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Remodeling of LD Converters into K-BOP —with Emphasis on Design and Construction*

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In Mizushima Works, all three LD converters of No. 2 BOF shop were remodeled into K-BOP (combined blowing processes) by March 1984, and have continuously been operating satisfactorily. Way of design and execution in bulk for remodeling LD into K-BOP was successfully established through this reconstruction by organizing self-executing formation, for instance, the dynamic analysis of the vessel, arrangement of environmental equipment and decision of specifications of incidental facilities which include piping, stand-by equipment and bottom maintenance equipment. To remodel the vessel, dynamic analysis was done by heat and stress analysis using FEM. The reconstruction was executed during two times of relining for each converter, without incurring any operation disturbance. Although vessel vibration was expected, it was fully solved by improvement in operation and design of tuyere arrangement. Three K-BOP's have been maintaining high productivity and economy in steel making.

1 Introduction

Apparently there has recently been a continuing trend of change-over from LD to top-and-bottom-blown (hereinafter called the "combined-blown") converter in the main stream of steelmaking process. In 1977 the company's first Q-BOP converter units were installed at No. 3 BOF Shop of Chiba Works. Some excellent operation results of their low carbon steel gave metallurgical engineers a vivid recognition of the significance of the strong stirring force in steelmaking process. It was a stimulation powerful enough to accelerate manifold developments$^{1)}$ of converter operating techniques, not to mention converter equipment and metallurgical research.

One of them is the top-and-bottom-blown process which, in combination with the top-blown process, aims to make full use of the stirring force by bottom-blown gas. Covered in this category are K-BOP, the development of Kawasaki Steel, and various others$^{2-4)}$ in progress elsewhere.

At No. 2 BOF Shop in Mizushima Works, No. 4 LD converter was remodeled into K-BOP in April 1980, and two other converters, No. 5 and No. 6 LDs, were also remodeled into K-BOP by March 1984. All of three K-BOPs have been maintaining satisfactory production.

This report is a summarized description mainly on hardware phase covering various study results of the LD remodeling into K-BOP program, including stress analysis of shell examined before the remodeling of Nos. 5 and 6 LDs, details of construction, and operation results.

2 Outline of K-BOP

2.1 Conception of K-BOP

Figure 1 shows the whole structure of K-BOP. The biggest difference from the LD converter is the bottom which is designed to be removable, with multiple number of tuyeres installed for blowing gas and flux. The bottom tuyere consists of a double (internal and external) pipe as in the case of Q-BOP. As shown in **Fig. 2**, the bottom tuyeres are capable of blowing gas in a large amount next only to that of Q-BOP.

2.2 Merits of K-BOP

As reported in previous paper$^{5,6)}$, the metallurgical characteristics of K-BOP are summarized as follows:

(1) Inhibition of excessive oxidation of slag and iron in bath by an increase in stirring force and a promotion of the slag-metal reaction.

(2) Promotion of dephosphorizing reaction by bottom flux injection, and the suppression of slopping.

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** Mizushima Works

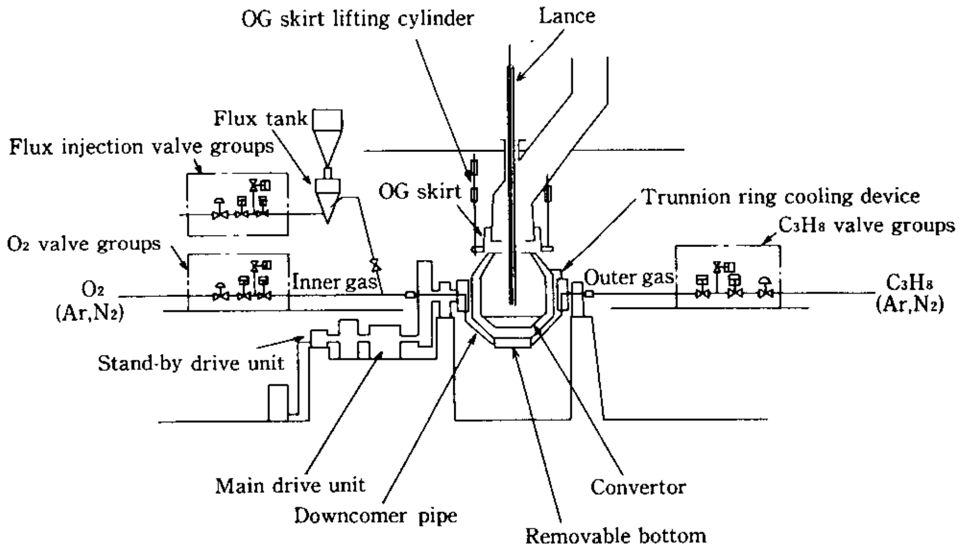


Fig. 1 Profile of K-BOP

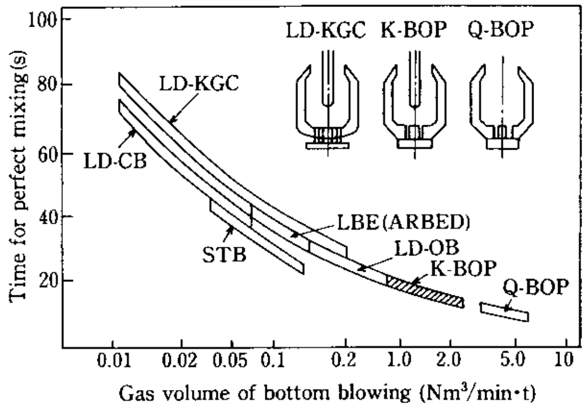


Fig. 2 Comparison of bottom blowing gas volume of combined blowing process

Table 1 Major specifications of K-BOP in Mizushima No. 2 BOF shop

Shell	Heat size		250 t
	Inner volume of shell		424 m^3
	Shell profile (H/D)		1.25
	Shell cooling System	Top shell	Water
		Shell barrel	Air
Blowing	Maximum oxygen blowing rate		1,000 Nm^3/min
	Maximum bottom blowing ratio		30%
	Maximum CaO injection rate		49 kg/t
	Number of tuyere		6 & 10

(3) Suppression of slag formation by multiple refining method (top-blowing lance, and top- and bottom-blowing pattern).

In other words, K-BOP is an excellent refining process in that desired refining effects are obtained with the merits of both, top and top-bottom blowing skillfully combined to full use.

3 Specifications of Facilities

Table 1 shows the major specifications of K-BOP. The LD barrel was mostly used as it was, with only the bottom reconstructed. Thus, the height/diameter proportion of the barrel became 1.25 considering the relation with existing facilities. Bottoms were minimized in number by designing them to be interchangeable among all three vessels. The operation was basically decided to take a 2 bottoms for one campaign system. The vessel can use nitrogen and argon as bottom-blown gas for either internal or external pipe, as necessary, other than oxygen gas for internal and C_3H_8 gas for external during the blowing period. The ratio of bottom-blown oxygen was determined to be 30% max. under the condition of the whole bottom flux injection.

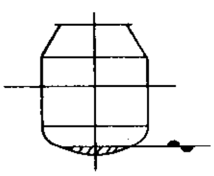
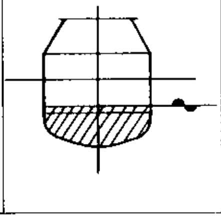
4 Furnace Design

4.1 Profile of Furnace

In cutting the shell to reconstruct the existing bottom, two positions (type 1 and type 2) were planned as shown in **Table 2** since the existing converter barrel was straight.

Type 1 is for a minimum possible cutting required for barrel reconstruction. This plan, however, is not always advantageous because the reconstruction term at site

Table 2 Shell cutting line

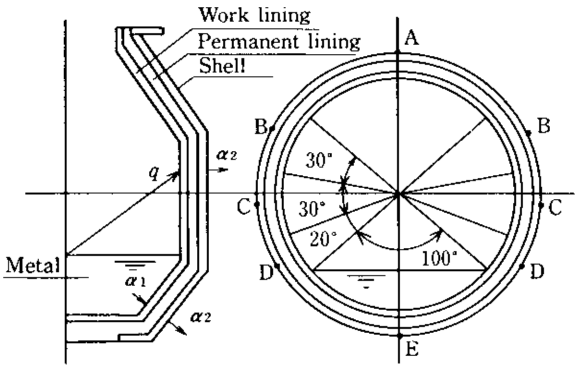
	Cutting line	Merit	Demerit
Type 1		Small area reforming & minimum cost	1. Long period at site works 2. Low precision
Type 2		Free design High precision & high confidence	1. Check of shell intensity 2. Shell deformation (probability)

becomes longer, with accuracy and reliability questionable about the bottom latching device. Type 2 is for installing a new bottom already welded to the bottom latching device at another shop. This is relatively advantageous because of the free design of the bottom, and a high accuracy and reliability of the reconstruction despite its larger scale compared with type 1. Type 1 was, therefore, applied to No. 4 K-BOP which had a more or less experimental nature and type 2 to No. 5 and No. 6 vessels. In the case of type 2, the furnace bottom was designed in cone type aiming at refractory saving of the stationary portion and the reduction of a converter rotating torque. This was done after confirming the strength by a furnace stress analysis as described in the next chapter.

4.2 Study on Furnace Strength

4.2.1 Heat analysis

Figure 3 shows the model for heat analysis of the furnace. Although this is two dimensional, the analysis was executed with the five regions as shown in Fig. 3, because of the non-symmetrical condition of the vessel in tapping. The thickness of work lining was decided to be 100 mm considering its condition in the end of the lining life of the barrel. As boundary condition, contacting heat transfer was considered for the wall contacting the bath. For the rest in the vessel, radiation was considered, and for outside the vessel heat radiation due to connection and radiation was taken into consideration. Factor of the contacting heat transfer between bath and refractory was taken to be 1 500 kcal/m²h°C. For radiation in the vessel, heat flux is calculated by equation (1) after calculating geometrical factor F.



(a) Vertical section (b) Cross section at tapping

Fig. 3 Model of heat transfer analysis

$$q = \frac{C_B}{\frac{1}{C_1} + \frac{1}{C_2} - 1} \left\{ \left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4 \right\} \times F \quad (\text{kcal/m}^2\text{h}) \quad \cdots (1)$$

where, $C_1 = \varepsilon_1 \cdot C_B$
$C_2 = \varepsilon_2 \cdot C_B$
C_B: Stefan-Boltzmann's constant (kcal/m$^2 \cdot$ h $\cdot$ K^4)
ε_1: radiation index of molten metal
ε_2: radiation index of refractories
T_1, T_2: absolute temperature on radiating face

The heat flux distribution by calculation is shown in **Fig. 4**. Simulation pattern for heat analysis should be decided according to operation conditions, but considering innumerable patterns existing because of the changes of operations and necessary maintenance of the converter, the cycle shown in **Fig. 5** was determined as the representative pattern cycle. Free cooling was considered for the empty time, and the temperature in charging (hot metal including scrap) was determined to be 1260°C (2300°F) by the weight ratio of the two. Each situation is assumed to be momentary. Calculation was

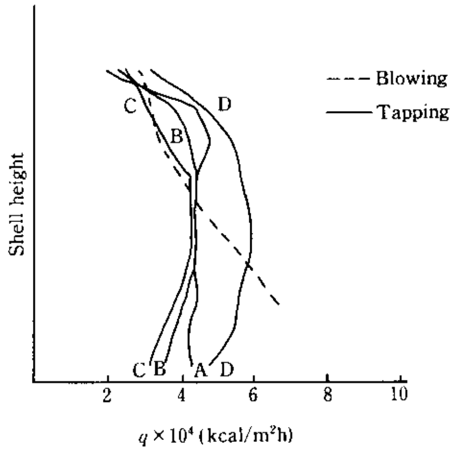


Fig. 4 Distribution of heat flux

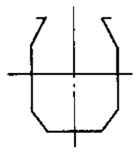
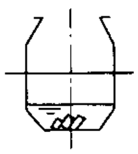
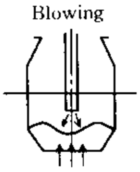
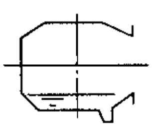
Time	10 min	15 min	20 min	5 min	Total 50 min
Condition	Empty 	H.M.+Scrap 	Blowing 	Tapping 	

Fig. 5 Simulation pattern of operation

continued until shell temperature reaches close to steady situation under the initial temperature 350°C for refractory and 50°C for shell. Consequently, the calculation was stopped at 450 min after operation-start, that is 9 heats, when the rise of shell temperature became negligible.

4.2.2 Temperature distribution

Figure 6 shows temperature distribution on shell surface at cross section C and E (Fig. 3) at 450 minutes after operation-start, bringing the shell temperature close to steady situation. A low temperature spot recognized in each corner is due to a larger radiation in the corner than other parts. This temperature distribution is reliable because of its good agreement with real temperatures measured as shown in Fig. 6. Since the temperature difference among neighboring spots through cross sections A to E is as negligible as below 10°C (50°F) from the result of analysis, the circumferential distribution of tempertures can be used to approximate shell temperatures in three dimensions.

4.2.3 Stress analysis

Stress analysis was performed by an FEM common use program (NASTRAN) using temperature distribution and mechanical load. The model and mechanical load for the analysis is shown in **Fig. 7**. In this model, furnace supporting parts and bottom latching device were counted as shell auxiliaries, but not refractory supporter, shell cover, and tap hole. In mechanical load, the latching force that affects the shell was also considered besides the loads shown in Fig. 7. The furnace supporting parts of the driving side were constrained, as necessary, so as to approximate the constraint condition to real furnace.

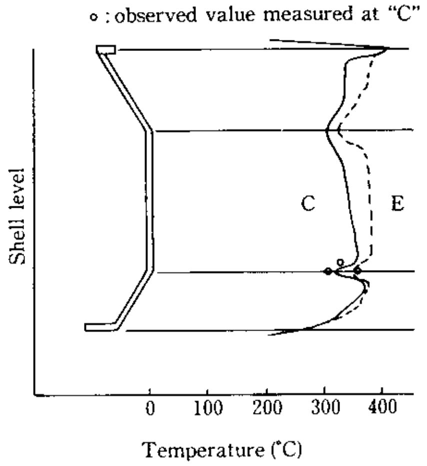
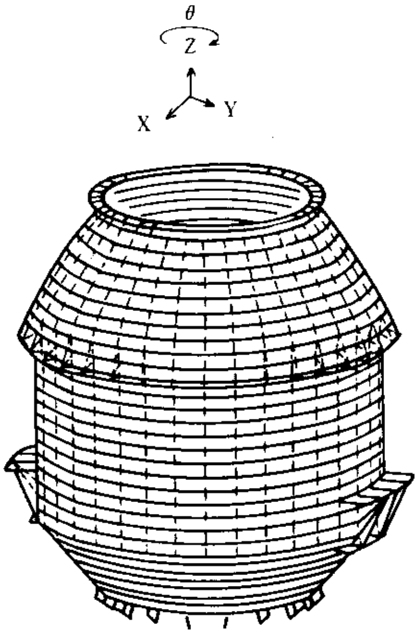


Fig. 6 Temperature distribution at 450 min after operation start



	Mechanical load (tf)
H.M.+Slag	300
Barrel lining	218
Bottom lining	45

Fig. 7 Shell model and mechanical load

4.2.4 Results of analysis

Figure 8 shows the time-passing changes of the stress of the bottom flange, lower cone and barrel around the lower barrel supporter. **Figure 9** shows the stress distribution on the shell in tapping at 250 min after operation-start. From this analysis, the following

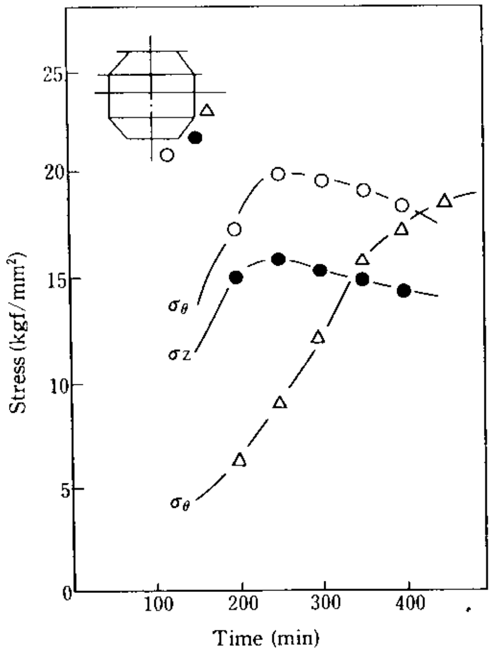


Fig. 8 Stress transition after operation start

findings are obtained:

(1) The stress by mechanical load is negligibly smaller (10% and under of total stress) than thermal stress.
(2) The stress is higher in tapping than in blowing.
(3) The time of the highest stress generation depends on the spot of the shell.
(4) The stress hardly changes by bottom profile whether it is cubic or conical.
(5) An optimum combination between the plate thickness of bottom flange and bottom cone exists.

4.2.5 Evaluation of shell strength

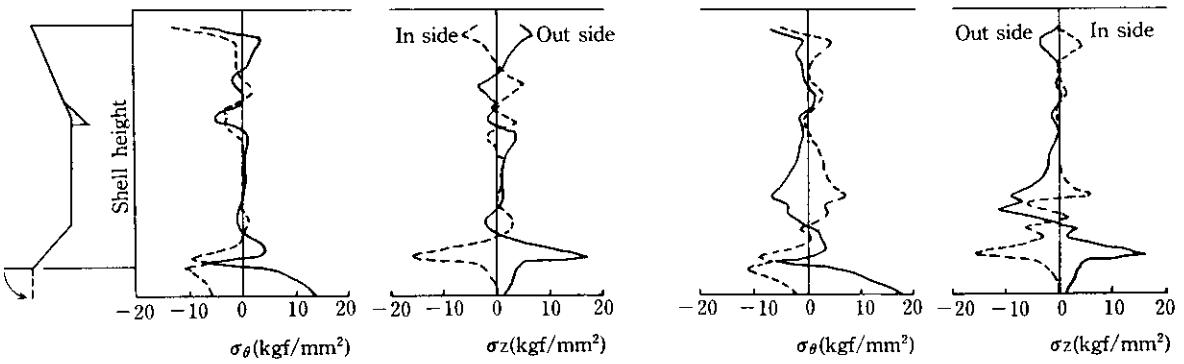
In selecting the material for converter shell, strength at high temperatures has been a decisive factor; recently, however, it has been replaced by SM (rolled steel for welded structure) at an increasing rate because of a shift of importance to toughness. SM41 was used also in this reconstruction. More recently, with development in progress aiming at a material superior in toughness and high temperature strength, the choice of the material in future will be made from the viewpoint of properties and manufacturing cost. Allowable stress σ_a of the converter shell, according to ASME CODE SEC. III, is 13.7 kgf/mm^2 in general and 22.5 kgf/mm^2 in specific portion. The stress values obtained by the analysis are all below the allowable stress, indicating no problem with strength. Using the same model, circumferential stress of hot-spot (partial overheat by falling down of work lining) was also analyzed.

As a result, it was found that the temperature on the hot-spot exceeded 600°C, causing a large bending stress over 30 kgf/mm^2 around the boundary between the hot-spot and normal place. From this, it was recognized that refractory falling gave a large damage to the shell, causing a deformation to the upper knuckle plate. Therefore, shell cooling is effective for the prevention of deformation.

4.3 Calculation of the Furnace Tilting

As the characteristics of the bottom-blowing process which flows gases constantly to prevent the tuyere from choking, if the tuyeres are dipped into bath, the hot metal charging becomes impossible because of the hot metal splash, and if the tilting angle is large, bath overflows from the vessel. Therefore, the relation between bath level and tilting angle should be recognized at all times. Moreover, as it was necessary to grasp the change of tilting torque, the program was developed to calculate the change of the bath level and torque during vessel tilting. Since lining is worn gradually at each operation, data on the vessel's inner profile was obtained by LASER (profile measuring equipment), and on this basis, a profile wear model was formulated.

Figure 10 shows the change of bath level in charging.



(a) Tap side (b) Trunnion side

Fig. 9 Stress distribution at 250 min after operation start

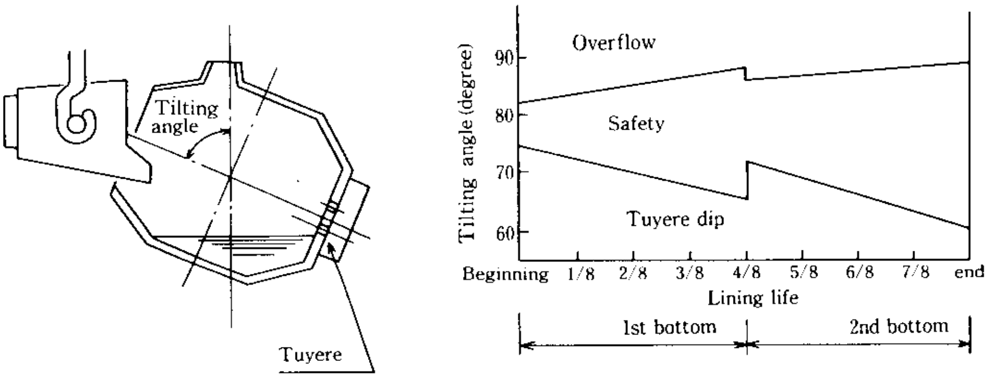
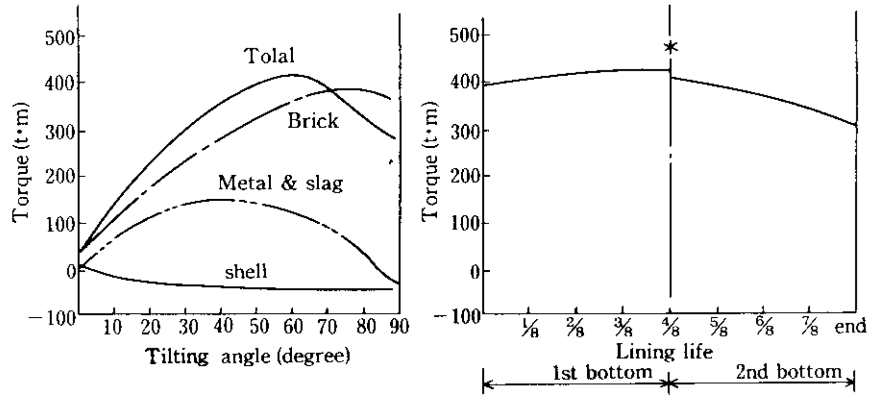


Fig. 10 Change of bath level at charging



(a) Tilting at end of 1st bottom*

(b) Lining life and driving torque

Fig. 11 Driving torque of K-BOP

This contributes to steady operation, because the determination on tilting angle in charging became easier. **Figure 11** shows the calculation result of tilting torque. In this, (a) shows the change of individual tilting torque, by shell, bath and refractory; (b) shows the relation between the change of refractory wearing and change of maximum torque. This figure means:

(1) The element most influential to tilting torque is refractory.
(2) Shell functions as negative torque.
(3) The maximum torque occurs at about a 60° tilting angle in the last period of the first bottom and it is smaller than the value of LD.

Therefore, the tilting mechanism of the LD was used as it was without remodeling.

4.4 Remodeling around Furnace

4.4.1 Trunnion ring cooling device

In conventional LD converters, the trunnion ring and shell have been cooled by the cold air supplied into the trunnion ring through a hole cut in the trunnion shaft. Along with the reconstruction into K-BOP, as the shaft hole was determined to be used as a path for the bottom-blown gases, the air must be supplied through another path. For this reason, a special rotating wind tunnel that rotates in sliding manner around the trunnion shaft on the non-driving side was developed. The wind tunnel is of spring-pushed type, making it possible to absorb the thermal expansion and an axial vibration, and has been making satisfactory operation.

4.4.2 Piping in trunnion shaft

In the designed function of this piping, gases and cooling water that were brought into the shaft through the rotary joint are drawn out to the barrel side through a hole opened normal to the trunnion shaft center. The pipe in trunnion and this leading pipe are connected with a bend made of stainless casting. The fluid of driving-side is internal pipe gases and that of following side are external gases and cooling water for the vessel mouth. The most important thing for the pipes in trunnion shaft is to maintain a steady sealing property for a long time in the severely vibrating shaft. Especially, the connection between the bend block and the leading pipe requires the accuracy of the shaft hole fabrication as a portion most liable to gas leak. In the case of K-BOP, its own sealing method was developed and it has been keeping an excellent sealing performance since its first operation.

4.4.3 Downcommer pipe

This is the pipe to lead the gases through leading pipe to the bottom and should be installed not to interfere with the existing facility when tilting. Adoption of a new type of pipe supporter made the numbers of expand-joints to the minimum and the connecting work easier and safer. The piping was guarded by cover from falling down of solidified material.

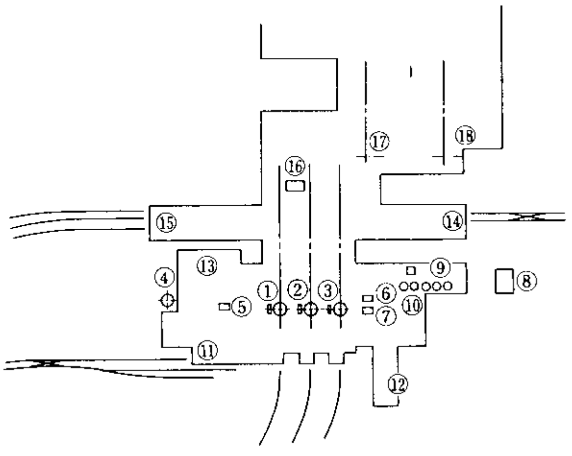
5 Flux Injection Facility

5.1 Layout of Flux Injection Tank and Piping Length

In determining the layout of flux injection tank, the following points were required:

1. Burnt lime as hazardous material should be treated according to laws and regulation.
2. Piping length should be minimized for minimum pressure loss and high response.
3. Vibration should be avoided to obtain higher accuracy of flux feeding.

Figure 12 shows the layout of converters yard at No. 2 BOF Shop in Mizushima Works. As No. 4 K-BOP was regarded more or less as an experimental converter, the flux injection tank was installed near-by the furnace to minimize the piping length and the flux was supplied from driving-side. The equivalent piping length from the supply point of the flux injection tank to the bottom can be calculated by equation (2).



① No. 4K-BOP
② No. 5K-BOP
③ No. 6K-BOP
④ Flux storage tank
⑤ No.4 injection tank
⑥ No.5 injection tank
⑦ No.6 injection tank
⑧ Propane tank
⑨ Bottom maintenance yard
⑩ Lance maintenance yard
⑪ H.M. yard
⑫ Scrap yard
⑬ Ladle yard
⑭ No.5 casting yard
⑮ No.6 casting yard
⑯ Degassing process
⑰ No.5 CC macnine
⑱ No.6 CC machine

Fig. 12 Layout in Mizushima No. 2 steel making shop

Table 3 Supplying direction & equivalent pipe length of flux injection line

(unit: m)

No. of K-BOP / Length \ Side	No. 4	No. 5		No. 6	
	Drive	Drive	Follow	Drive	Follow
L	44.4	88.1	78.0	64.8	44.6
$L_{eq1}+L_{eq2}$	133.6	177.6	188.4	176.5	149.2
L_{eq}	178.0	265.7	266.4	241.3	193.8

$$L_{eq} = L + L_{eq1} + L_{eq2} \quad \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

where, L_{eq} : total equivalent piping length (m)
L : axial length of pipe (m)
L_{eq1}: equivalent length of bend to axial length (m)
L_{eq2}: equivalent length of upright to axial length (m)

In the case of K-BOP vessels Nos. 5 and 6, a supply of flux from the driving side seemed to be advantageous, because the flux storage tanks are located in the following-side as shown in Fig. 12. As shown in **Table 3**, however, there is not a significant difference in equivalent length between the driving-side and the following-side in the case of No. 5 K-BOP where conditions are most disadvantageous.

Therefore, the flux supply to the vessel was decided to be made from the driving-side to obtain a common use among the bottoms. The maintenace and managing of bottoms became easier by this arrangement.

5.2 Pressure Loss of Gas Injection System

As shown in Table 3, the flux transportation distance of Nos. 5 and 6 K-BOP vessels is longer than that of No. 4. Therefore, the calculation of gas pressure loss was made in two categories of pure gas flow and flux transportation as followed in equations (3) and (4), and based on the calculation results, valve characteristic value C_V was decided to be 390 and the pressure of oxygen gas holder 17 kgf/cm^2.

pressure loss of pure gas

$$\Delta p_1 = \lambda \frac{L_{eq}}{d} \cdot \frac{\gamma v^2}{2g}(p+1)\frac{273}{273+t} \quad \cdots\cdots\cdots (3)$$

pressure loss by flux transportation

$$\Delta p_2 = K \cdot L_{eq} \cdot v(p+1)\frac{273}{273+t} \quad \cdots\cdots\cdots (4)$$

where, Δ_{p_1}, Δ_{p_2}: pressure loss (mmAq.)
λ: resistance factor of pipe
L_{eq}: equivalent pipe length (m)
d: inner diameter of pipe (m)

γ: specific gravity (kg/m^3)
p: gas pressure (kg/cm^2, gauge)
t: gas temperature (°C)
v: gas speed (m/s)
K: factor decided by the ratio of flux and gas

Consequently, the feeding rate of flux and oxygen and the responsiveness of control have no problems.

5.3 Sorts of Gases and Piping System

As shown in Fig. 1, the bottom-blown gases are divided into two; internal-pipe gas and external-pipe gas. The former consists of three; oxygen, argon and nitrogen, and is used for flux injection and blowing. The latter also consists of three: propane, argon and nitrogen; propane is used for cooling tuyeres. From the view of pressure, these gases are divided into high-flow gas blown into metal and low-flow gas for empty vessel. Automatic shut-off valves are installed in both high-flow and low-flow systems to prevent gas mixing at the same time. The upper stream of the shut-off valves is for high pressure facility.

6 Auxiliary Facilities

6.1 Shelters

Shelters for the bottom-blown converters require higher heat-proof and durability than conventional converters. For No. 4 K-BOP, the shelter doors with water-cooling jacket were installed both on the charging side and tapping side. Especially on the charging side, the door was designed to be hydraulically-driven to give a max. 20 t of opening and closing force, considering a possible sticking of the door due to slag or metal adhesion. Fortunately, the troubles have not happened so far. For Nos. 5 and 6 K-BOP, therefore, a membrance-type motor-driven shelter was adopted to reduce its weight to about one-half of No. 4 K-BOP.

6.2 Stand-by Facilities

Unlike LD converters, the bottom-blown converters require a continued supply of gases even when the tilting mechanism is in trouble during blowing, causing molten steel to solidify or over-oxydize, thus leading to a big trouble. This situation is difficult to recover and it takes a long time. For these reasons, stand-by facilities with high reliability should be installed. The facilities recently installed are as follows:

6.2.1 Stand-by tilting facility

When the vessel is in stoppage caused by electrical trouble with tilting mechanism, this facility tilts the vessel hydraulically until the tuyeres get out of metal immersion, driven by hydraulic pressure released from accumulators. The capacity of accumulator is calculated by torque-tilting angle relation in Sec. 4.3, although it can be calculated by torque curve of rotating and hydraulic motor. The driving method of the accumulator was designed to be of single-driving from the consideration of reliability.

6.2.2 OG skirt stand-by lift-up facility

The vessel can not tilt in sequence if OG skirt fails to rise. Especially in the case that lift driving is made by hydraulic cylinders, the stand-by accumulator can not be used, if the cause comes from hydraulic system. The reconstruction was made by using a newly developed multiplex hydraulic cylinder to utilize the existing lifting system, after studying on various systems, such as motor-powered winch and parallel-set cylinders.

The system has a couple of hydraulic cylinders, installed face-to-face with one rod in common use and the following merits are obtained:

(1) Less space for the system
(2) Possible for remote control with rapid operation
(3) Common use for stand-by and normal work with same cylinder.

One hydraulic unit was installed in common use for Nos. 4–6 vessels, and the valve stand was set up for each vessel. For the prevention of inclination of the skirt, the synchronizer was also set up to another valve stand.

6.3 Bottom Maintenance Facilities

The frequency of bottom change is once or twice a month in the case of the "two in operation–one stand by" operation, because of 1 barrel–2 bottoms system. It means three K-BOP vessels need 5 bottoms for smooth operation. The maintenance yard and the place for the bottoms, the bottom exchanger, the bottom reverser and bottom relining machine should be placed close to the converters yard. As shown in Fig. 12, in the case of Mizushima Works, an ingot-making yard was converted into this yard.

7 Remodeling Construction

In remodeling for K-BOP operation, not only the remodeling of the vessel itself, but also auxiliary facilities should be involved to realize full function of K-BOP. As is well known, it is not allowed to stop such a key operation as the BOF shop even if for remodeling construction. For this reason, preliminary construction around the vessel was performed in regular repair days in advance and main construction including movable parts were executed in each relining term.

The outline of site construction is shown in **Fig. 13**. Type 1 in Fig. 12 is the case of No. 4 vessel, and type 2 for Nos. 5 and 6 vessels. The volume of the site construction work of type 2 took 12 days shorter than in type 1, although type 1 seems to be less in construction work.

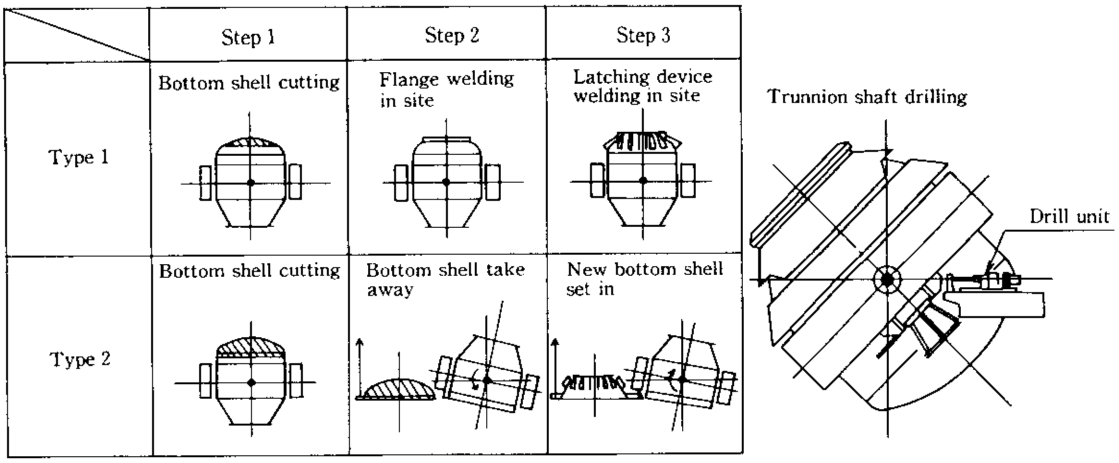


Fig. 13 Reforming of converter

The method for step 2 and step 3, named "hinge-method", showed excellent result on handling the bottom in small space, by vessel tilting and utilizing a charging crane. This method can be effective for exchange of the upper knuckle of the shell. The reconstruction was done using two relining terms for each converter. The first term was used in drilling the shaft and constructing the air-chamber for about one month as preliminary construction. Then, main construction was performed covering the remodeling of converter itself and installation of auxiliary facilities in the next relining term for about two months. Consequently, the reconstruction term of each converter took about half a year from the beginning to the end of the construction.

8 Facilities Expense

Figure 14 shows the ratio of expenses of each item in the whole facilities. The ratio of injection facility and its control facility is more than one-half of total, while the ratio of vessel reconstruction and piping construction is comparatively small.

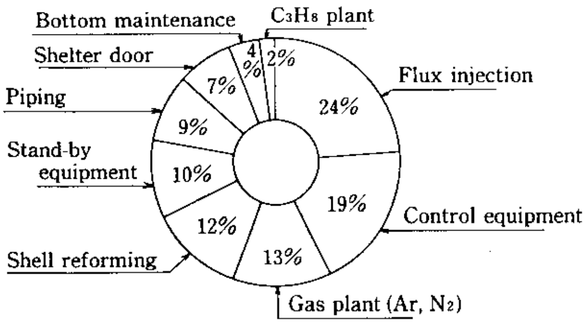


Fig. 14 Ratio of investment

9 Operation

Since the start-up of No. 4 K-BOP in April 1980, steel production by the three K-BOPs came up to 17 000 heats showing high productivity and superior economy.

A start-up problem was furnace vibration. The one in the case of No. 4 K-BOP exceeded the preliminary study, although the vibration itself had been expected by experience of Q-BOP in Chiba Works of the company. However, the vibration was controlled within allowable range, after the improvement of operation concerning the blowing patterns and the improvement of facilities such as tuyere arrangement. Some of the studies for improvement are described below:

(1) Countermeasure for vibration

From the observation of vibration waves, it was inferred that an impulsive force other than the bath vibration was in action along the direction of trunnion shaft even in steady period. Then, the vibration load was calculated by a vibration equation using spring constant of the supporting system and measured amplitude. These loads work mostly on driving-side in the direction of trunnion shaft and work evenly each on driving-side and following-side in the right-angled direction of trunnion shaft. As is well known, excessive vibration gives bad effect to driv-

Table 4 Improvement ratio of vibration

	Amplitude		Vibration load			
			Drive side		Follow side	
	Thrust	Horizontal	Thrust	Horizontal	Thrust	Horizontal
Before improvement	1.0	1.0	1.0	1.0	1.0	1.0
After improvement	0.5	0.67	0.74	0.66	1.0	0.65

ing system and bearing life. In the case of No. 4 vessel, re-investigation of the operation and a study on the relation between the tuyere arrangement and the change of bath level using cold model experiment were conducted to restrain the noticeable vibration in the start-up stage. Consequently, it was found that by changing the tuyere arrangement, the furnace vibration was markedly reduced.7) Improvement ratio of vibration after these countermeasure is shown in **Table 4**. The effect is excellent and vibration trouble has not since been found.

(2) Bearing life

The life estimation of usual bearings is given by equation (5); however, the one for low speed revolution and cradle rotation like the converter trunnion bearing has not been established.

$$\frac{C_0}{P_0} > 2 \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \textbf{(5)}$$

where, C_0: fundamental static rated load
P_0: static equivalent load

By using the equation (5) another equation for the estimation of cradle bearing was tried. In this equation, revolution is regarded as equivalent to the value obtained by dividing the total cradle angle by unit cradle angle. As a result, trouble is not found at present, but continuous watch will be necessary.

10 Conclusions

Kawasaki Steel Corporation established a total technology for remodeling LD converters into K-BOP, covering from designing to operating phases, all by itself at its No. 2 BOF Shop of Mizushima Works. Not only the bottom-blown Q-BOP technology but also some other new addition of originality were incorporated into this remodeling. The success in this remodeling project has contributed immensely to the fine reputation for K-BOP, combined with its high level operating technology.

Above all, the technology for stress-analysis of the shell, the piping in the trunnion shaft, remodeling work itself and the countermeasures for vessel vibration is in common use for all combined-blown converters in its wide application. These technologies will further be improved hereafter.

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