Abridged version

KAWASAKI STEEL TECHNICAL REPORT
No.8 (September 1983)

Improvement in Off-Gas Recovery from Q-BOP

Hajime Bada, Sumio Yamada, Motoyasu Yaji, Fumio Sudo, Mikio Kodaka

Synopsis :
No.3 Steelmaking Shop at Chiba Works has two 230t Q-BOPs for the first time in Japan, which are equipped with OG system as off-gas cleaning equipment, and consequently off-gas energy from Q-BOPs is recovered effectively as fuel for power plant. To increase energy recovery, it is effective to reduce combustion ratio of off-gas from Q-BOPs. Chiba's Q-BOPs have decreased the combustion ratio from 5% to 2 or 3% by means of improvement of sealing between furnace and skirt hood. Then, the recovery time of off-gas from Q-BOPs has been extended and the reliability of gas sampler and gas analyzer has been improved. Consequently, the amount of energy recovered from off-gas has increased to about 270 x 10 3 kcal/t. Q-BOP has shown additional advantage of CO gas recovery by injecting limestone powder through the bottom tuyeres.

The body can be viewed from the next page.

KAWASAKI STEEL TECHNICAL REPORT No. 8 September 1983

Improvement in Off-Gas Recovery from Q-BOP*

Hajime BADA** Sumio YAMADA** Motoyasu YAJI**
Fumio SUDO** Mikio KODAKA***

No. 3 Steelmaking Shop at Chiba Works has two 230 t Q-BOPs for the first time in Japan, which are equipped with OG system as off-gas cleaning equipment, and consequently off-gas energy from Q-BOPs is recovered effectively as fuel for power plant. To increase energy recovery, it is effective to reduce combustion ratio of off-gas from Q-BOPs. Chiba's Q-BOPs have decreased the combustion ratio from 5% to 2 or 3% by means of improvement of sealing between furnace and skirt hood. Then, the recovery time of off-gas from Q-BOPs has been extended and the reliability of gas sampler and gas analyzer has been improved. Consequently, the amount of energy recovered from off-gas has increased to about 270 × 10^3 kcal/t.

Q-BOP has shown additional advantage of CO gas recovery by injecting limestone powder through the bottom tuyeres.

1 Introduction

To increase a converter off-gas recovery rate presents a challenging problem among possibilities of various energy-saving measures in the steelmaking process. With the recent sharp rise in energy costs as a momentum, strenuous efforts have been made in operational improvement and development of new techniques[1,2].

No. 3 Steelmaking Shop at Chiba Works installed a bottom-blown converter (Q-BOP) for the first time in Japan and employed the OG System as off-gas recovery equipment.

An effective off-gas recovery requires an appropriate control system well fit for in-furnace reactions, and the Q-BOP has its metallurgical reaction characteristics different from those of the conventional LD converter. Therefore, in designing the OG system as the off-gas recovery equipment for the Q-BOP, an elaborate consideration was taken covering dust-collecting efficiency, safety, and economy.

One of the Q-BOP features, compared with those of the LD converter, is a minimal slopping and spitting, with a markedly stabilized furnace reaction. Further, the hydrocarbon gas, which is used for tuyere cooling, enhances hydrogen gas concentration and increases the volume of the generated gas.

Since its start, various improvements suitable for its above-described features, have been made on the off-gas recovery equipment, resulting in the establishment a record unit energy recovered of 270 × 10^3 kcal/t-steel has been established. The outline is reported below by laying emphasis on measures for improving unit off-gas recovery.

2 Outline of Equipment

Figure 1 shows a schematic diagram of the equipment. Generally, the gas cooler of the OG recovery equipment employs the membrane system in combination with the open-system cooling tower, and such gas cooler has the following three drawbacks:

(1) The open system makes it difficult to effect water-quality control of the cooling water system and is liable to cause scale deposition.
(2) Repeated temperature changes which the gas cooler undergoes are liable to generate a crack on the tube of the gas cooler.
(3) Construction of the hood is complicated, thereby incurring high maintenance cost.

In order to cope with the above-described drawbacks and recover the sensible heat of the off-gas which was formerly dispersed in the air, the hood has been designed to be the evaporation cooling type, and the radient part the boiler type.

* Originally published in *Kawasaki Steel Giho*, **15** (1983) 2, pp. 40–44
** Chiba Works
*** Chita Works

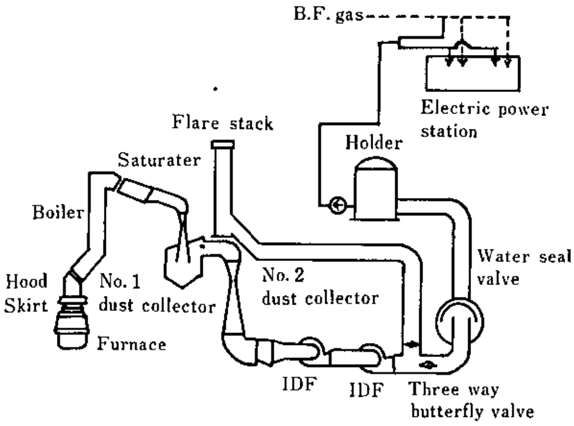

Fig. 1 Schematic drawing of gas flow of OG system

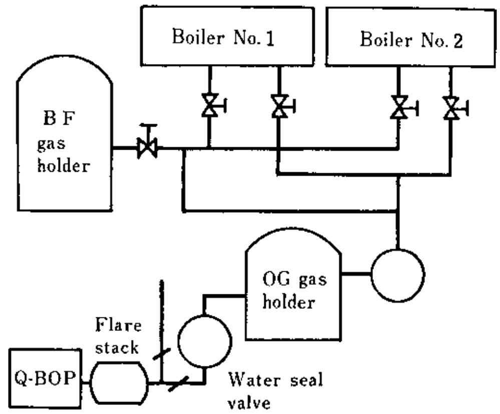

Fig. 2 Schematic flow of OG and BF gases

3 Measures for Enhancing Unit Energy Recovered

3.1 Improvement in Gas Recovery/Heat ratio

At the initial stage of equipment operation, start-up trouble of the recovery equipment, improper set up values of recovery conditions, unfamiliarity with operation, etc., caused total or intermediate unrecoverable heats, but improvement in the equipment reliability and thoroughgoing equipment maintenance through scheduled and refractory maintenance have eliminated troubles caused by breakdown of the equipment.

At present, off-gas recovery is performed immediately from the 1st heat after refractory or scheduled maintenance, bringing the gas recovery/heat ratio to as high as 100%.

3.2 Extension of Recovery Time

3.2.1 Computer control for gas consumption

Since the off-gas is generated intermittently, a gas holder is installed to function as a buffer for keeping a balance between the quantities of generation and consumption of the off-gas. **Figure 2** shows a schematic diagram of the recovery gas at No. 3 Steelmaking Shop area. The recovered gas is stored in the holder having a capacity of 60 000 m^3 and sent to the power plant, where the off-gas can be burnt independently or in a mixture with the blast furnace gas, etc., but it is difficult to make sudden changes to the volume of consumption. For this reason, a prediction and control system has been introduced for the purpose of stabilizing the usage of the off-gas.

Figure 3 shows a conceptual diagram of the prediction and control system, which finds out the condition of Q-BOP operation and predicts the volume of off-gas generation, thereby controlling the gas holder level. **Figure 4** shows an example of the usage of

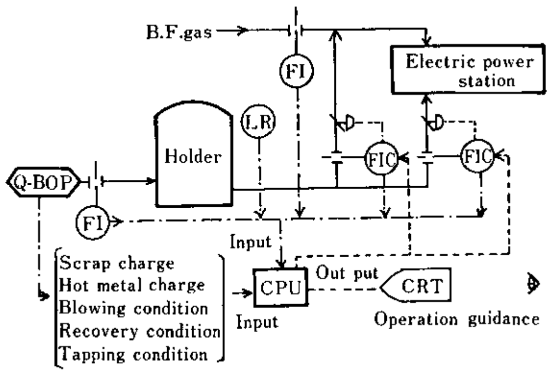

Fig. 3 Computer control system in use for Q-BOP and BF gases

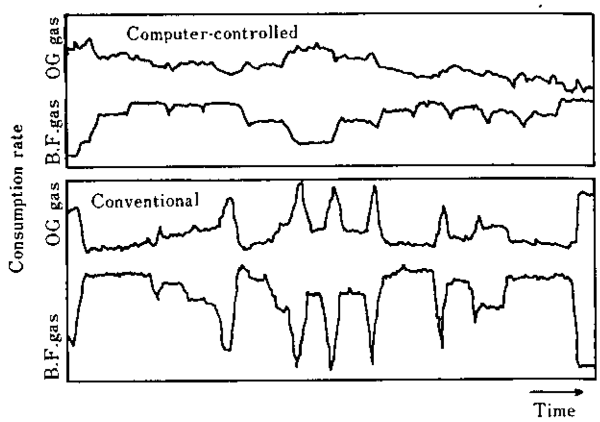

Fig. 4 Effect of computer control on OG and BF gases

the off-gas and BF gas at the power plant. After the initiation of the prediction and control system, variation in gas consumption has become smaller, thus demonstrating the favorable effects of the present system. The system has completely eliminated gas dispersion from the holder caused by the overfilling of the gas.

3.2.2 Reduction in gas analyzing time

The basic concept of safety measures against explosion at the off-gas recovery equipment lies in preventing the mixing in the recovery system of the off-gas containing CO or H_2 above explosion limit and the gas(air) containing oxygen above the critical value. Namely, the skirt is raised at the initial and final stages of blowing to burn the off-gas at the furnace mouth, so that all the CO, H_2 and O_2 gases form an inert gas layer at a value lower than their respective critical values. However, the conditions of inert gas layer forming vary with the chemical compositions of hot metal and blow-end molten steel, as well as flow rate of the oxygen gas. It is necessary, therefore, patterns be preset for the respective stage of initial (pre-combustion) and final (post-combustion) blowing covering the oxygen gas flow rate, feeding rate of iron ore, and suction flow rate of off-gas.

In order to recover the off-gas by avoiding the pre- and post-combustion stages, the concentrations of O_2 and CO gases in the duct during blowing are continuously measured to judge the OG recoverable conditions. At No. 3 Steelmaking Shop of Chiba Works, the OG recoverable conditions are set at a CO concentration of 30% or above and an O_2 concentration of 1% or below. In order to commence off-gas recovery at an early stage and prolong recovery time while maintaining safety, it is necessary to reduce analysis time and enhance the reliability of analysis values.

Figure 5 shows a schematic diagram of the off-gas sampling system in the off-gas recovery equipment. The sampling probe, sampling pump and piping were improved to reduce analysis time. The probe incorporated a primary filter and had its volume reduced to the limit at which the filterating capacity of the filter would not be dropped. Dust which deposited on the filter would lower the pump capacity, and therefore, the pump capacity was expanded and the pipe diameter corresponding to the increased capacity was selected. As a result, the gas recovery time was extended by about 30 sec (8 400 kcal/t).

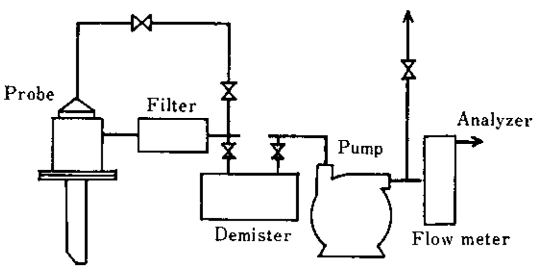

Fig. 5 Off-gas sampling system

3.2.3 Improvement in pre- and post-combustion patterns

For increasing the volume of recovered off-gas, it was desirable to reduce pre- and post-combustion time as short as possible. Time required for the inert gas to be generated in the duct and the staying condition of the gas in the duct were examined by simultaneously performing gas analyses at the furnace top and flare stack. The results of the investigation indicated that the gas at the furnace top and flare stack showed no discernible difference between variations in the off-gas chemical composition and formed an ideal piston flow condition. This fact proved that even if the inert gas generation time was reduced to about several seconds, there would be no danger of explosion due to the mixture of the combustible gas and air. Simultaneously with this investigation, the efficiency of decarburization in the Q-BOP was examined, and pre- and post-combustion patterns were set up in such a manner as to form an inert gas layer without fail and prolong the recovery time. Through this improvement, recovery time was increased by 1.7 min (29 000 kcal/t).

3.3 Lowering of Combustion Ratio

In order to increase the recovery of off-gas energy, it is desirable to prolong the recovery time and also to suppress air suction, thereby recovering the off-gas generated from the Q-BOP unburnt as far as possible.

3.3.1 Control on gap between skirt and furnace

The combustion ratio and the gap between skirt and furnace have a relation as shown in **Fig. 6**, and in order to lower the combustion ratio, it is important

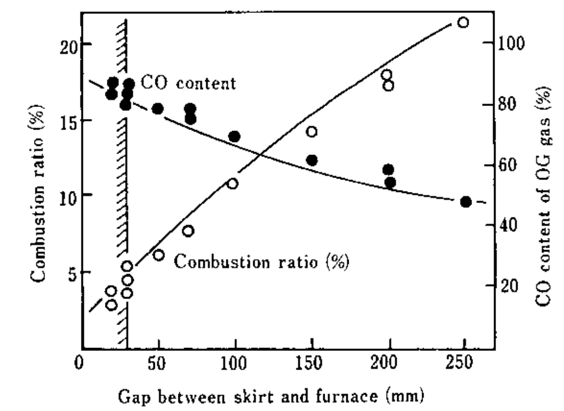

Fig. 6 Combustion ratio and CO content in relation to skirt-furnace gap

to decrease the gap between skirt and furnace[3]. The Q-BOP permits easy suppression of slopping and spitting, prevents deposition on the top of furnace-mouth fittings, and can regulate the gap between skirt and furnace within a small limit, thereby making it possible to perform operation at a gap of 20 to 30 mm between skirt and furnace and with a combustion ratio of 4%.

3.3.2 Stabilization of pressure in hood

A decrease in the gap between skirt and furnace increases variation in pressure in the hood, resulting in an increase in the blow-out gas rate or in the air suction rate. Variation in pressure in the hood is considered to be induced by sudden changes in an oxygen feed flow rate or by variation in a refining reaction rate. As the Q-BOP maintained stabilized refining reactions, the effect of the former was predominant. When the feeding of solid oxygen source such as iron ore was started or ended during blowing, the oxygen flow rate showed sudden changes and increased variation in pressure in the hood. Therefore, control was so performed as to make constant the total amount of oxygen supply, as shown in **Fig. 7**, and to stabilize the pressure in the hood.

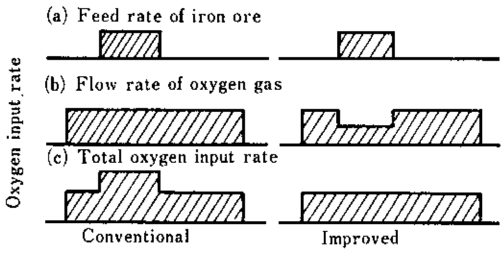

Fig. 7 Improved blowing schedule to stabilize the pressure fluctuation in the hood

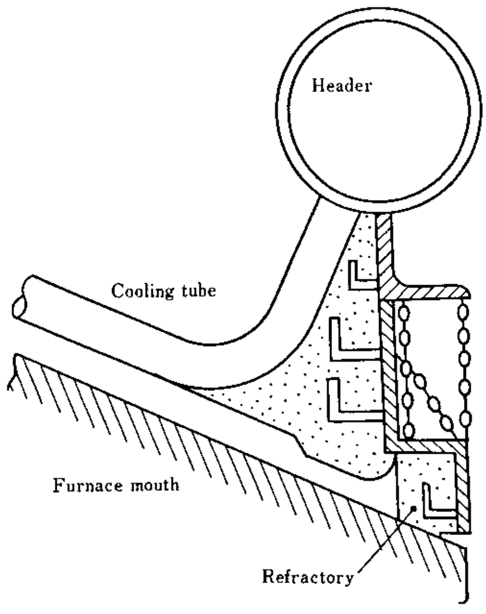

Fig. 8 Schematic drawing of new sealing device

3.3.3 Sealing-up of gap between skirt and furnace

Through establishment of techniques for preventing variation in pressure in the hood, the gap between skirt and furnace was made still narrower to reduce the combustion ratio. If the skirt had been lowered closer to the furnace mouth according to the conventional method, deformed furnace mouth fittings would have damaged the tube of the skirt, thereby possibly causing water leak. Therefore, modification in construction was made in such a way that a sealing member made of refractories as shown in **Fig. 8** was suspended with chains to the lower part of the skirt. This method almostly completely sealed up the gap between skirt and furnace. The seal was so durable as to be used for one campaign of the furnace without maintenance. This modification reduced the combustion ratio of the recovery gas from 4% to the lowest possible limit value of 2 to 3%, and improved the unit gas recovery to 6 200 kcal/t.

3.3.4 Energy balance of recovery gas

Table 1 shows the mean compositions of gases recovered from Q-BOP and LD. High CO gas concentration in the Q-BOP permits an increase in calorific heat due to combustion. **Figure 9** is the ratio of

Table 1 Typical gas composition recovered from Q-BOP

(vol.%)

	CO	CO_2	H_2	N_2
Q-BOP(Improved)	85.6	2.6	5.9	5.9
Q-BOP(Conventional)	73.5	6.2	6.0	14.3
LD(Chiba)	64.5	18.4	0.7	16.4

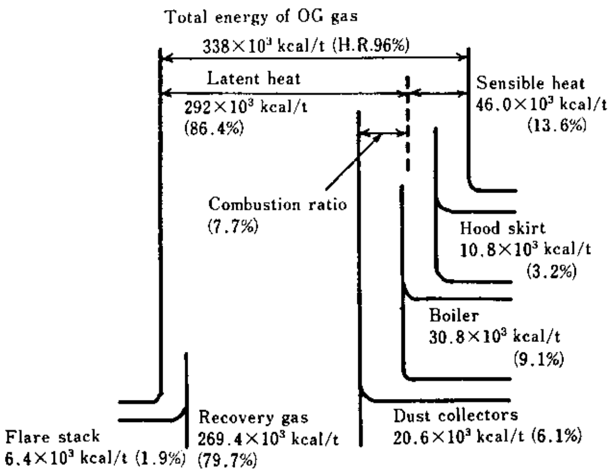

Fig. 9 Averaged heat balance of OG gas through blowing period

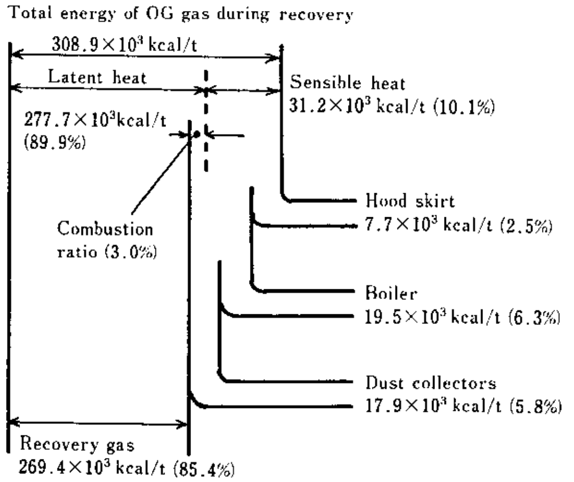

Fig. 10 Heat balance of OG gas during recovery period

recovered energy to energy (combustion heat + sensible heat) possessed by the off-gas in Q-BOP, as shown by the mean value of the total blowing time including the pre- and post-combustion stages.

A low value of 7.7% can be obtained as the combustion ratio for the Q-BOP, compared with that of 22.2% for the LD. Energy recovery in the gas form amounted to 79.7% of energy possessed by the off-gas, and if a 9.1% recovery of sensible heat at the boiler is added, the total energy recovery will reach 88.8%.

Figure 10 shows an example of the measured value of the energy balance during the energy recovery period. The combustion ratio is as low as 3.0%, and 85.4% of off-gas energy is recovered as a recovery gas. If recovery through steam at the boiler is added to this, the total recovery amounts to 91.7%.

3.4 Increase in Off-gas Recovery through Limestone Injection[4]

An attempt has been made to use the off-gas recovery equipment as energy conversion equipment by further developing the concept of effective recovery of Q-BOP off-gas[5]. The test on limestone injection into the Q-BOP is an example of such a concept, and constitutes a technique for recovering the CO gas generated by the reaction shown in eq. (1).

$$CaCO_3 + \underline{C} \rightarrow CaO + 2CO \quad \cdots\cdots\cdots\cdots (1)$$

3.4.1 Test method

Table 2 shows the chemical compositions of limestone used in the present test and burnt lime conventionally used. Part of burnt lime which was to be injected from the bottom was replaced with limestone, while CaO content remained equivalent, and thus both burnt lime and limestone were injected into molten steel by means of an oxygen current. **Figure 11** shows the injection patterns of burnt lime and limestone. Limestone was injected during the period of off-gas recovery.

Table 2 Composition of burnt lime and limestone

(wt. %)

	CaO	$CaCO_3$	SiO_2	Fe_2O_3	P	S
Burnt lime	97	1.7	0.36	0.001	0.01	0.01
Lime stone	(55.6)	99	0.20	0.03	0.01	0.01

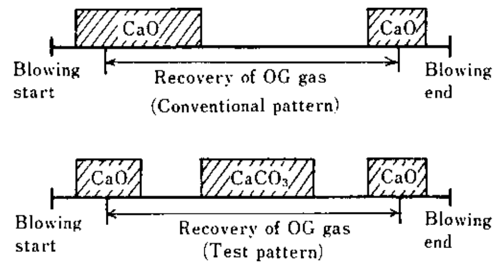

Fig. 11 Flux injection pattern

Table 3 Effect of limestone injection (10 kg-limestone/t-steel) on OG gas recovery

	Calculated	Observed
OG gas recovery (kcal/t)	$+6.78\times10^3$	$+6.50\times10^3$

$$CaCO_3 \longrightarrow CaO + CO + \tfrac{1}{2}O_2$$

3.4.2 Increase in off-gas recovery

Table 3 compares the calculated and measured values in respect of the increment of off-gas recovery due to limestone injection. The observed value corresponds to 95.8% of the calculated value.

3.4.3 Effects of limestone injection on Q-BOP operation

Limestone injection was employed in commercial operation for a long period and a comparison was made between the heat with limestone injection and the one without. **Table 4** shows a comparison between the calculated and observed values in units of off-gas recovery, burnt lime consumption, ore consumption, yield of molten steel and oxygen consumption, when 10 kg/t-steel of limestone was injected. The decomposition endothermic reaction of limestone decreased the addition quantity of iron ore which was fed as a

Table 4 Advantage and disadvantage of limestone injection (10 kg-limestone/t-steel) in Q-BOP

	Calculated	Observed
OG gas recovery	$+6.78\times10^3$ kcal/t	$+6.50\times10^3$ kcal/t
Burnt lime consumption	-5.6 kg/t	-7.6 kg/t
Ore consumption	-8.2 kg/t	-6.9 kg/t
Yield of molten steel	-0.57 %	-0.40 %
Oxygen consumption	$+0.60$ Nm³/t	$+0.35$ Nm³/t

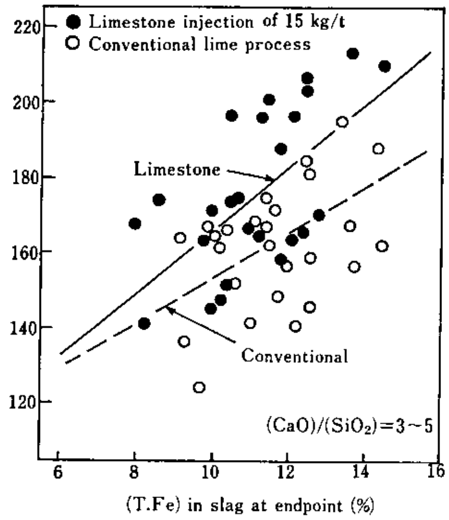

Fig. 12 Effects of limestone injection on phosphorus partition ratio at end point

cooling medium, and diminished the advantage to be obtained by direct reduction of iron ore. Limestone injection also decreased the total CaO quantity (CaO contents of both the burnt lime and limestone), because limestone injection enhances dephosphorization power compared with the conventional injection of burnt lime alone, as shown in **Fig. 12**. The advantages and disadvantages of limestone injection are determined by the unit costs of auxiliary raw materials and the gas shown in **Table 4**, and therefore, the location conditions of the respective steel mills and energy balance must be taken into consideration in actual implementation of limestone injection.

4 Operation Results

The waste gas recovery equipment has undergone various improvements described above since its start in May, 1977, with recovered off-gas energy per ton of steel steadily up as shown in **Fig. 13**. Recently the off-gas recovery has reached 270×10^3 kcal/t and, if

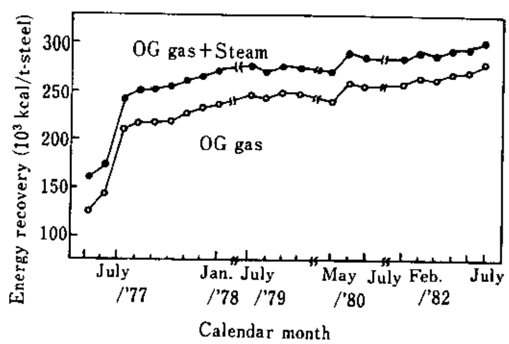

Fig. 13 Monthly variation of energy recovered from Q-BOP

steam unit recovery is added, the total waste gas recovery has exceeded 300×10^3 kcal/t which accounts for 3.4% of the total energy consumption per ton of steel at Chiba Works.

5 Conclusions

No. 3 Steelmaking Shop at Chiba Works which adopted the OG Process for Q-BOP off-gas recovery made improvements on the waste gas recovery operation techniques by fully utilizing the refining characteristics of the Q-BOP, and realized high energy recovery ratios. Main improvements made can be summarized into the following three points:

(1) Reduction of combustion ratio through almost complete sealing-up of gap between skirt and furnace
(2) Prolongation of recovery time by forming an inert gas layer without fail and by developing such blowing pattern as will establish recovering conditions at an early stage.
(3) Prolongation of recovery time by reducing gas-sampling and gas-analysing time

As a result of the above-described improvements, off-gas recovery per ton of steel has reached 270×10^3 kcal/t and the economic superiority of the Q-BOP over the LD has further been enhanced.

The results of the test on limestone injection during the off-gas recovery period have proved that the CO gas generated by limestone can be recovered almost completely.

References

1) S. Maebara et al.: *Seitetsu Kenkyu*, (1977) 291, p. 89
2) I. Tanaka et al.: *Tetsu-to-Hagané*, **66** (1980) 4, S229
3) J. Nagai et al.: *ibid.*, **64** (1978) 11, S592
4) M. Kodaka et al.: *ibid.*, **66** (1980) 4, S240
5) T. Tagami et al.: *ibid.*, **68** (1982) 4, S76