basis: .05% C at Turndown, Low P Hot Metal

capabilities of the process (6). One of the inherent metallurgical advantages of the OBM/Q-BOP process imposed a practical limitation to the application of the process. Less oxidation of iron in the process while increasing process yield also meant less heat generation and consequently less coolant requirement, or, in other words, inherently less scrap melting capability of about 2 to 4 percentage points lower than the conventional LD/BOF. The yield, expressed as liquid steel from total charge weight is higher by about 1 to 1½ percentage points. The combined effect is a small difference in liquid steel output per ton of hot metal charged, with the Q-BOP falling short of the BOF by about 0.040 tons per ton of hot metal. Figures 1 through 3 show these charge, yield and production differences for a full range of carbon levels. Table II lists comparative yield loss data of the OBM/Q-BOP and the BOP.

KMS Process

The technical developments directed to increase the scrap melting capability of the standard OBM/Q-BOP Process can be summarized as the KMS Process - K standing for Klockner, M for Maximilianshuette (the inventor of the OBM/Q-BOP Process owned by Klockner) and S is for increased scrap melting capability. These developments can be divided into three parts:



SCRAP MELTING CAPABILITY OF 200 TON BOP AND OBM/Q-BOP FURNACES AT DIFFERENT CARBON LEVELS

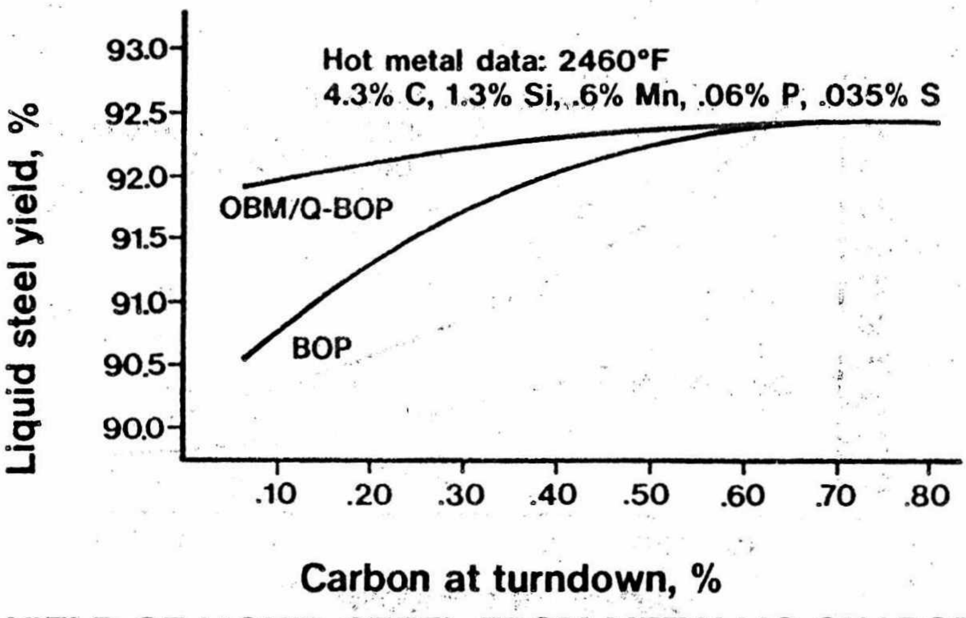
Fig. 1

i) Simultaneous bottom and top blowing, where partial combustion of the carbon monoxide inside the furnace is effected, thereby adding sufficient heat transfer to the melt to achieve roughly a 30% scrap (coolant) requirement at significantly lower iron oxidation levels than experienced with the "classic" LD/BOF. This part is essentially "autothermic".

ii) In addition to this "autothermic" method, the injection of fuel oil through the bottom blowing tuyeres (in stoichiometric amounts with available oxygen flow rates) for the purpose of preheating scrap before charging blast furnace metal in the furnace has been developed. Scrap preheating through the bottom proving to be more than twice as fuel-efficient and therefore speedier than preheating from the top, as practised in the conventional LD/BOF.

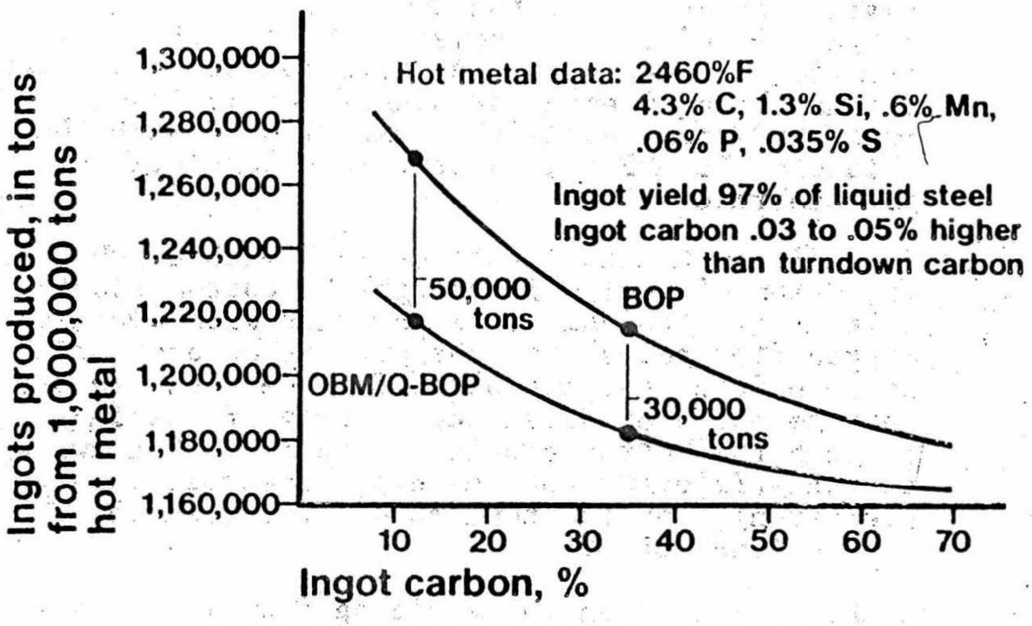
Without significantly oxidizing iron in the scrap, charges of 40% scrap and 60% hot metal are achieved with the combination of scrap bottom preheating followed by partial CO combustion inside the furnace during the oxygen blow.

iii) One additional step which sharply increases scrap consumption in the bottom blown pneumatic process incorporates the injection of carbon in the form of coke or low volatile coal into the



YIELD OF LIQUID STEEL FROM METALLIC CHARGES IN 200 TON BOP AND OBM/Q-BOP FURNACES AT DIFFERENT CARBON LEVELS

Fig. 2



INGOT PRODUCTION FROM 1,000,000 TONS OF HOT METAL WITH 200 TON BOP AND OBM/Q-BOP FURNACES AT DIFFERENT CARBON LEVELS

Fig. 3

melt during the oxygen blow. Combined with the scrap bottom preheating or by itself, but in any case always in conjunction with the partial burning of CO in the furnace, this method allows scrap consumption of well over 50% in the charge for a heat of steel.

With the KMS method, full advantage can be taken of scrap availability and advantageous scrap costs. The steelmaker can also make up for swings in hot metal production due to lengthy repair times for blast furnaces. Most significantly, it provides a low-cost method for maintaining steel production in an existing melt shop with curtailed coke oven/blast furnace production; and in the case of modernization programs, provides one of the lowest cost methods to increase steel production in an existing or new melt shop by eliminating the need to add new or initiate improvements of existing hot metal production facilities through the increased usage of scrap and/or metallized feed in the basic oxygen steelmaking process.

Engineering and Equipment for KMS Developments

Engineering and equipment developments to meet these requirements have led to modifications of the conventional OBM/Q-BOP facility and equipment designs to incorporate various methods to provide increased scrap melting capability through:

i) Post-combustion of converter off-gases using side-tuyeres and/or top lances.

ii) Preheating of scrap within the converter using the OBM/Q-BOP bottom tuyeres as oxy-fuel burners using liquid hydro-carbon during the preheat mode and switch-over devices for introduction of gaseous hydro-carbon during the process blow mode.

iii) Methods to introduce external energy by carbon injection during the process blow.

iv) Capability to introduce and control the blowing of process gases simultaneously from top and bottom.

These developments have led to various modifications to suit specific situations. For example, in the case of an OBM/Q-BOP facility based on conversion of an open hearth shop, side tuyeres must be used. In the case of a converted LD shop, the existing top lance is used in combination

TABLE III - OBM AND KMS DATA SUMMARY

66 TON FURNACE (7)

	$OBM/Q\text{-}BOP_D$ (*)	KMS_D	KMS_S (**)
Scrap Charge, tons	17.85	24.42	32.4
Scrap Charge, %	24.3	33.5	42.3
Preheating Time, Minutes	0	3	8
Oil Consumption, Gal/Ton	0	1.0	2.67
Oxygen Consumption, (for Preheating) SCF/Ton	0	470	750
Main Blow Time, Minutes	11	9.6	8.2
Charge to Tap Time, Minutes	28	30	34

*) D = Double Slag Practice

**) S = Double Slag Practice
Second Slag Tapped

Hot Metal Data: 2275° F

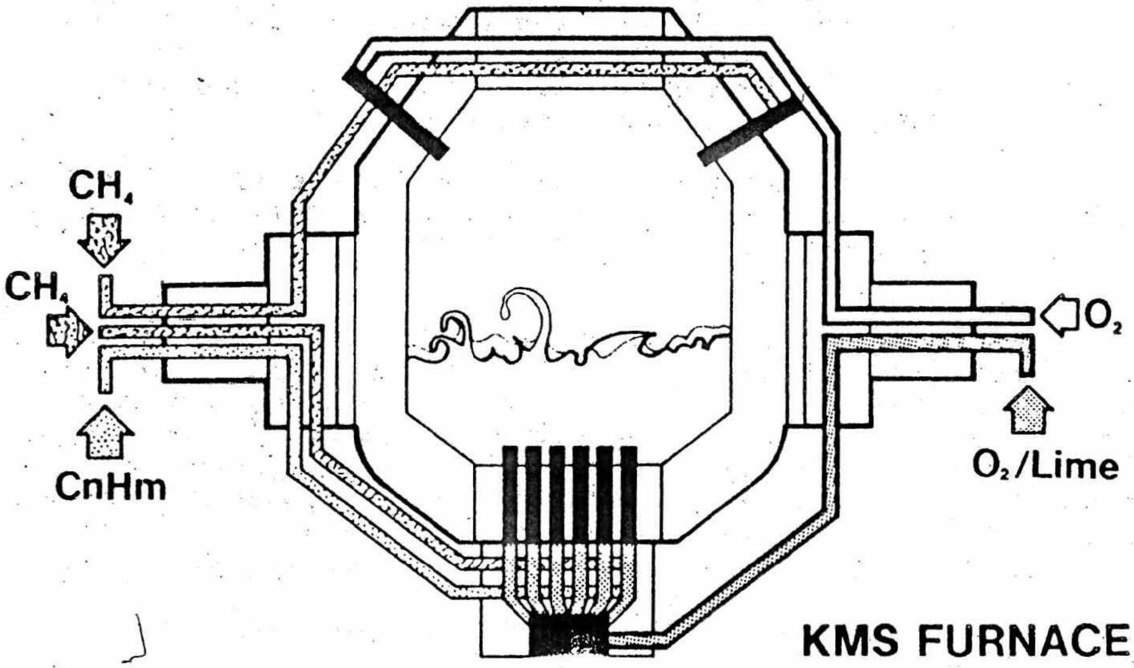
3.4% C, .8% Si, 2.75% P

Aim Turndown: 3000° F

.02% C

with bottom injection of process gases. For preheating of scrap and/or other cold metallic materials, necessary hardware to permit the normal bottom tuyeres to be used as oxy/fuel burners of large capacity were developed. The annular gap designed for a small flow of propane or natural gas will permit plenty of fuel flow if liquid hydro-carbon is pumped through it during scrap preheating, and alternately gaseous hydro-carbon during the regular oxygen blow into the hot metal. Also, side tuyeres were re-tested and found to be effective, provided that a suffi-ciantly large oxygen quantity is introduced at the right place in the furnace. Together with scrap preheating and side tuyere induced after-burning during the regular oxygen blow, a very substantial[7] scrap charge increase was achieved.

Data from the Maxhuette development work(7) is summarized and presented in Table III. The efficiency of scrap preheating fuel input is between 60 and 75%. During demonstration tests, using hot metal with lower phosphorus



KMS FURNACE
Schematic piping diagram

Fig. 4

contents and 10 minutes preheating, scrap charges of 48% were made successfully.

The schematic piping diagram for a typical KMS furnace is shown in Figure 4. The process gases are piped to the furnace shell through multiple rotary joints and passages in the trunnion pins and trunnion ring. Oxygen and oxygen/flux mixtures are kept on one side, usually the idle side or expansion side. Hydro-carbons are piped through the drive side. The process steps for KMS are briefly described as follows:

1) Furnace empty, refractory hot, all tuyeres protected from overheating by low flow of air or nitrogen.

2. Scrap is charged in one or two boxes, furnace is turned up.

3. Preheating starts with oil and oxygen flow through the bottom tuyeres, ignition is verified.

4. Preheating is stopped according to computer calculated time based on heat and charge material balance, oxy/fuel flow is kept constant.

5. Furnace is turned down to receive hot metal charge and then turned up while bottom buyeres get high flow of nitrogen.

6. Blow starts by switching from nitrogen to oxygen flow through bottom and through side tuyeres. Natural gas (or propane) is used as protective sheath. Pulverized lime is added as required with oxygen through the bottom tuyeres.

7. Blow is stopped by switching tuyere flow to nitrogen and furnace is turned down for sampling according to computer calculated amount of total oxygen required.

Assuming accurate weight and chemistry inputs into both, the furnace and the computer, the turndown will result in a steel temperature and carbon content as ordered. Despite the additional process step, turndown temperature on-target performance has not changed at Maxheutte since the introduction of the KMS method for production in late 1977. Since March 1978, Maxhuette produced more than 1.5 million tons of steel in three 60 ton OBM furnaces almost entirely with the use of the KMS method. No significant changes in refractory life or consumption were experienced with the KMS process for the two-slag method, consisting of about 3 minutes scrap preheat and the use of side tuyeres during the main oxygen blow. The same metallurgical performances and advantages as established with the basic OBM process have been noticed. Notably, the iron oxidation has remained at the same low level with the KMS method as experienced with the OBM Process.

KMS Economics

There are three main economic advantages to be gained from the high scrap KMS operation:

i) The first one is the ability to continue steel production at a high level when hot metal production is reduced by unforeseen mishaps. With scrap melting capability approaching the flexibility of the basic open hearth process, the impact of either unexpected or planned hot metal production curtailment on steel production and sales can be lessened considerably.

ii) The second main advantage of KMS is the ability to reduce ingot costs, substituting usually more expensive hot metal with scrap and oxy/fuel. Figure 5 shows these savings on the basis of a varying cost differential between hot metal and scrap and fixed scrap preheat time, scrap rate and energy costs. The reduction of the amount of oxygen needed during the main blow due to the reduced amount of hot metal in the charge has been considered in this graph. For this example, the break-even condition would be a cost difference of about $17.00 between the cost of one ton of hot metal and one short ton of scrap mix. For a cost difference of $70.00, the benefit from the KMS method would be about $8.50 per ton of liquid steel.

iii) The third main advantage is the ability to increase ingot production for a given amount of hot metal. To do this at lower cost per ingot ton is a most compelling reason to consider KMS.

The influence of the KMS method on productivity is important when engineering high scrap OBM/Q-BOP facilities. The net increase of the charge to tap time is made up from the preheating time minus the savings of the blow time. The net time increase will be typically five minutes for an eight minute preheat. If the scrap handling system is such that typically a one box charge is made for BOP or OBM/Q-BOP, a second box charge may be required for KMS since the scrap weight will be generally fifty percent greater. Depending on the material handling system and space on the charging side of the furnace, the net time increase may be a full eight minutes from charge to tap. In most two-furnace shops, this increased heat cycle time can be accommodated without a reduction of the number of daily heats. If oxygen is available at higher rates, and if the waste gas cooling and cleaning systems are compatible with increased oxygen blow rates, then the inherent capability of the OBM/Q-BOP process to blow harder will shorten the heat cycle. No general statements can be made beyond this, and it follows that a general capital cost estimate for conversions of BOP to KMS, OBM/Q-BOP to KMS, or a comparison of green-field facilities is not justified without a study, especially a careful scrap handling study. On a very broad basis, however, a conversion of a two 200 ton furnace BOP shop to KMS would cost between $12 and $20 million. A study of Figure 5 shows that a payback of the conversion costs in two years or less is quite likely.

Operation of the side tuyeres without the scrap preheat practice generally allows a scrap charge increase of about 5-6 percentage points. It should be noted that this increase in scrap charge weight already more than offsets the inherent lack of scrap melting capability of the OBM/Q-BOP. This method requires no additional time and only a relatively small amount of oxygen is used for after-burning. A major portion of the side tuyere

BOF furnace converted to Q-BOP

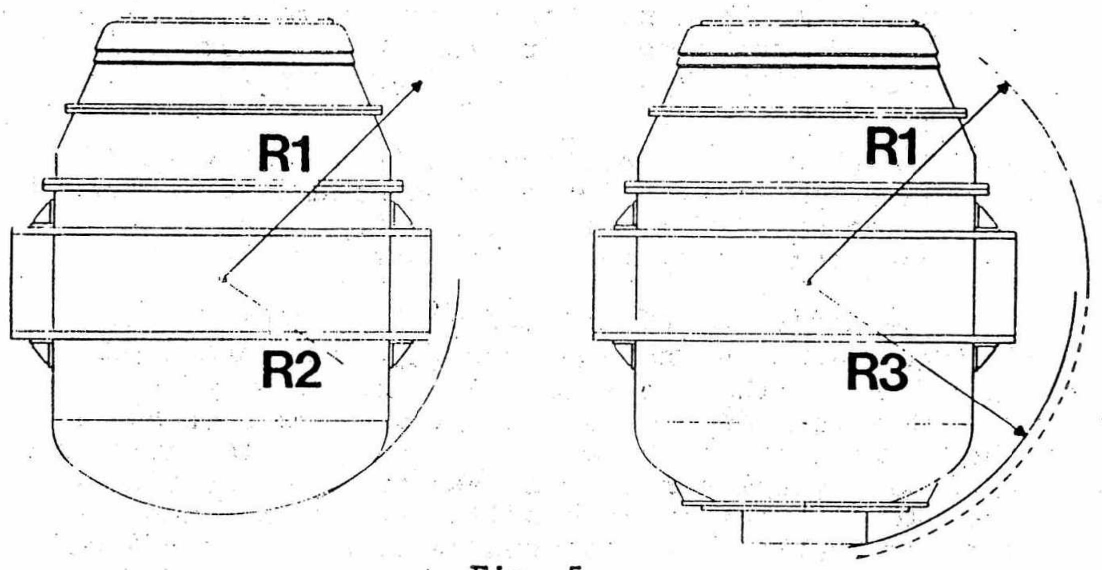


Fig. 5

oxygen reacts with the liquid in the furnace. To estimate cost savings from such a partial use of the KMS method, a line can be drawn in Figure 5, starting near the zero point and sloping at roughly twice the angle of the line shown, so that for a hot metal cost differential of $70, approximately $3.00 can be saved per ton of liquid steel.

FACILITY PLANNING AND CONVERSION CONSIDERATIONS

The subject of facility planning of OBM/Q-BOP facilities and the impact of such planning on the capital investment of steelmaking shops has been the subject of several papers (4,5,8). These papers have covered the conversion requirements of existing open hearth and LD/BOF shops to the bottom blown process as well as designs for greenfield OBM/Q-BOP facilities. Each specific situation has to be evaluated and planned to suit local conditions, covering available raw materials, capacity and product-mix, environmental restrictions, existing plant infrastructure, and other relevant factors. Some salient features requiring attention based on the latest developments can be summarized, particularly with relation to conversion of existing LD/BOF shops:

i) Furnace or Converter Conversion

ii) Melt shop Modifications

iii) Emission Control

iv) Flux Systems

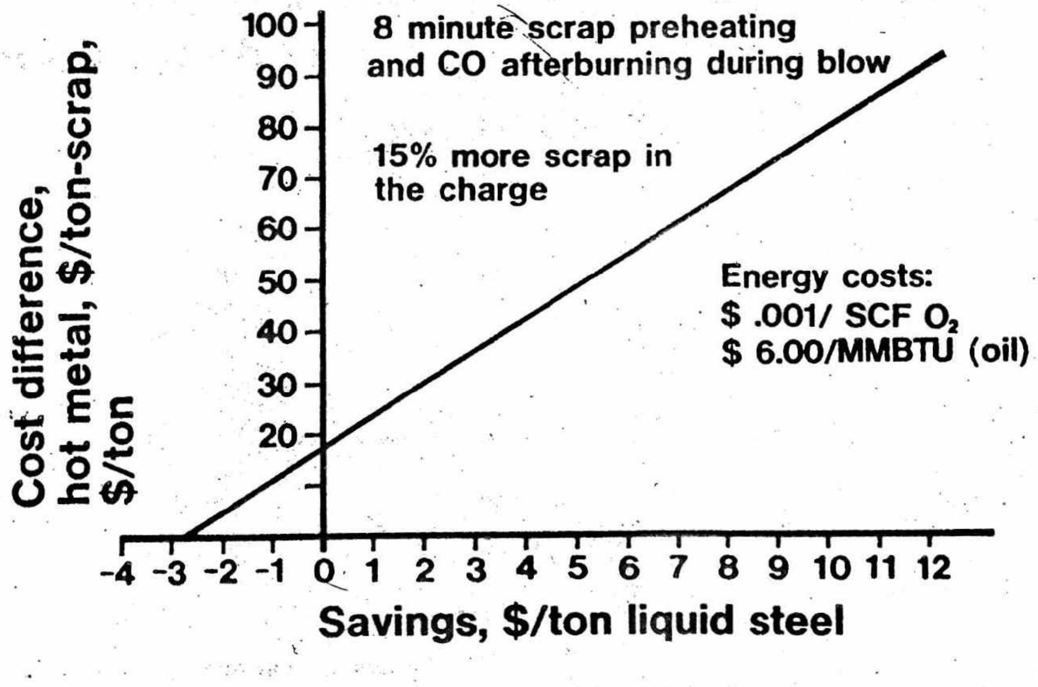
v) Controls and Utilities

vi) Conversion Schedule

Furnace Conversion

In any conversion program, the heart of the operation, the oxygen steelmaking furnace, presents the most difficult problems. First of all, production must not be interrupted at all if possible. Secondly, the furnaces considered for conversion are typically in the range from 150 to 300 ton size and therefore, do not lend themselves to anything else but modification in place. This, however, is mainly a scheduling problem which will be dealt with later on. The physical problems with the conversion are apparent from a discussion of the following five figures.

Figure 6 shows a typical BOF furnace of the mid sixties on the left side. The swing radius of the nose cone is typically larger than the swing radius of the bottom area. For a 200 ton furnace, this difference may be about 0.8 meters. This, of course, is a result of the designer's attempt to balance the torque requirements of the furnace tilt drive. The converted furnace is shown on the right hand side. The bottom has been cut, a flange has been added for the removable Q-BOP bottom. The bottom turning radius R3 has now increased to clear the shroud that surrounds and protects the tuyere piping. The difference in the swing radius dimension for the nose and the bottom has shrunk based on the previous



COST SAVINGS WITH KMS

Fig. 6

example to approximately 0.25 meters. In this condition, the drive will usually still be adequate to rotate the vessel with the various torque requirements stemming from the different phases of the operation.

The conversion problem is shown in more detail in Figure 7 which presents the volume study for the conversion of the rather slender BOF vessel. Unlike the conversion of a Thomas furnace, the volume available in the sampling position is restricted by the position of the lower row of tuyeres which should be completely free of the slag layer to permit adequate observation and sampling. In a Thomas furnace, lip pouring allows placement of tuyeres asymmetrically on the bottom thus increasing the available volume in the sampling position in addition to the usually larger belly or elliptical design of those furnaces. In Figure 7, a symmetrical configuration is shown with a minimum tuyere spacing. Most BOF furnaces of older vintage have been designed for smaller tap weights than operated with later on. This has, of course, advantages connected with larger heat size as well as lower specific refractory requirements. On studies performed so far, it was invariably noticed that after a conversion to Q-BOP, the volume availability based on the above mentioned tuyere position criteria is smaller than before. This is in most cases not acceptable. The following example may be cited. A BOF may have been designed for 200 tons tap weight and it may now be operated with a tap weight of 225 tons, whereas a conversion without special measures would result in a tap volume of perhaps

Volume study for conversion of a BOF to bottom blowing

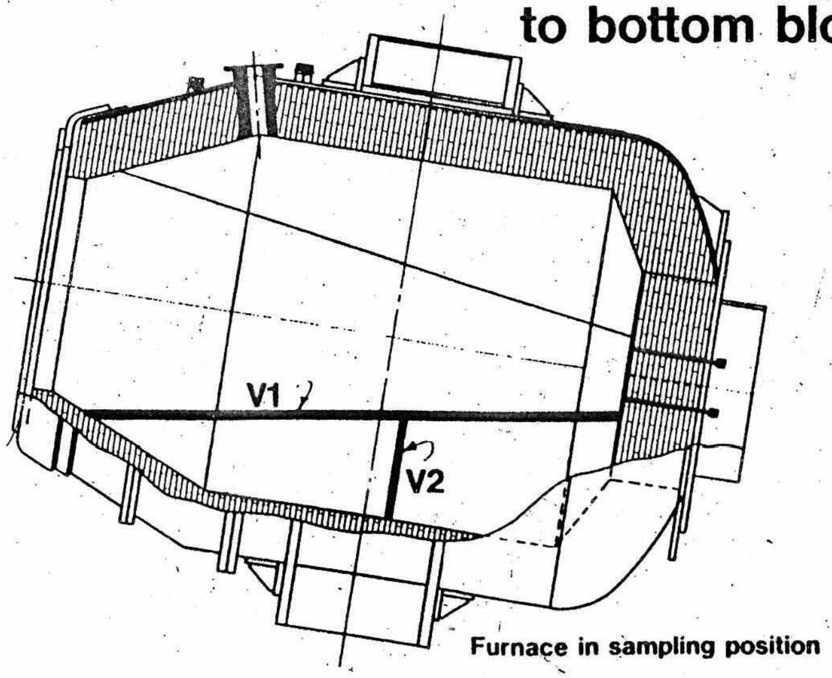


Fig. 7

only 190 tons. An attempt to increase the available volume by lengthening the shell of the furnace below the trunnion ring until the bottom turning radius equals the nose turning radius is indicated at V 2 in Figure 7. V 1 shows a volume increase gained by displacement of the tuyere pattern to the tap hole side or a slightly different bricking of the nose cone to effect a smaller mouth diameter. The lengthening of the furnace shell, apart from its cost and time delay, would also require, most likely, placement of counter-weights in the nose area. A small change in the tuyere pattern or the mouth opening will result in a much larger volume increase than that possible under normal conditions with shell lengthening. A change in lining thickness will have similar effects, although of limited influence. The greatest flexibility is, therefore, provided with an asymmetrical tuyere pattern. This results in some spitting and smoking during a brief initial period of tapping because the tuyeres are submerged in slag or steel. Since Q-BOP furnaces normally require furnace enclosures, this should not be an objectionable design feature considering also that the volume calculations are all based on the worst case of a brand new lining, a condition that prevails for relatively few heats.

Additional problems with the furnace conversion are to be solved for the provision of passages for process fluids, usually in addition to existing passages for water used for trunnion and sometimes nose cooling. Figure 8 shows the new classic method of providing for the basic Q-BOP requirements. The idle side is used for oxygen and flux. A passage is drilled through the pin and another one at right angles to the trunnion casting; a large rotary joint is bolted to the pin. On the drive side featuring a typical shaft mounted drive, two rotary joints are shown. The existing cavity through the trunnion pin is enlarged to allow for the insertion of concentric piping and attachment of two rotary joints providing for the supply and return of trunnion

Typical process fluid and water supply to trunnion ring

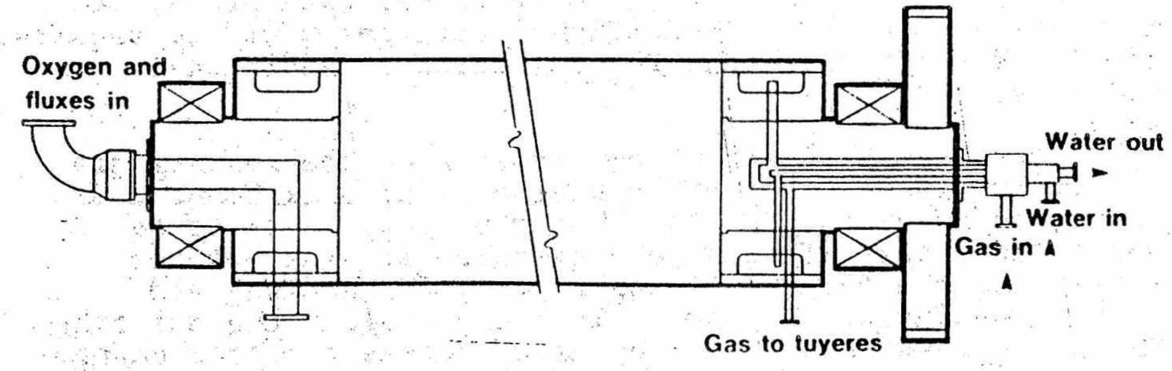


Fig. 8

Design for fluid passages for drive side of trunnion ring

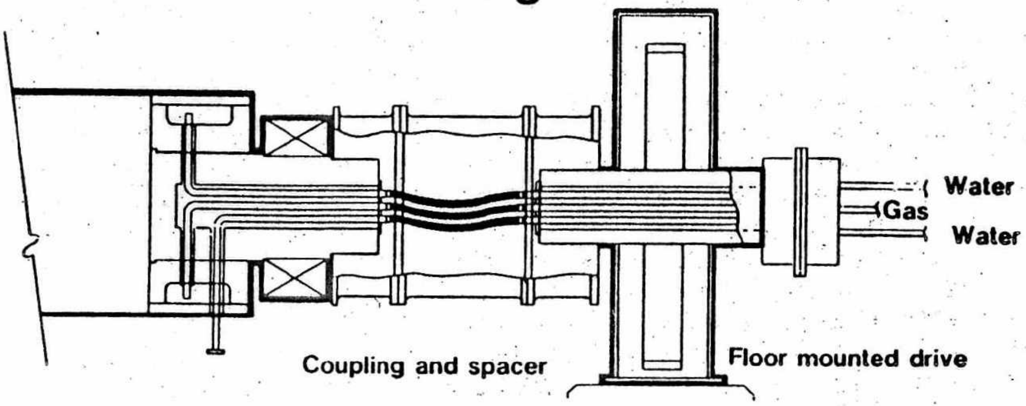


Fig. 9

cooling water as well as the supply of hydro-carbon gas to the tuyeres in the outermost annulus between the water pipe and the enlarged cavity. The drilling of these passages requires field set-ups which entail partial removal of the side shields protecting drives and bearings and provision of boring machinery bases. Unfortunately, the drilling and other operations have to be interrupted when the operating furnace is approaching the end of its lining life, and the side shields will have to be re-installed.

Figure 9 shows a different set of circumstances for the case of a floor mounted furnace drive. Here the passages for process gas and water not only have to extend through the trunnion pin and casting, but also through the shaft of the bull gear and the coupling. Shown here is the method of providing large drilled passages through which assembled pipes with high pressure hose sections are placed. For accessibility, the spool piece between the coupling will have to be sectionalized into two halves. On the outboard side of the drive, a multiple passage rotary joint is provided.

Figure 10 shows the principle to change from concentric piping as used typically in the BOF water passages to an enlarged cavity containing a number of separate pipes, in this case a total of 5. Additional cavities would be required to meet special conditions for injection of additional materials.

Further modification requirements on the furnace are relatively minor. They are concerned with attachment and protection of piping and the bottom proper. Also to be considered a part of furnace conversion are the methods of bricking the furnace lining as well as handling and bricking of furnace bottoms. In a conversion, the existing BOF reline tower can always be used whereas a bottom change

Multiple passage design through trunnion pin casting

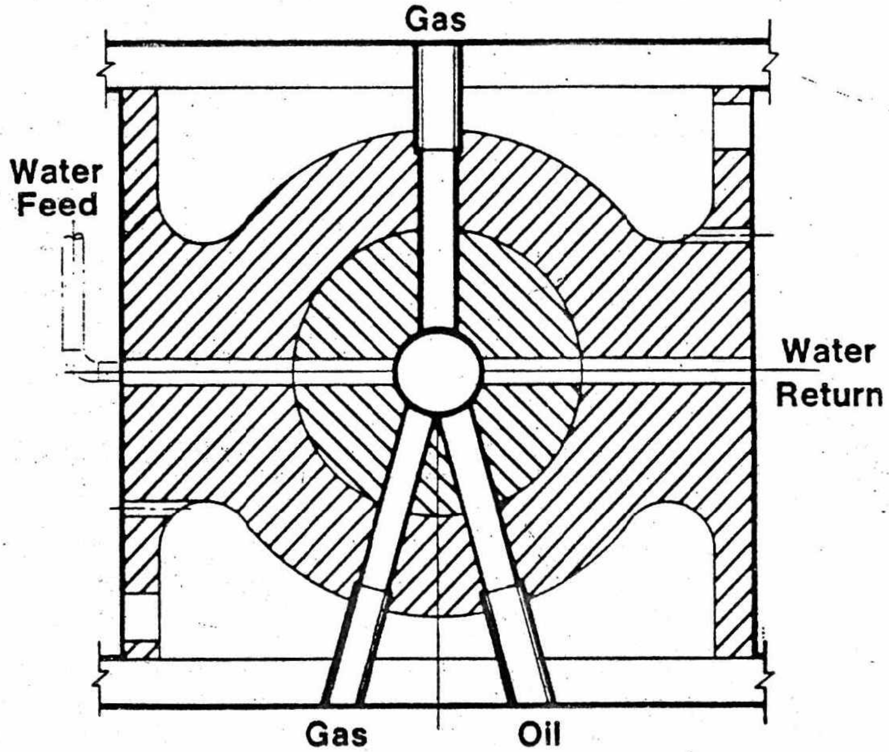
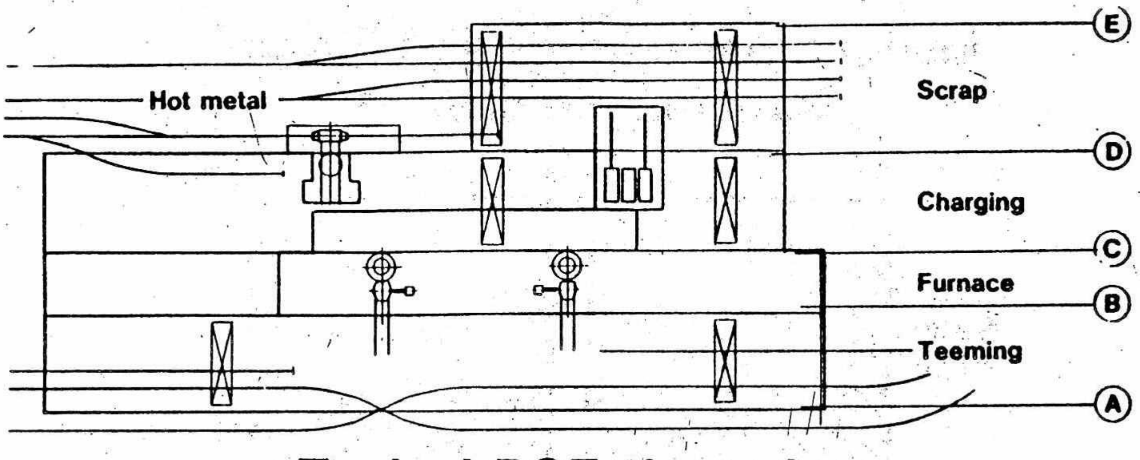


Fig. 10

device has to be provided as an additional piece of equipment together with other bottom handling equipment to facilitate transport and rebricking.

MELT SHOP MODIFICATIONS

With designs decided upon for the conversion of the BOF's furnaces proper, the entire steelmelt shop layout must be studied for additional requirements. Figure 11 shows a typical BOF shop consisting of a scrap yard, a melt shop with the classic charging, furnace and teeming aisles and hot metal supply from one side and scrap supply through a transfer system on the other side of two furnaces. All melt shop facilities must be studied depending on the overall plans for steelmaking tonnage. Keeping in mind that invariably, the incentive for a conversion of an operating BOF shop is the possibility to increase production, it is necessary that the increase has to be studied beyond the confines of the melt shop considering the entire raw material supply and the facilities required to convert liquid steel into rolled semi-finished tonnage. An overall study, as well as a study of the shop itself, will point out bottlenecks that may require solutions.



Typical BOF shop plan

Fig. 11

BOF shop converted to a Q-BOP facility

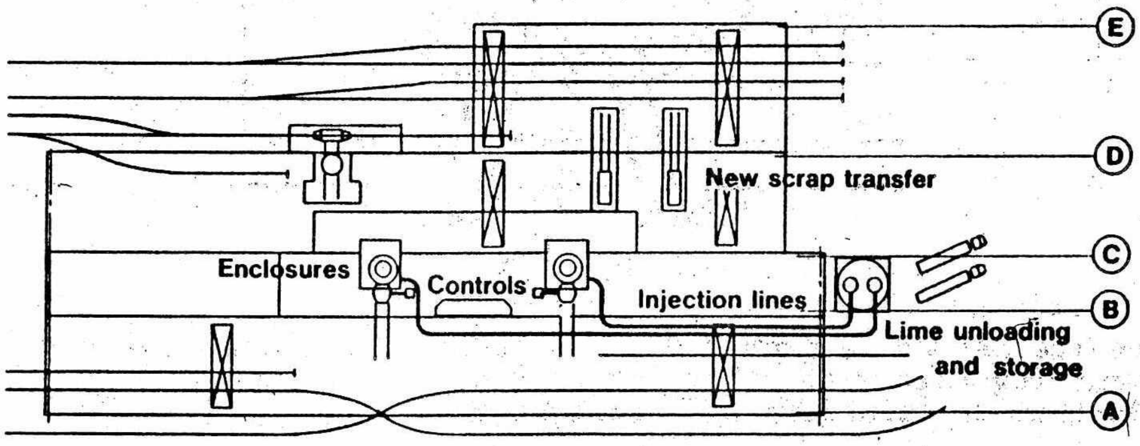


Fig. 12

Figure 12 points out the main areas in the shop which are subject to change. The control room typically located between the two furnaces requires modifications to accommodate the process gas, secondary emission and flux injection controls. Leading to the furnace trunnions are new oxygen lines designed for injection of burnt lime. The entire system for lime injection is shown outside the shop, in line with the furnace aisle. The system includes flux unloading and storage. Based on additional production capabilities, the scrap handling method will in most cases require revisions. Shown here schematically is a change in the transfer scheme from the scrap yard to the charging aisle. Studies have to be performed to insure that additional scrap tonnage as well as a greater number of heats, also requiring more frequent hot metal handling, can be accomplished. Crane time and motion studies must be conducted and often it was found that a bottleneck existed in the scrap yard rather than in the charging aisle. A second scrap magnet crane and a second, independent scrap box weigh/transfer car is invariably the solution recommended.

EMISSION CONTROL

In a conversion program, typical partial enclosures found on BOF furnaces are not sufficient to contain the fumes generated by Q-BOP's turning up or down due to the operation of bottom tuyeres. Full furnace enclosures with motorized charging doors are required. The enclosures feature secondary hoods on the inside of the door openings directly above the area of hot metal charging for effective control of charging emissions. More and more BOF furnaces are equipped with the same type of furnace enclosure since it is the most effective way to handle secondary emissions, not only during charging but during sampling, slagging, and tapping. Figure 13 shows an enclosure around such a furnace.

Furnace enclosure

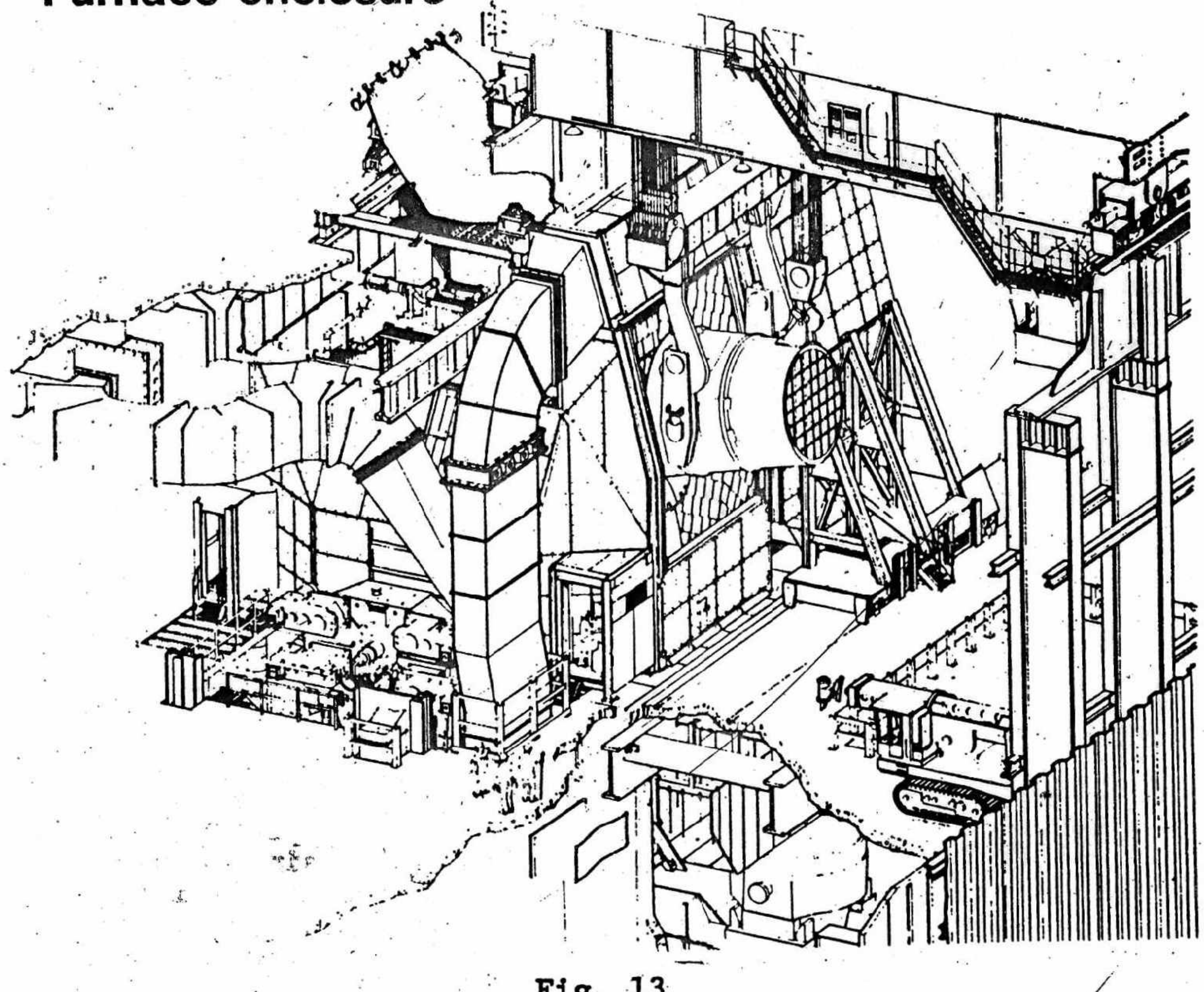
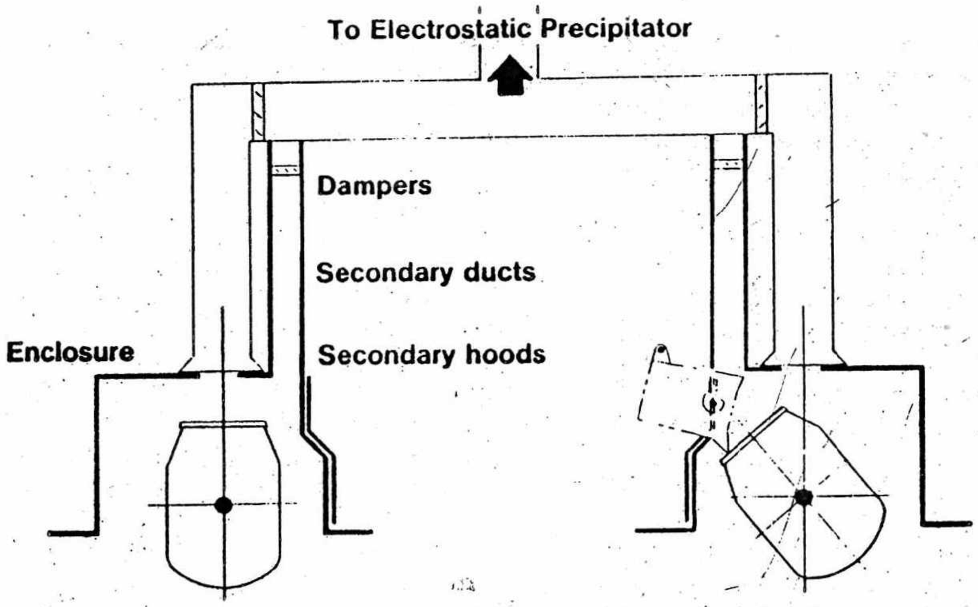


Fig. 13



Secondary emission control added to BOF/Q-BOP shop

Fig. 14

The existing off-gas cooling and cleaning system should naturally be maintained unless it is deficient either in meeting emission regulations or it is worn out to a point where replacement is justified. The most typical case is a full combustion system with electrostatic precipitators which in North America was the major technology available and selected in the sixties and seventies. Many shops also have capability only for single vessel operation, each vessel cooling stack being connected to a common duct leading to the common precipitator system. Figure 14 shows this condition schematically. The oxygen blowing rates for which the system is designed can of course not be increased after the conversion to Q-BOP. Figure 14 also shows the addition of a furnace enclosure, secondary hoods and ducts and isolation dampers. With the system comprised of a total of four dampers, two existing ones and two new ones, one furnace system can be completely isolated whereas the other one will provide draft alternately through the main stack or through the secondary hood for control of the tapping and charging emissions.

FLUX SYSTEMS

Steel production with low phosphorus hot metal in the bottom blowing process requires injection of powdered burnt lime together with the process oxygen to obtain the best metallurgical results and provide the greatest flexibility to handle a wide range of hot metal analysis fluctuation. All other flux materials commonly used in steelmaking can be added in lump form through the furnace hood. If the coke injection feature of KMS is incorporated, provision to inject this material through the furnace bottom must be made.

In conversions of open hearth shops to bottom blowing oxygen steelmaking, typically three flux injection systems per furnace are provided plus coke injection if this feature is required. The main reason for this is the absence of overhead storage and material handling room. It has been found that a small advantage was realized from injection of limestone for cooling purposes. This method showed great speed and reproductibility compared to conventional cooling methods using top additions. This benefit from a multiple injection system is, however, not easily justified for a BOF conversion where overhead material handling and storage systems are already available. The example of the U.S. Steel Gary Works conversion may serve as an example. There each of the three furnaces has a separate burnt lime injection system while all other additions are made with the originally provided overhead lump addition system.

Figure 15 shows schematically a stepwise conversion of the BOF flux system to a pneumatic handling and injection system for one furnace. There are a number of disadvantages and problems associated with the approach shown. First, room has to be found more or less directly below the burnt lime storage bins for the gravimetrically filled pressure weigh tank. If this presents no insurmountable problem, there is usually the problem of limited storage capability. As shown here, the storage capacity can be switched from one furnace to another by a reversing belt conveyor. In a stepwise conversion, the remaining burnt lime storage capacity for the top blowing furnace would be inadequate and during the conversion, some production losses may be incurred. Figure 16 shows the typical case of double handling of the powdered lime material because the new storage capacity inside the shop alone is found to be inadequate. Depending on the particular lime supply situation, it may be necessary to provide for more storage capacity of the powdered material than normally considered adequate for the lump material which can be obtained conveniently from several different suppliers and also does not require the type of vehicles required for the transport and conveying of powdered material. The top half of Figure 16 shows an outside storage provided with pneumatic unloading equipment, in this case from trucks, an additional equipment to transfer from the large storage into the smaller overhead storage in the building converted to handle powdered material. In the lower half of Figure 16, a preferred arrangement is shown which requires only single handling of powdered burnt lime. One storage and injection building is supplied. This is the same as shown previously in Figure 12 outside the furnace aisle of the melt shop. Two injection tanks, one per furnace, are located directly

First step in the conversion of the flux system of a BOF/Q-BOP shop

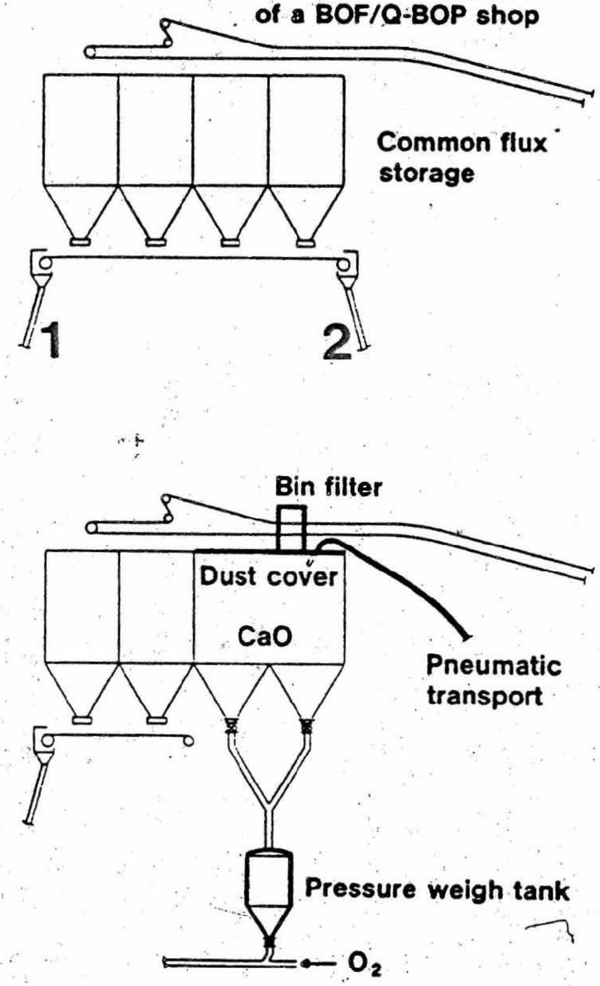


Fig. 15

Choices for the Q-BOP flux injection addition in a BOF shop

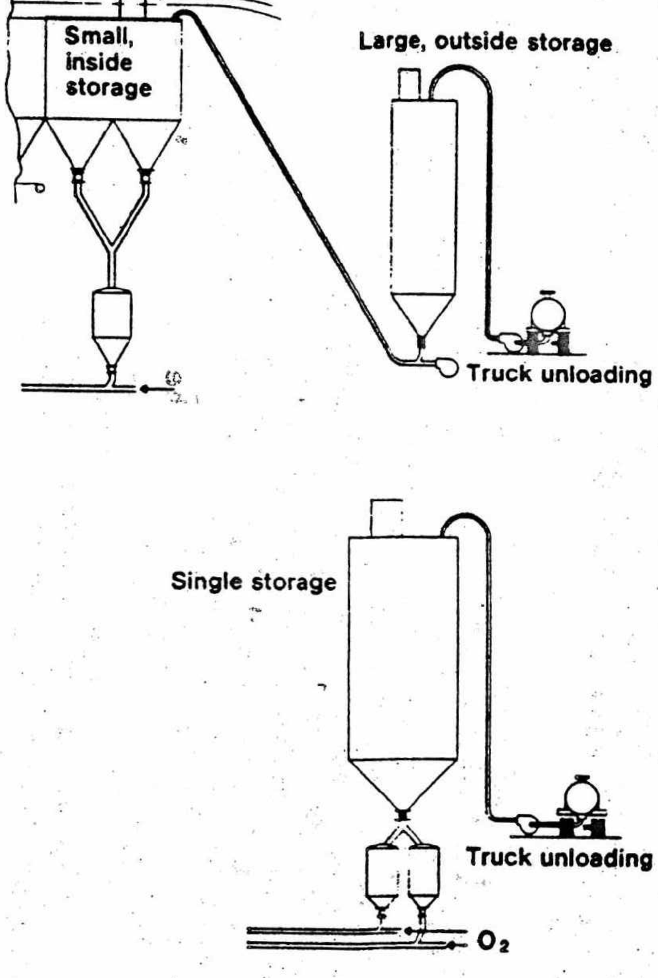


Fig. 16

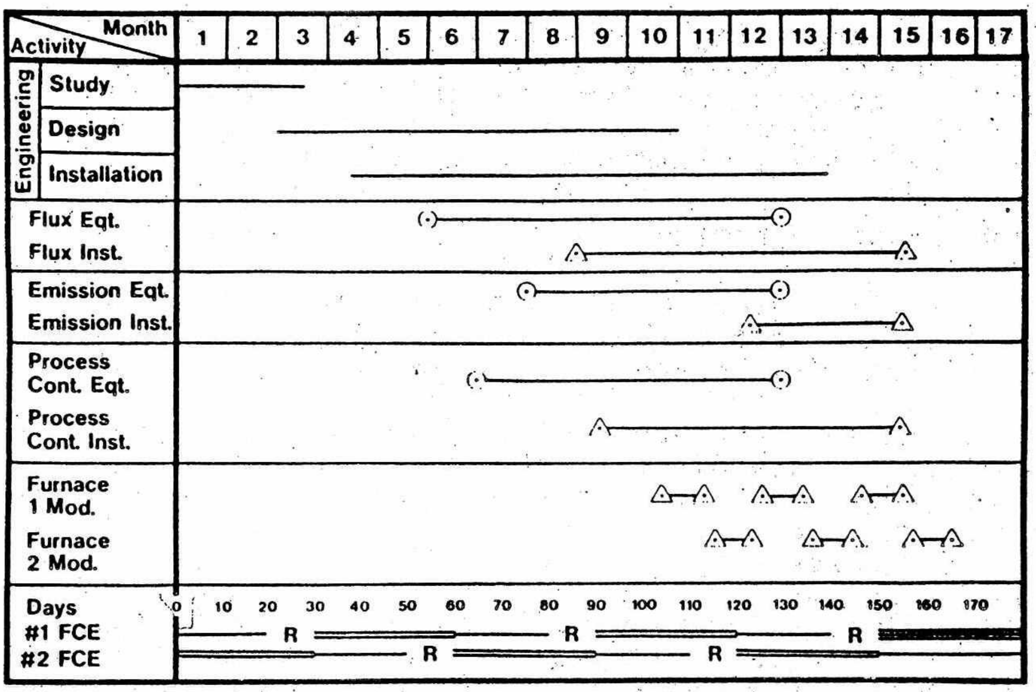
below the large single storage bin. This solution is considered not only more economical as far as capital cost is concerned, but far more adaptable to a conversion of an operating shop despite the ground rules of having to use existing equipment whenever feasible.

CONTROLS AND UTILITIES

The conversion problem in providing additional utilities such as nitrogen, hydro-carbons and possibly argon to the control and furnace areas is one of the easiest ones to solve. Quite often existing controls can be worked into the new system and most control pulpits are adaptable to the installation of additional equipment, thanks mainly to the progress made recently in miniaturization, solid state control and computerization. A color cathode ray tube can replace a large arry of instruments and recorders. Sometimes the pressures required for the Q-BOP operation pose a problem since existing pipe lines are not designed for higher pressures. As far as oxygen is concerned, three is no solution other than a replacement of the fittings and valves and possibly the entire pipe line. As far as low available hydro-carbon pressures are concerned, proper instrumentation can overcome the problem which in the past has been caused by the scheme of bringing on a new gas and verifying its flow and pressure before the previously used gas was shut off. As far as nitrogen is concerned, it is usually not available in the BOF shop and, therefore, a new line with high pressure capabilities will be constructed. A similar situation exists with argon. If KMS preheat and carbon injection features are to be incorporated, these must be additionally considered along with requisite storage, transport and injection equipment.

CONVERSION SCHEDULE

The problem of the furnace conversion proper also presents the greatest problem to the conversion schedule. As mentioned earlier, the conversion in an operating BOF shop requires great skill and coordination between engineers, construction management and the operators of the shop. Many conversion aspects have to be detailed as far as scheduling is concerned to a minute degree if production delays or losses are to be avoided. Figure 17 shows a typical schedule for a facility conversion. This is for a two furnace facility and the time required for the total scope of work is shown as 16 to 18 months. The initial requirement is a three month period of study to determine all requirements in the shop. The total scope of work should be sufficiently defined that a budget estimate can be prepared. Actual design engineering can overlap the end of the study period and installation engineering can commence during the fourth month of the project. Equipment deliveries and



Schedule for a BOF to Q-BOP Facility Conversion

Fig. 17

engineering pace the job with the longest delivery items being the special flux injection equipment, rotary joints and instrumentation and control equipment. For these areas as well as for the emissions control areas, installation completion dates falling in the 15th month of the project are shown. The most critical item is the modification of each furnace. At the bottom of the schedule in Figure 17, the work is shown in greater detail. It should be noted that this is an idealized or averaged schedule based on 30 day furnace campaigns and 10 day repair and furnace reline periods including a four day "cushion". This leaves an average of 20 days of round-the-clock work and the schedule shows three periods of this kind of work for each furnace. During the interruption of the work on the furnaces, the work forces can be concentrated in other areas which are not affected by the operating requirements in the immediate furnace area. Together with the furnace modifications, the furnace enclosure and the secondary hood connections as well as piping to the furnace have to be scheduled. The first of the three twenty day periods will be scheduled such that furnace trunnion drilling operations are brought to a convenient point that they can be resumed in the second twenty day period. The removal of the furnace side shield and reinstallation before the furnace goes back into the top blowing operation is an added difficulty brought about by the inplace work requirements. During the second twenty day period, parts of the furnace enclosure can be erected and during the third period, the furnace conversion work will be finished mainly consisting of piping; the secondary hood as well as the ductwork can be connected. There is no opportunity to have a lengthy period available for checkout and dry runs and operator training as would be the case in an open hearth conversion or in a greenfield facility. This is, of course, due to the fact that the operation has to be switched back and forth and operation has to be switched from 100 percent top blowing production to hopefully no less than 80 or 90 per cent bottom blowing production during the first campaign. For the start-up, it would be best to have both furnaces available, so that single bottom blown heats can be made alternately with top blowing. The future operation is anticipated to continue in the same fashion as shown on the schedule, that is switching furnaces in campaigns rather than alternate blowing. This operation is recommended mainly because of the need to change bottoms. With alternate blowing, two bottoms are worn out and it is felt that an insufficient safety margin would exist based on staggering according to bottom life as compared to the staggering based on lining life.

SINGLE REPLACEABLE Q-BOP FURNACE DEVELOPMENTS

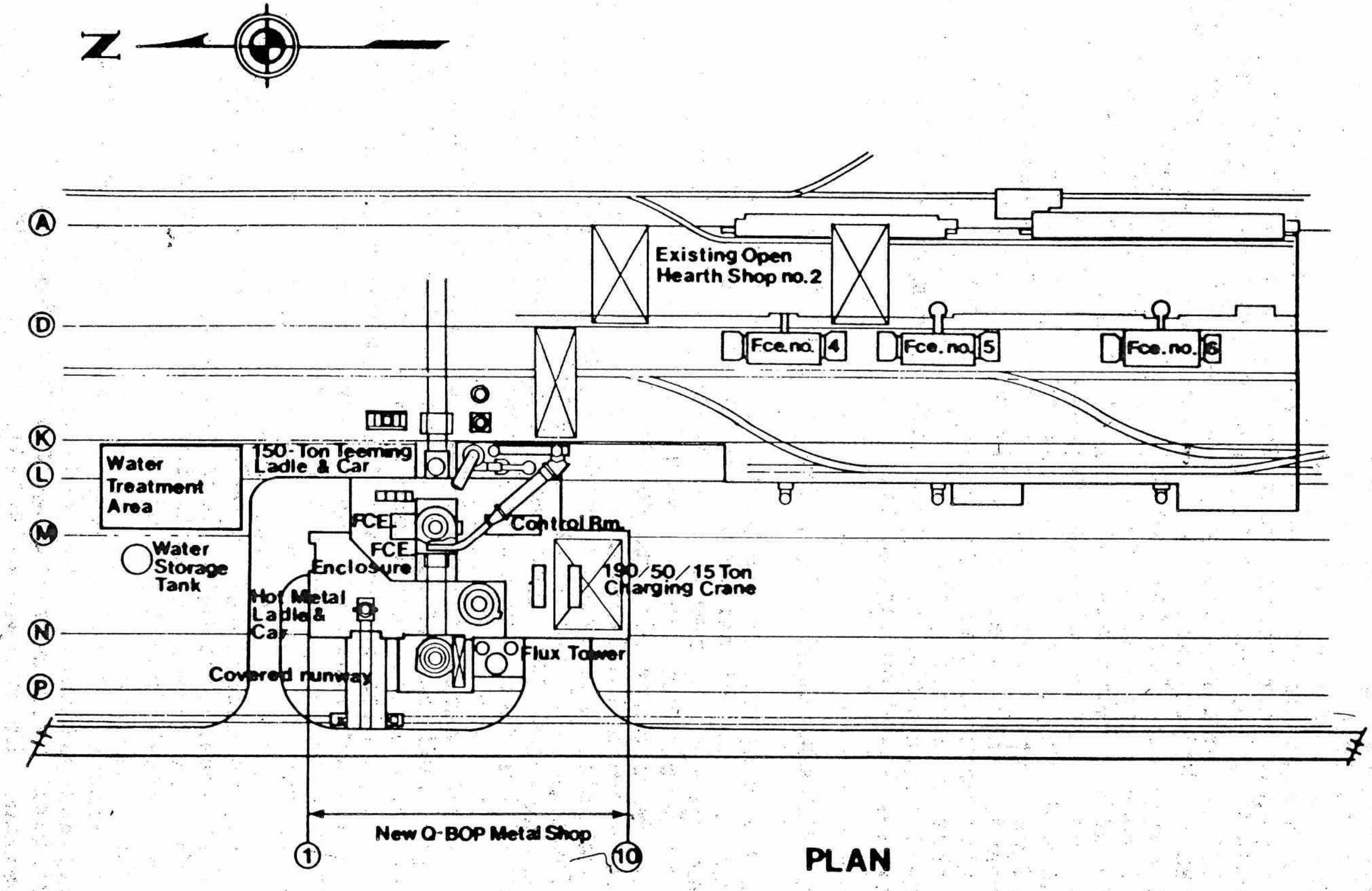
While the benefits of the rapid heat cycle of the Q-BOP and ability to take higher oxygen inputs per unit of time can be advantageous to new plants, there are many open hearth conversion programs where the total steelmaking output is limited by soaking pit and rolling mill capacity, and the need to maintain a large heat size to be compatible with existing facilities. In such cases, a conventional two (2) furnace Q-BOP installation results in available steelmaking capacity far in excess of requirements. Two possible solutions available in such a situation are:

a) Operation of the Q-BOP facility on a reduced basis such as two turns divided into 8 hours on - 4 hours off - 8 hours on and 4 hours off, which permits scheduling of operations without problems in the blast furnace area.

or

b) To incorporate a Q-BOP facility with a single operating Q-BOP location with the ability to replace a complete furnace using furnace interchanging equipment.

Figures 18 and 19 show the plan and cross section of a single replaceable Q-BOP facility designed to feed into the teeming aisle of an existing open hearth shop. In this situation, the space availability and head room in the open hearth precluded introduction of a Q-BOP of sufficient heat size to match with existing equipment. The replaceable


Z
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Existing Open
Hearth Shop no.2
Fce.no. 4
Fce.no. 5
Fce.no. 6
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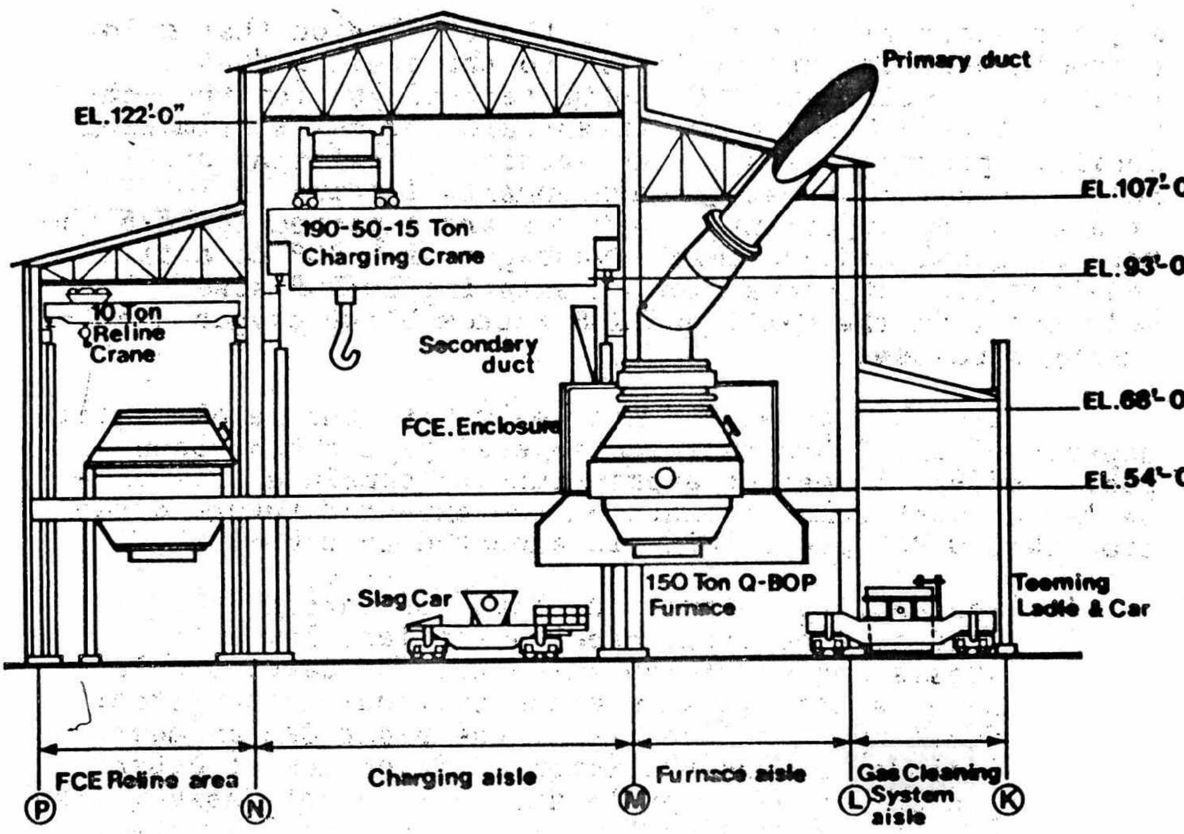
Ladle & Car
Water
Treatment
Area
FCE
FCE
Enclosure
Control Rm.
Water
Storage
Tank
190/50/15 Ton
Charging Crane
Hot Metal
Ladle &
Car
Flux Tower
Covered runway
New Q-BOP Metal Shop
1
10
PLAN

Fig. 18



ELEVATION

Fig. 19

Q-BOP furnace is designed with a horse-shoe trunnion ring. A special car with in-built hydraulics lifts the furnace out of the trunnion ring at the end of a campaign and transfers it to a holding stand where the furnace bottom is removed and lining knocked out.

The furnace replacement car transfers a fully relined furnace equipped with a new bottom into the furnace trunnion for continued operations. This concept provides for significant savings in Q-BOP facility costs which are approximately 30-45% lower than for a two (2) furnace Q-BOP facility. Furnace replacement time is in the order of 4-7 hours. Bottom changes in the middle of a furnace campaign are planned using the same furnace replacement equipment.

CONCLUSION

The influence of some of the latest developments on the engineering, construction and planning aspects of the Q-BOP facilities for bottom and combined blowing has been reviewed together with some salient parts that would impact on the economics of a steelmaking facility. These major factors all contribute to the conclusion that major economic benefits are available to the steel industry through the utilization of Q-BOP technology over the conventional LD/BOP for both 'greenfield' or new steelmaking facility programs, and for conversion of existing open hearth shops. The latest developments leading to increased scrap input into the Q-BOP are expected to take the metallurgical and economic advantages of Q-BOP to active consideration of conversion of existing LD/BOP steelmelt shops in the Q-BOP and KMS bottom blown oxygen steelmaking processes.

While this paper has not dealt with the metallurgical aspects of the Q-BOP on which several papers have been published(9), it may be appropriate to conclude this presentation with some comments on the expected future direction that Q-BOP steelmaking is expected to take:

1. The ability to produce ultra low carbon steel grades, electrical steel qualities, low alloy steels and even high alloy sophisticated steels such as stainless in a conventional carbon steel facility. In such cases, the plant design must include for the provision of injection of other gases such as argon in the basic plant design. Also, the ability of the flux injection system to be modified in the future to permit injection of materials other than lime, fluorspar and limestone so that more sophisticated metallurgical treatments may be employed.

2. The ability to either utilize lower grade materials in primary iron production (such as higher sulphur coals) due to the high desulphurization ability of the Q-BOP; or alternatively to produce ultra-low sulphur grades on a production basis. The fact that the desulphurization capability of the Q-BOP is higher in high and low carbon ranges compared to the medium carbon range may become important.

3. The ability to conserve energy through off-gas recovery which is favoured in the Q-BOP in terms of volumes collected per ton of steel produced due to the smooth blowing characteristics of the process.

4. The development of specific double slag techniques to permit the Q-BOP to handle difficult hot metals when both relatively high silicon and high phosphorus (Si: 1.2-2.0 per cent, P: 0.3-0.5 per cent) are present at the same time, together with a high sulphur level as well. Such techniques already developed for high phosphorus hot metals permits the second slag to be re-utilized as the

first slag in a subsequent heat. This approach will permit the total flux consumption to remain at relatively low levels when compared with conventional LD/BOP operations.

5. The development of hybrid bottom designs which will permit switching from gaseous to liquid hydrocarbons during a heat or normally on a scheduled basis. Such designs will eliminate any reservations with respect to sudden shortages in particular hydrocarbons currently being reviewed by the steel industry with respect to energy conservation and use of alternative fuel options.

6. With the high predictability and turn-down performance of the Q-BOP, it will not be far in the future when automatic steelmaking with a punch card from the planning department will become a common practice.

7. On the refractory side, as bottom life improves (supported by the consistent 700-800 heat results at U.S. Steel and Kawasaki Steel), the important criteria is predicted to be the bottom line or the cost of actual Kgs of refractory per ton of steel. While achievement of record results by employing gunning practices will still prevail, it is anticipated that some steelmakers will attempt to modify the quality and desing of sidewall refractories to match the increasing bottom life which will be consistently obtained. This will mean taking a Q-BOP furnace out of production for a bottom change and sidewall reline at the same time. Obviously, each steelmaker will choose the approach most appropriate to his situation and interchangeable furnaces will also be developed to optimize Q-BOP refractory costs.

8. Based on qualities of steel and nature of dust, it is predicted that off-gas dust in the future will be recycled and injected through the tuyeres of the Q-BOP.

9. The utilization of preheating and carbon injection together with post combustion techniques of the KMS will find major application in the conversion of existing LD/BOP facilities to the Q-BOP, particularly in plants with restricted hot metal availability, and in cases where hot metal costs are higher than scrap prices. It will also provide a basis to modernize and expand the production capability of existing oxygen steelmaking melt shops with fixed hot metal availability at the lowest possible capital investment. The substitution of metal-

lized prereduced materials instead of steel scrap will also prevail. The use of the sub-lance for process control in such conversion programs is expected to find ready application to reduce time requirements for chemistry and temperature control in the top-to-tap cycle. High scrap charge operations would thus be readily achieved within a 40-50 minute Q-BOP cycle time.

Most modern Q-BOP steel melt shops are being designed with the future in mind, and the type of in-built provisions that will permit steelmakers to obtain a competitive edge over their competitors through the flexibility of their steel plants to reduce costs, increase product quality and the range of product mix that may be produced. The foresight and ability of engineers to equate such future considerations with the reality of capital investment is thus an important factor in engineering and construction of oxygen steelmaking facilities for bottom and combined blowing.

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