Development of the Oxygen Converter Gas Recovery Process (OG Process) and Its Economy*

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I. Background of the Development of OG Process

1. Collection of Oxygen Converter Generated Gas

The development of the oxygen converter process is one of the most creditable technological innovations in the history of the iron and steel industry. As seen in Table 1, the process has achieved a phenomenal progress particularly in Japan. It is, therefore, not too much to say that it constitutes a firm backbone for the prosperity of the iron and steel industry in this country.

The most conspicuous advantages of the oxygen converter process, which greatly attracted the Japanese industry on the way toward the expansion of the equipment, are low operation expenses due to high productivity, and low cost of construction as compared with the open hearth process which formerly was the major, prevailing steelmaking method.

It is, however, inevitable in this newly developed process utilizing much pure oxygen that a large volume of high calory waste gas is produced containing particles of iron oxide. And accordingly, to cope with this problem, it became necessary to construct huge waste heat recovery boilers and dust collectors at staggering expenses.

Table 1. Oxygen converters in the world
(Unit : 1,000 tons)

	Oxygen converters started operation by 1962		Oxygen converters scheduled to start operation by 1965	
	Annual capacity (t)	No. of oxygen converters	Annual capacity (t)	No. of oxygen converters
Austria	1,790	7	1,790	7
Belgium	1,900	5	3,890	11
Brazil	1,980	8	2,280	13
Canada	1,720	7	1,720	7
France	—	5	—	21
Italy	550	1	4,200	6
Japan	10,480	24	17,970	39
The Netherlands	2,650	5	2,650	5
U.S.S.R.	2,300	7	12,350	21
England	3,930	11	3,930	11
U.S.A.	11,510	22	12,510	24
West Germany	4,950	17	13,110	32
Others	3,230	17	7,640	31

(Tekko Kai Ho, No. 641, September 1, 1963)

2. Problems in Conventional Process

The conventional process, namely the process of complete combustion of waste gas at the top of the converter, utilization of waste heat in the boiler, and finally the performance of dust collection, has the following problems.

(1) High calories produced during refining are

estimated at approx. 245,000 kcal/t steel, that is, the 130-ton converter generates approximately 32,000,000 kcal/heat.

(2) Large volume of waste gas:

Since the generated gas whose main constituent is carbon monoxide is burned with the air at the top of the converter, the 130-ton converter generates a stupendous amount of waste gas, reaching approximately 342,000 m³/heat (1,850°C).

(3) Variation of the amount of generated gas and its calories:

The gas and its calories are generated intermittently and accordingly their amounts vary forming peaks, because the operation of the converter is performed intermittently.

(4) Huge dust collector:

As the dust particles generated are extremely minute and moreover the volume of gas is enormous, a huge dust collector is required.

(5) Necessity of tall structure:

When the waste heat boiler is installed, the 130-ton converter requires a structure for this purpose approximately 50 meter high which will be the highest building in the works.

(6) Low energy recovering efficiency:

Energy recovery is now being performed only at an extremely low rate because of the aforementioned reasons, particularly for the reason that the operation is made intermittently. That is, although the thermal efficiency of boilers for power generation and for general purposes as well is more than 85 per cent, that of the waste heat boiler is 60 per cent.

3. Necessity of Oxygen Converter Gas Recovery

Along with the trend toward a larger oxygen converter, it is quite apparent that conventional waste heat boiler is not economical.

If the generated gas is recovered in the unburned state, it is theoretically possible to lower the gas temperature to 1,250°C, to decrease the amount of gas volume to about one sixth, i.e., to 59,500 m³/heat, and to hold the sensible heat within one sixth, namely to 5,700,000 kcal/heat. Consequently the recovering equipment can be designed to be very compact.

Meanwhile, recovered gas can be utilized as fuel, as the occasion demands. Also due to the high content of 80% CO, the gas may be utilized as a raw material for the organic chemical industry. In the light of such conditions, it is natural to consider the realization of these merits of the gas recovery process. However, the development of devices which enable the separa-

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tion of CO rich gas from the atmosphere and ensure the prevention of explosion was not easily solved. Therefore no iron and steel company in the world has succeeded in the practical adoption of this concept.

II. Development of OG Process

1. Start of Joint Research on OG Process

Since Yawata Iron & Steel Co. finished the construction of the Kukioka LD plant equipped with conventional waste gas equipments in 1957, this company fully recognized the merits of the unburned gas recovery and started to examine the possible measures of solving this question. Meanwhile, Yokoyama Engineering Co., Ltd., after an examination of the same problem from the standpoint of a boiler manufacturer, also came up with a concrete idea for gas recovery. However, as there were many problems to be solved before hand, both companies agreed to make a joint research for the development of the OG process.

2. Organization and Assignment of Joint Research

Besides the knowledge about the engineering of the converter and its operation, it was essential to have various other knowledge about the nature of the gas, heat exchange, dust collection, and so on for this development. Having headquarters in the Technical Department of the Head Office of Yawata Iron & Steel Co., Ltd., the engineers from both companies formed the OG committee in October, 1959, through which it decided to jointly push forward an organized research with all efforts for this development. The term “OG” stands for “Oxygen Converter Gas Recovery”. The title of the Committee, “OG”, was later adopted as the designation for this process.

The tasks of the OG Committee were the examination of intermediate results of research and the steering of the planning and performing of the joint research, with the view of adding a theoretical examination particularly to the study of the problems pertaining to perfect prevention of explosions. The Committee arranged to receive special guidance from Kiroku Yamazaki, professor at Tokyo University, and Rempei Goto, professor at Kyoto University, both of whom are authorities in this field.

In addition, since this process naturally requires adoption of high-precision meters, the meters themselves are required to be high and advanced in performance; accordingly, we acquired the participation of the Fuji Electric Mfg. Co., Ltd. in this project a little after the formation of the Committee, which resulted in a vigorous pursuit in this field.

3. Fundamental Research

The basic aim of the research and development is to

completely recover hot gas principally containing carbon monoxide generated from the oxygen converter, by tightly sealing the outlet of the converter to prevent the hot gas from making contact with the external air, subsequently cooling the gas in the unburned state, and by removing dust from the gas by means of a series of dust collectors. The principal part of the method which was to be adopted for this purpose consisted in the sealing of the outlet of a converter for keeping apart combustible hot CO gas from the external air by forming around it an inactive gas curtain of nitrogen, which is available from the waste gas of the oxygen generator for the converter plant. However, the realization of this method could be conceivable only after solving many problems, of which some of the most important are as follows:

(1) A method of forming an effective curtain of nitrogen gas around the top of the converter.

(2) A method of preventing air from entering the converter by tightly sealing the opening of the oxygen blowing lance of the converter and the fluxing material feeding hopper.

(3) Accurate control of the converter gas pressure, especially the pressure at the outlet of the converter, grasping the dynamic characteristics of the whole recovery system.

(4) Particularly, as important measures for prevention of gas explosions:

i. Making the relation between gas combustion and gas composition clear, especially deciding the tolerance limits of hydrogen and oxygen

ii. Relation between gas flame propagation velocity, and gas flowing velocity.

iii. Solution of the problem of how to develop a method of quickly discharging or absorbing energy in case a sudden combustion of gas in the gas recovery system takes place.

iv. Designing of a proper gas circuit throughout the gas recovery system to avoid the danger of a gas combustion.

(5) Adoption of an automatic control and perfect sequence.

(6) Development of an oxygen analyzer which is capable of making a quick response to any irregularity in the oxygen gas recovery system.

Needless to say, most of these problems could not be solved without basic, theoretical study and tests. The problems were solved consecutively by performing successful tests, using a pilot plant.

As to the pilot plant, a hermetically-sealed waste gas discharger for the discharging of waste gas in the unburned state was already being used at the 200-kg LD test converter in the Technical Research Institute of Yawata Iron & Steel Co., Ltd. It was, however, small and unsuitable as a preparatory test plant for

future designing and building of a large-type converter plant with OG equipment.

An OG test plant having a 2-ton converter was installed in the 3rd Steel Making Plant, Yawata Works for the purpose of performing various experiments. An outline of the plant is shown in Fig. 1. The hot metal discharged from the special small mixer is further led into the tilted converter by opening the nozzle at the bottom of the pan. At the top of the converter was installed the movable hood which had the gas curtain forming mechanism. The hood was provided with a lance sealing device and the fluxing material feeding device. The gas passes the hood, gas cooler and the dust collector, and is led by the blower, through the three-way valve, either to the tank or to the stack. The hood pressure can be be controlled automatically

only by operating the damper.

By using the 2-ton test converter, the following tests, survey and analysis were carried out.

- (1) Purge test
- (2) Blowing test
- (3) Tests on the three way valve and the gas holder
- (4) Test on the dust collector
- (5) Survey of the characteristics of dust collected
- (6) Gas analysis

Given below is a brief description of each of the tests.

(1) Purge Test

With a view to reducing the amount of oxygen present in each part of the gas recovery plant to below the explosion limit given in Fig. 2 at the time when

Fig. 1.
Schematic diagram of a 2-ton test converter

Fig. 2. Effect of N_2 dilution in early stage of blowing

the blowing of oxygen into the converter was started, the purging method utilizing nitrogen was adopted. Purging time and amount of nitrogen required at the early and last stage of blowing were obtained; that is, we were able to obtain the standard. A short purging time has no influence upon adequate steel-making efficiency and only a small amount of nitrogen gas is required to perform the work at a very low expense.

(2) Blowing Test

The blowing test aimed at ascertaining safety from an explosion and permitting a discussion on the subject of a converter internal pressure control system. With regard to the prevention of explosions, we conducted examinations and tests by taking into consideration all the possible cases as follows, and determined that the process was thoroughly safe.

- (i) Entrance of the gate sealing water into the converter due to sudden change of oxygen pressure.
- (ii) Abnormal reaction inside the converter.
- (iii) Shocks at the time of additionally feeding fluxing material into the converter.
- (iv) Electric power-off.
- (v) Explosion of coke dust at the time of preheating the converter lining.
- (vi) Closing of the flue.
- (vii) Partial omission of purge.
- (viii) Failure of gas curtain.

The discussions on the hood pressure, while referring to the results of the aforementioned fundamental research on gas curtain, focused on how to grasp the dynamic characteristic of this equipment by means

of various kinds of meters. As a result, we confirmed that, even if the damper control system was adopted at the inlet of the induced draft fan, the meter made a quick response to any variation of hood pressure by selecting the dust collector of sufficient low pressure loss, and thus achieving the aim of control of hood pressure.

(3) Tests on the Change-Over Valve and the Gas Holder

The three-way change-over valve discharges into the air the gas containing a low amount of carbon monoxide generated at the early and last stage of blowing. This was essential for recovering the CO rich gas from the middle stage and storing it in the gas holder, for further utilization. However, it was made clear that there would be a necessity to check the change of gas pressure and flow at various points in the equipment at the shifting operation of the three way valve for ascertaining a practical utility of this equipment, and, at the same time, by preventing a sudden change in static pressure in the circuit after the induced draft fan.

(4) Dust Collector

Regarding the dust collector, various discussions were also made on the use of combined dry- and wet-type dust collectors. As a result, it was found that some dust collections proved to be unsuitable for the automatic control system of the converter due to great loss of internal pressure. Some were not desirable on account of the dust deposits on the inner wall of the collector and because of the low dust-collecting efficiency. Consequently, we gave up using the dry-type dust collector, and decided to adopt the spray dust collector and the venturi scrubber. Thus, we obtained an increased dust collecting efficiency by using this equipment.

(5) Survey of the Characteristics of Dust Collected

During the blowing test, we surveyed the variation of the amount of dust caused by lapse of blowing time, and also made examinations of the particle size, distribution, composition and magnetism of dust collected by the dust collector.

(6) Gas Analysis

Continual inspection of the gas composition with the lapse of blowing time gives the most effective measure for the assumption of oxygen blowing conditions as well as an indication for varied operations such as selection of gas recovery time and purge. Particularly in the OG process, it was considered difficult to discern the blowing conditions by the flame, since the top of the converter was sealed tight-

ly; and therefore continuous gas analysis was particularly important.

There was no special problem with the continuous carbon monoxide and carbon dioxide analyzers. However, we tried to place exceptional emphasis on the development of continuous oxygen and quick analyzers for the prevention of explosions. In the development, Fuji Electric Mfg. Co., Ltd. made energetic research, successfully developing a continuous oxygen analyzer, designed so as to make quick response to slight change in the amount of oxygen being blown in.

For the future utilization of recovered gas as raw materials in the organic chemical industry, we also made an analysis of the amounts of nitride, sulfide and phosphide contained in the recovered gas.

4. Results at Test Plant

As a result of the study on the equipment and development of operating technique, the OG process at the test plant proved superior and safe fully showing the possibility of the adoption of the OG process to a converter in practical use.

The pilot plant tests took about one year and four months, during which we performed more than 200 blowing tests.

III. Practical Use of OG Process

As a result of various basic tests described in chapter II, we were able to determine by October, 1960 that the OG process would be successful both in principle and in practical use.

At that time, the Tobata No. 2 LD converter plant construction program was in its final stage, and we were pressed to decide which we would adopt for disposing of waste gas, the waste heat boiler as before or the OG process. However, after discussions made on the basis of tests at the pilot plant, the merits of the plant in the case of application at the Tobata No. 2 LD converter, general problems, the world trend, and so on, the adoption of the OG process at the Tobata No. 2 LD converter plant was decided upon in November, 1960.

For about one year after the decision to employ the OG equipment, we made discussions principally on the following matters.

(1) Detailed specifications of the 130-ton converter OG equipment.

(2) Tests by the pilot plant to acquire technical know-how necessary for the operation of the 130-ton converter.

Particularly these problems about the shifting operation of the three-way valve, the recovery of gas, the effect of the curtain formed around the top of the

converter, and the suitability of the dust collector.

(3) The control system of the OG equipment (hood pressure control, diluting amount and time, and order of sequence control).

(4) Explosion proofing mechanism.

(5) Elimination of danger, countermeasures against poisoning emergency, electric power off.

Thus, the construction of the plant was started in November, 1960, its test operation being made in accordance with the following since January, 1962.

- i. 1st test run (individual test run): from January 4, 1962 to February 6, 1962
- ii. 2nd test run (combination test run or cold test run): from February 4, 1962 to March 6, 1962
- iii. 3rd test run (hot run test): from March 9, 1962 to the end of April, 1962

A part of the 3rd test run and various kinds of tests made on the OG equipment were conducted in parallel with production; and in June, we performed the gas recovery operation, completing the test run.

The fact that no accident or trouble occurred through these test runs until the equipment successfully started practical operation is considered to be fully indicative of the safety of this process.

Table 2 gives a calendar of progress since the start of the OG Committee until the success of the test run with the OG equipment at the Tobata No. 2 LD converter plant.

Fig. 3 shows a sectional view of the Tobata No. 2 LD converter plant, while Fig. 4 gives a general layout of the OG process. The 1,250°C gas generated passes, in the unburned state, the hood part ③ gas cooler ⑧ and the 1st ⑨ and the 2nd dust collector ⑪ in which it is effectively cooled and dust in it is collected during passage. The gas temperature at the outlet of the induced draft fan ⑭ measures as low as 30°–50°C. As the CO content of gas is low at the early and the last stage of blowing, it is discharged into the atmosphere through the stack ⑰. However, the CO rich gas at the middle stage is recovered and stored in a gas holder ⑱ by shifting three way valve ⑮.

Since the commencement of operations with the OG process on March 9th, 1962, the Tobata No. 2 LD plant has been operating smoothly and continuously as expected, in respect to both working efficiency and safety, and now constantly maintains an output of 119,000 to 125,000 tons per month. The total tapping amount for about eighteen months from the start of operation till the end of August, 1963, has reached 12,141 heats and the steel ingots obtained reached 1,730,000 tons. Of the steel ingots produced, rimmed steel (0.06–0.25%C) for strip accounts for about 95 per cent, and the rest is semi-killed steel. Table 3 gives the operational results of monthly steel-making since the start of operation. As seen in the

table, steelmaking by the LD converter equipped with OG process shows a high yield. This is a great economical advantage of the process.

Also noteworthy is that we conducted gas recovery tests during a 19-day period from June 22 to July 10, 1962, gaining a satisfactory result; and accordingly

we later performed gas recovery as a regular operation. The whole amount of the recovered gas is utilized as fuel for the boiler. Table 4 presents the trend of the results of gas recovering operations performed from June 1962, to August 1963.

The actual results of application of recovered gas

Table 2. Researching and construction of OG equipment in Tobata No. 2 LD converter plant

Year	Research	Plant	Construction	Test run
1959	The OG committee started (Aug.). Held the 1st meeting of the OG Committee (Oct.).			
1960	Launched performance of the plan for designing a larger equipment (Feb.). Started construction of the 2-ton test equipment (June). Started the tests of the pilot plant (Aug.); discussions on leak test, purge test, safety operation, attaining of technique for operation & other necessary conditions for blowing, amount of gas, composition of gas, etc. (Aug.).	Decided adoption of the OG equipment (Nov.). The OG Research Group was formed (Dec.).	Began pile driving for constructing the structure of No. 2 LD converter plant (Nov.).	
1961	Tests on the forming of N ₂ curtain & the curtain of hood pressure control by using models. Tests on the three-way valve, change-over valve, gas holder & dust collector. Analysis of gas.	Decided installation of the soot blower (Apr.). Decided installation of the screen (May). Made the final specifications of the dust collector (Sept.).	Started assembling of the structure for the No. 2 LD converter plant (Mar.). Started assembling of the OG equipment (Sept.). Completed independent boiler (Dec.).	Prepared test run procedure (Oct.).
1962			Completed installation of the converter body; completed the OG equipment & oxygen gas holder (Jan.). Completed the N ₂ holder, sludge disposer, cooling tower & the 4th oxygen generator (Feb.). Completed the 5th oxygen generator (June).	Started test run (Jan.). Started hot run test (Mar.). No. 2 LD converter plant opened (Apr.). Succeeded in gas recovery (June).

Fig. 3. Sectional view of Tobata No. 2 LD converter plant

Table 3. Operational results of steelmaking

Date	Number of heat	Good ingot (t/m)	Good ingot per heat (t/heat)	Produce- tion rate (t/h)	Charging amount						Tap to tap			Yield**		Yield***		O ₂ con- sump- tion (Nmm ³ /t)	N ₂ con- sump- tion (Nmm ³ /t)
					Hot metal (t/heat)	Cold pig (t/heat)	Scrap (t/heat)	Total charged metal (t/heat)	Pig ratio (%)	Charg- ing (min)	Blow- ing (min)	Tapp- ing (min)	Charge to tap (min)	Molten steel (%)	Good ingot (%)	Molten steel (%)	Good ingot (%)		
1962, 3	58	6,906	119.1	119.4	108.4		26.7	135.1	80.3	9.0	27.0	3.6	58.2	90.0	88.4	88.8	87.1	59.5	79.8
4	340	44,209	130.0	143.5	112.0		31.7	143.1	77.9	10.2	28.2	2.8	55.2	91.5	90.5	91.4	89.5	58.7	91.3
5	532	73,116	137.4	152.9	113.2		37.1	150.3	75.3	10.0	27.9	3.8	53.6	92.3	91.4	91.5	90.0	55.7	70.0
6	548	78,151	142.6	163.4	118.9		36.4	155.3	76.6	10.0	28.0	3.6	53.8	92.6	91.7	91.5	89.9	53.8	66.9
7	494	68,826	159.3	170.0	114.9		36.7	151.6	75.8	8.0	27.9	3.6	49.7	92.7	91.9	91.6	90.1	54.8	61.3
8	691	97,471	141.1	191.8	116.7		37.0	153.7	75.8	6.5	24.4	3.6	44.5	92.6	91.8	91.9	90.3	53.4	53.8
9	768	108,213	140.9	198.4	114.8		38.0	152.8	75.1	6.1	23.8	3.7	42.7	92.8	92.2	92.0	90.6	54.4	46.3
10	751	105,909	141.0	197.8	114.9		38.1	153.0	75.1	6.1	23.2	4.0	42.9	92.8	92.1	91.8	90.4	54.8	44.3
11	759	110,871	146.1	207.1	119.0		40.6	159.6	74.6	6.4	22.7	4.1	42.5	92.3	91.6	91.8	90.5	53.9	45.1
12	776	112,577	145.1	199.3	119.0	1.6	37.7	158.3	76.2	6.4	22.7	4.0	43.3	92.5	91.6	92.0	91.0	54.9	45.0
1963, 1	815	110,986	136.2	194.8	111.4	4.9	29.8	146.1	79.7	6.4	21.5	3.9	41.9	93.7	93.2	92.5	91.5	55.2	44.3
2	766	107,816	140.8	201.1	111.7	5.5	32.6	149.8	78.2	6.0	22.7	3.9	41.9	94.3	94.0	93.3	92.1	52.4	40.5
3	838	119,835	142.9	201.9	114.7	5.9	32.1	152.7	79.0	6.0	23.6	3.9	42.5	94.2	93.7	92.5	92.0	52.6	40.3
4	791	114,736	145.1	200.8	117.1	7.3	29.1	154.1	80.8	6.0	23.6	4.0	43.5	94.7	94.2	92.8	91.7	53.9	37.1
5	807	118,269	146.6	197.3	120.4	9.1	26.4	155.0	83.1	6.0	24.2	4.0	44.6	94.7	94.0	92.8	91.4	51.6	36.8
6	812	118,690	146.2	199.9	123.2	6.8	25.3	155.4	83.7	6.0	23.9	3.9	44.0	94.8	94.1	92.0	91.3	51.3	38.6
7	838	127,279	151.9	199.2	127.1	10.5	31.9	169.5	84.7	6.3	25.9	4.0	46.0	94.5	93.8	92.9	92.2	51.7	37.7
8	757	113,003	149.3	192.2	122.5	10.0	27.9	160.4	82.6	6.1	26.0	3.9	46.6	93.7	92.9	91.7	91.0	53.8	39.8

* good ingot (t) charge to tap (hr) ** molten steel or ingot pig+scrap *** molten steel or ingot pig+scrap + ferro-alloy + (0.65×mill-scale)

to a general boiler are shown in Table 5. This general boiler is now in use to supply 30 to 40 per cent of all the general steam to be used in Tobata Works.

Table 6 and Fig. 5 show the gas composition from the start to the end of blowing. In this case, only the CO rich gas is sent to the gas recovering equipment. At the early and last stage of blowing, the gas is diluted with nitrogen gas in order to prevent any big change in the flow of waste gas and also to assure safe operation by holding the composition of waste gas outside the explosion range.

Tables 7 and 8 give the dust collecting efficiency and the chemical composition of recovered gas at the Wakayama Works of Sumitomo Metal Industries, Ltd. which was the second company in Japan after Yawata to install and use OG equipment. The outstanding feature in the OG equipment is the dust as compared with dust in the case of waste heat boilers. The gas contains much FeO and metallic Fe which are less liable to oxidation because of the atmosphere in the flue. The dust particles are considerably large in diameter and greater in specific gravity, compared with

Fig. 4. General layout of OG process at Tobata No. 2 LD converter plant

Table 4. Monthly performance of gas recovery

Date	(A) Number of heats	(B) Number of gas recovered heats	(C) Total gas recovered (m ³)	(B/A×100) Recovery rate (%)	(C/B) Recovered gas amount per heat (m ³ /heat)	Recovered gas amount per ingot* (m ³ /t-ingot)	Average CO of recovered gas (%)	Average blowing time (min/heat)	Average recovering time (min/heat)	Remarks
1962 6	548	6	42,000	1.1	7,000	47.6	68.9	28.0	12.7	Gas recovery test
7	494	5	30,400	1.0	6,180	56.2	66.1	27.9	12.2	Gas recovery test
8	691	155	828,000	22.4	5,347	37.1	74.4	24.4	9.4	{Boiler combustion test (Aug. 11-13, 25-28)}
9	768	332	1,825,000	43.2	5,497	39.8	79.4	23.8	11.2	
10	751	621	3,688,300	2.7	5,939	45.2	72.4	23.2	12.1	
11	759	700	5,917,750	92.3	8,458	57.4	73.4	22.7	12.7	
12	776	644	5,099,600	83.8	7,858	53.9	72.5	22.7	13.0	
1963 1	815	674	4,512,200	82.8	6,695	49.2	72.4	21.5	12.8	
2	766	698	5,094,200	91.1	7,298	50.9	71.7	22.7	14.4	
3	838	780	6,611,760	93.6	7,843	54.9	70.4	23.6	14.6	
4	791	771	5,879,300	97.5	7,626	52.5	70.8	23.6	13.4	
5	807	723	5,933,200	89.6	8,210	55.8	72.8	24.2	15.0	
6	812	723	5,214,100	96.2	6,680	45.5	74.2	23.9	11.9	
7	838	717	4,461,600	85.6	6,220	45.6	73.5	25.9	11.9	
8	757	711	4,514,900	94.0	6,350	47.9	71.5	26.0	11.6	

* Only for gas recovered heats.

Table 5. Results of OG gas utilization for boilers

Date	Quantity of steam evaporated (t/h)	Total boiler working hour (h/m)	No. of boilers	Fuel consumption		OG gas using rate* (%)	Boiler efficiency (%)	Calorific value of OG gas (kcal/Nm ³)	
				OG gas (m ³ /h)	Fuel oil (kl/h)				
1962	10	26.8	689	1	5,350	0.752	63.3	85.5	2,280
	11	44.6	1,265	2	9,350	1.104	67.0	85.0	2,250
	12	47.0	1,223	2	8,330	1.600	55.2	84.0	2,220
1963	1	50.6	1,301	2	6,930	2.260	42.1	83.6	2,230
	2	48.4	1,344	2	7,570	1.916	48.0	84.8	2,200
	3	38.9	1,216	2	8,550	0.900	6.6	86.5	2,190
	4	28.4	906	1	8,320	0.202	89.9	86.2	2,180
	5	32.9	1,488	2	7,510	0.662	72.6	85.5	2,250
	6	27.5	816	1	7,430	0.313	83.9	86.7	2,270
	7	27.3	747	1	6,640	0.151	90.5	86.3	2,280
	8	27.0	740	1	6,350	0.236	79.0	83.0	2,210

* OG gas using rate (%) was calculated on the basis of calorific value.

Table 6. Change of converter gas composition (N-2789 Tobata)

Elapsing of blowing time (min)	CO ₂ (%)	O ₂ (%)	CO (%)	H ₂ (%)	N ₂ (%)	Calorific value (kcal/Nm ³)
2	18.4	0	26.6	1.0	54.0	830
4	19.6	0.3	43.4	1.8	34.4	1,380
6	23.3	0.1	69.6	1.1	5.9	2,140
8	21.3	0.2	73.3	1.0	4.2	2,250
10	17.2	0.4	78.0	1.1	3.3	2,400
12	13.4	0.3	81.5	1.1	3.7	2,500
14	18.3	0.3	72.9	1.3	1.2	2,250
16	12.4	0.2	81.4	0.9	5.1	2,490
18	11.3	0	82.7	0.9	5.1	2,530
20	9.4	0	85.7	0.9	4.7	2,600
22	7.6	0.2	62.8	0.9	28.5	1,930
24	8.8	0	14.9	0.9	75.4	480

Operational conditions (N-2789)

Furnace life	135 (6th campaign; No. 2 converter)
Skirt distance	0~30 mm
Flow rate of curtain N ₂	7,000 Nm ³ /h
Flow rate of O ₂	17,000 Nm ³ /h
Amount of hot metal	114.1 t
E. Pt (C)	0.05%
Blowing time	23.4 min

those in the case of the waste heat boiler; and accordingly, sufficient dust collecting efficiency is obtainable.

IV. Prospect of OG Process

1. Economy of OG Process

As compared with the conventional waste heat boiler, use of the OG process is markedly economical.

The economical advantages of OG process are as follows :

(1) Advantages in Construction Cost

The total installation cost of OG process, including

Fig. 5. Diagram of N₂ dilution

gas holder and process boiler, is 50 to 60 per cent of that of the waste heat boiler including accumulator, dust collector, and boiler accessories in the converter plant of the same capacity. Further, if the economy in the construction cost of the plant building is considered, the economic difference between these two processes becomes even greater. Fig. 6 shows a comparison of gas cooler sizes of OG equipment and the waste heat boiler. As the vessel becomes larger, economical advantage becomes greater.

(2) Higher Thermal Efficiency

As seen in Fig. 7, the conventional waste heat boiler for the converter has a thermal efficiency of only 60% or less. On the other hand, total thermal efficiency of 70% is obtained when gas is recovered by the OG equipment, and is utilized as a heat source for the process boiler.

(3) Advantages in Steam Supply Adjustment

Because of intermittent blowing of the converter, steam supply from the waste heat boiler fluctuates from

time to time, and accordingly even the boiler with 110 t/hr of peak load, generates on the average only 40 t/hr of steam. According to the fluctuation of steam supply, when the OG process is applied, an appropriate operation becomes possible with the installation of the process boiler as a source of steam supply.

(4) Advantages of Dust Collecting Equipment

As the unburnt gas is directly admitted to the dust collector in the OG process, the volume of the gas is kept one sixth smaller and the size of the dust collector can therefore be smaller.

Further, as the dust is prevented from changing into Fe_2O_3 and kept in a larger particle state with a rich content of FeO , metallic Fe , and Fe_3O_4 , the mechanism of the dust collector and sludge treating equipment can be simplified.

(5) Advantages in Utilizing Recovered Gas

Calorific value of the recovered gas is approximately 2,300 kcal/Nm³. Therefore, recovered gas can well

be used as fuel. Besides, it can conceivably be utilized as raw material in the field of organic chemical synthesis and in iron making.

(6) Balance of N_2

The amount of N_2 to be used for sealing the clearance between the converter mouth and the OG equipment and also for purging space incurvations, etc. is less than about 40 m³/t steel in the case of the Tobata No. 2 LD converter (130-t). This is fully satisfied by utilizing N_2 generated as a by-product at the time of manufacturing pure oxygen.

2. Diversion of Thomas Converter

Along with the progress of the oxygen converter process, there is a tendency that the Thomas converter will be remodeled to an oxygen converter. In this case, however, there will inevitably occur the problem of waste gas and dust disposal; and consequently it may well be considered that the unburned dust collecting and gas recovering systems will be adopted much more widely than the waste heat boiler system.

Table 7. Dust collecting efficiency (Wakayama Works of Sumitomo Metal Industries, Ltd.)

Item		Test No. 1	Test No. 2
Operational conditions	Charging amount (t)	133	133
	Blowing time (min)	22.33	22.30
Dust concentration (g/Nm ³)	At the outlet of cooler	63.7	110.8
	At the outlet of 1st dust collector	4.42	6.83
	At the outlet of I.F.	0.362	0.234
Dust collecting efficiency (%)	1st dust collector	93.2	93.8
	2nd dust collector	91.4	96.6
	Total efficiency	99.43	99.83

Table 8. Dust composition (Wakayama Works of Sumitomo Metal Industries, Ltd.)

(Unit : %)

Part \ Composition	C	SiO ₂	T·Fe	M·Fe	FeO	Fe ₂ O ₃	CaO	MgO	P ₂ O ₅	TiO ₂	Cr ₂ O ₃
Cooler	0.70	1.30	86.17	66.69	21.45	4.01	3.70	tr.	0.36	0.66	0.11
1st dust collector	0.18	1.20	79.09	50.17	36.45	0.84	1.57	tr.	0.34	0.21	0.16
2nd dust collector	0.18	1.25	76.28	22.72	67.20	1.90	1.57	tr.	0.33	0.25	0.16

Table 9. A list of the unburnt converter gas processes

Process	Company	Works	Converter capacity	Gas utilization	Steel ingot obtained (t)	Operation starting period
OG	Yawata Iron & Steel Co., Ltd.	Tobata Works	130-t×2	Fuel	1730,000	Mar. 1962
OG	Sumitomo Metal Industries, Ltd.	Wakayama Works	110-t×2	Fuel	450,000	Feb. 1963
IRSID-CAFL	USINOR	Dunkerque	130-t×2	None	?	Dec. 1962
Krupp	DHHU	Hörde	130-t×2	None	?	May 1963

3. Application of OG Process to LD-AC Process

The LD-AC process presently being developed in Europe is a process of blowing both pure oxygen and lime powder together into the steel bath. Meanwhile,

Fig. 6. Comparison of sizes of gas coolers for 130-t converter

a study for the application of the OG process to the LD-AC process has already been started.

4. Results of Unburnt Converter Gas Process

Being very economical as described above, unburnt converter gas process is currently attracting keen attention of the steel industry in every country. And a few iron and steel plants have already adopted the system. However, none of these process are designed to recover gas, but are of the unburnt discharging type.

Fig. 7. Comparison of thermal efficiency between waste heat boiler and OG process

Therefore, although the gas cooling and dust collecting equipment may be designed compactly, there is no merit of practical utilization of recovered gas. A listing of the unburnt converter gas process, including the OG process, is shown in Table 9.

5. *Export of Technical Know-How*

In Japan, the OG process has already been adopted, by Yawata Iron & Steel Co., Ltd., and the Wakayama Works of Sumitomo Metal Industries, Ltd. In both plants, the process has been performed smoothly attracting the attention of iron and steel machinery manufacturers in many countries abroad. We are now receiving many applications from them for technological tie-ups. Of these foreign manufacturers, DEMAG and BAUMCO of West Germany, VÖEST of Austria, and Loftus Engineering Co. of the U.S.A. concluded agreements for a technical tie-up with the joint group of Yawata Iron & Steel Co., Ltd. and Yokoyama Engineering Co., Ltd. Some others are now negotiating with us for the conclusion of agreements for technical tie-ups. We further expect that some iron and steel plants in Europe and the U.S.A. will adopt the OG process in the near future.

V. *General Review of the Development of OG Process*

We have described the progress of development and industrialization of the OG process. Just as, "Rome was not built in a day", many years and months passed and many people's efforts were expended before the process was successfully industrialized.

To review the major factors of the success of this development, we have to mention that the joint research by many people with the OG Committee as the leader, was performed very smoothly, and achieved great success. Yawata Iron & Steel Co., Ltd. undertook the performance of various tests for the actual adoption of the concept; Yokoyama Engineering Co., Ltd. added discussions and examinations with respect to the equipment as boiler makers; and Fuji Electric Mfg. Co., Ltd., contributed greatly to development of the process by producing high-precision meters. Also to be noted is that, as regards the theoretical foundation on the prevention of explosion, we asked K. Yamazaki, professor of Tokyo University, and R. Goto, professor of Kyoto University to render us their theoretical aid. Research and development in these various fields all together contributed to the bearing of superb fruit.