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Application of Exhaust Gas Recirculation System at Tobata No. 3 Sinter Plant

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Abstract:

After 17 years of operation at the Tobata No. 3 sinter plant, the exhaust gas electrostatic precipitators became markedly obsolescent and declined in dust collection performance, requiring their replacement. In October 1992, an exhaust gas recirculation technology capable of sharply reducing the volume of exhaust gas to be treated and decreasing the consumption of sintering energy was applied. This measure was in consideration of compliance with increasingly stringent environmental regulations and promotion of energy conservation in the future. The technology succeeded in recirculating 25% of the sinter bed exhaust gas and reducing stack emissions by the same degree without appreciable effects on sinter productivity and quality. The 25% reduction in the exhaust gas emissions allowed a lowering in dust collection capacity, resulting in the closure of one electrostatic precipitator.

1. Introduction

Improvements have been made to the sintering process to meet various requirements, such as raising productivity and yield, saving energy and labor, protecting the environment, and recycling resources. Sinter has always exhibited quality and cost advantages as a principal feed material for the blast furnace. In addition, sinter is higher in reducibility than other blast-furnace burden materials, superior in burden distribution controllability, and well suited for blast-furnace operations. Controlling sinter quality and reducing sinter cost by improving sinter manufacturing technology will remain an important issue.

At the Tobata No. 3 sinter plant of Nippon Steel's Yawata Works, actual dust, oxides of sulfur (SO_x), and oxides of nitrogen (NO_x) emissions have changed against emission standards as shown in **Table** 1. Environmental regulations surrounding the sintering process and emission standards are predicted to be tightened further in the future. In particular, dust and NO_x output from the sinter plant will require large-scale equipment innovations. To comply with increasingly tough antipollution laws in the future without detracting from the competitiveness of the sintering process, it is indispensable to sharply reduce the volume of the exhaust gas to be treated.

As a technology expected to be greatly effective in meeting future environmental regulations, an exhaust gas recirculation technology that can substantially decrease the volume of exhaust gas to be treated was applied at the Yawata Works' Tobata No. 3 sinter plant. The equipment outline and operating performance of the exhaust gas recirculation system are reported here.

2. Background for Introduction of Exhaust Gas Recirculation Technology

After 17 years of operation, the Tobata No. 3 sinter plant's exhaust gas electrostatic precipitators became markedly obsoles-

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cent and declined in dust collection performance. As a result, the low-temperature exhaust gas electrostatic precipitators EP (A) and (B) shown in **Fig. 1** had to be replaced. Given increasingly strict global environmental regulations and greater promotion of energy conservation, it was decided to apply the exhaust gas recirculation technology based on the ideas shown in **Fig. 2**. Instead of the conventional method of installing new pollution control equipment, which might increase carbon dioxide emissions and costs, the exhaust gas recirculation technology was introduced to reduce the generation of exhaust gas by an amount corresponding to the capacity of one electrostatic precipitator (300 kNm³/h).

This means that the exhaust gas recirculation technology has lowered the required pollution control capacity, allowed one electrostatic precipitator to be shut down, and helped downsize the pollution control equipment. It is envisaged that the exhaust gas recirculation technology will minimize the equipment investment required for specific pollutants when the environmental regulations are tightened. Efficient reuse of the exhaust gas is expected to concentrate the substances to be treated and improve dust collection efficiency, desulfurization, denitrification and other treatments. The sensible heat of the exhaust gas can also be effectively used in the firing of sinter, contributing to energy savings. Since the work concerned was predicted to take a long period of time for such procedures as installing recirculation hoods, connecting recirculation gas ducts, and partitioning main ducts, it was decided to introduce the exhaust gas recirculation technology during the major repair of the sinter plant, which was scheduled for October 1992.

Table 1 Prediction of environmental regulations for Tobata No. 3 sinter plant

			Measured value before recirculation (Oct. 1991-Sep. 1992)	Regulated value (reported value): Present (with desulfurization)	Regulated value (reported value): Future
Exhaust stack gas characteristics	Exhaust gas emission rate (Nm^3/h)		925×10³	Maximum 1,195×10³ Normal 878×10³	
	Dust	Concentration (mg/Nm^3)	50	Maximum 100 Normal 50	Invisible < 5-10 mg/Nm^3
		Emission rate (kg/h)	46	<83	
	SO_x	Concentration (ppm)	9	Maximum 104 Normal 102	—
		Emission rate (Nm^3/h)	8	Maximum 124 Normal 89 Environmental tax System	
	NO_x	Concentration (ppm)	190 at (O_2=15%)	Maximum 260 Normal 210	For example, maximum < 190 ppm for steelworks situated near cities
		Emission rate (Nm^3/h)		<311	

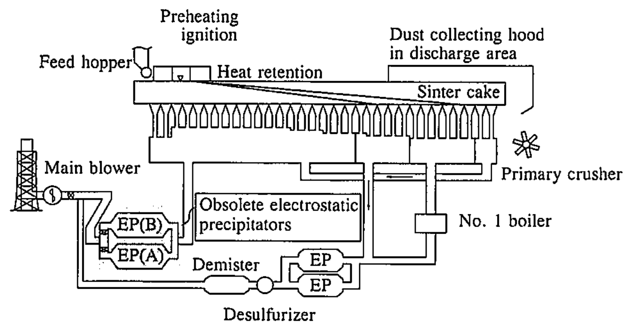


Fig. 1 Layout of exhaust gas system before introduction of exhaust gas recirculation technology

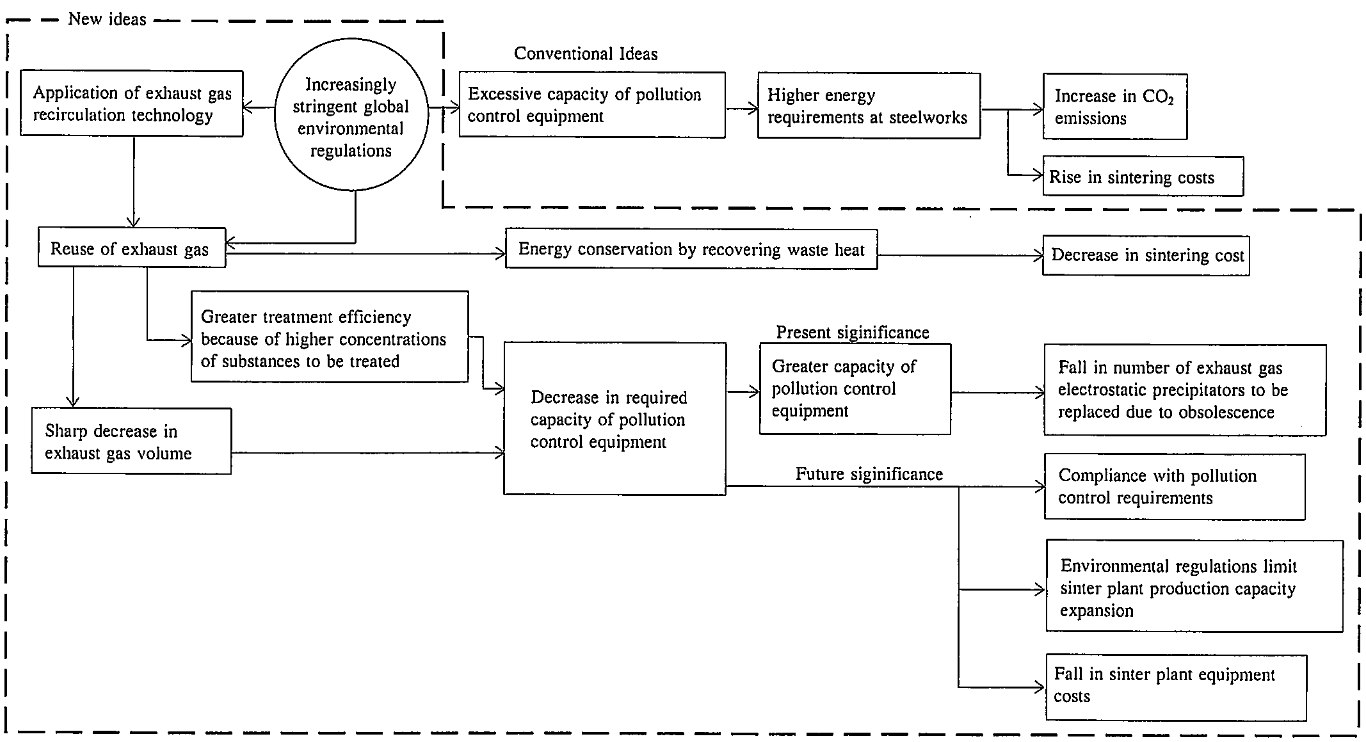


Fig. 2. Ideas behind application of exhaust gas recirculation technology

3. Features of Exhaust Gas Recirculation Technology at Tobata No. 3 Sinter Plant

3.1 Features of exhaust gas system before introduction of exhaust gas recirculation technology

The exhaust gas from a 480-m^2 total suction area is handled by a main blower with a capacity of about 1,000 kNm^3/h (see **Fig. 1**). To reduce desulfurization equipment investment costs, the exhaust gas is drawn in two portions, or low-SO_x (low-temperature) and high-SO_x (high-temperature) concentrations at a ratio of 6:4. The high-SO_x line is equipped with desulfurization equipment. Of the total suction area, 26 m^2 is occupied by a furnace to preheat the raw mix with sinter cooler waste heat before ignition, contributing to productivity improvements and energy savings.

3.2 Exhaust gas reuse (recirculation) concept

The changes in the characteristics of the exhaust gas along the strand length at the Tobata No. 3 sinter plant are shown in **Fig. 3**. The data were measured in the wind legs below the wind boxes and constitute typical patterns. Compared with the exhaust gas from the middle of the sinter strand, the exhaust gas emerging from the charge end after preheating the raw mix is high in oxygen and low in moisture, and the exhaust gas from the discharge end is high in temperature and oxygen and low in moisture. In other words, the exhaust gas from the middle of the sinter strand is comparatively low in temperature and oxygen and high in moisture and, therefore, unsuitable for reuse from a productivity perspective. The following three conditions were taken into account when determining whether the exhaust gas should be reused or recirculated. The first condition was the oxygen content of the recirculation gas. The second was the moisture content of the recirculating gas. The third was limiting the exhaust gas temperature to prevent acid corroding the electrostatic precipitators.

To clarify that the first and second conditions of the sinter bed suction gas would not affect the productivity of the sinter plant, 60-kg pot tests were conducted by changing the oxygen content of the suction gas. The test results are given in **Fig. 4**. As evident from **Fig. 4**, the sintering time as an index of sinter productivity changes little if the exhaust gas oxygen and moisture contents vary between 16% and 10%. Plant tests were conducted using test pieces because the critical temperature for acid corrosion varies with the exhaust gas SO_x content. The plant test results indicated that the maximum electrostatic precipitator inlet temperature must be 100°C for the low-SO_x line and 120°C for the high-SO_x line.

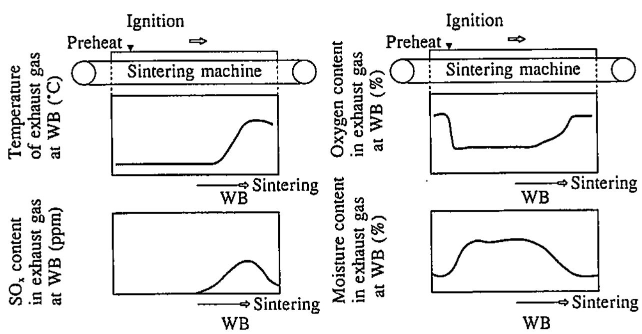


Fig. 3 Changes in exhaust gas properties along sinter strand

A simulation was run to determine the highest possible extent that exhaust gas can be reused under the constraints noted above. The simulation revealed that the exhaust gas can be recirculated at ratios of 5% and 20% at the charge and discharge ends of the sinter strand, respectively. This is due to the maximum utilization of the unused oxygen and low-moisture exhaust gas at the charge end where the raw mix preheating furnace is located and at the discharge end of the sinter strand. As a result, the oxygen content of the recirculating gas is 19.8%, and the moisture content of the recirculating gas ranges from 3.6% in winter to 4.4% in summer. These values pose no problems. The temperature of the exhaust gas at the inlet of the electrostatic precipitator is 105 to 125°C and is equivalent to the critical temperature for electrostatic precipitator acid corrosion. This temperature range governed the setting of the exhaust gas recirculation ratio at 25%.

3.3 Outline of exhaust gas recirculation system

Fig. 5 details the layout of the exhaust gas recirculation lines after the introduction of the exhaust gas recirculation technology. The charge-end recirculation line B1 was provided with a 90-kNm^3/h recirculation blower and a preduster matching the blower capacity and dust properties. The discharge-end recirculation line B2 was provided with a 200-kNm^3/h recirculation blower and a preduster befitting the blower capacity and dust properties. At the sinter strand discharge end, which becomes relatively hot, the exhaust gas was drawn after the ignition of the raw mix so that its

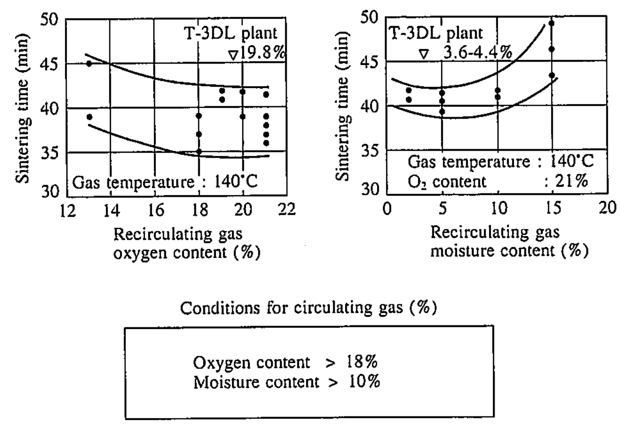


Fig. 4 Recirculating gas conditions required to maintain desired productivity (pot test results)

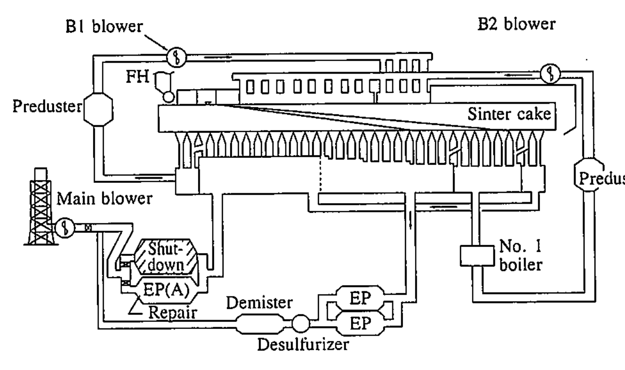


Fig. 5 Layout of exhaust gas system after introduction of exhaust gas recirculation technology

sensible heat could be used to fire the raw mix. After preheating the raw mix, the exhaust gas from the low-temperature charge end was drawn through the middle of the sinter strand. A recirculation hood was installed above the sinter strand to capture the exhaust gas. The partition plates in the main ducts were repositioned to keep the load of the high-temperature and high-SO_x line constant at 400 kNm^3/h and to change the load of the low-temperature and low-SO_x line from 600 to 300 kNm^3/h. Since the exhaust gas volume to be handled decreased, the runner capacity of the main blower was reduced from 1,000 to 740 kNm^3/h capacity, and the 300-kNm^3/h electrostatic precipitator EP (B) was shut down.

The features of the exhaust gas recirculation system introduced at the Tobata No. 3 sinter plant may be summarized as follows:

(1)The unused oxygen at the charge end of the sinter strand where the sinter mix was preheated and at the discharge end of the sinter strand was utilized to the greatest possible extent. The exhaust gas recirculation ratio was raised to 25%.

(2)The exhaust gas from the sinter strand was drawn in four different positions to achieve a high-efficiency exhaust gas treatment system.

4. Comparison of Operating Performance before and after Introduction of Exhaust Gas Recirculation Technology

4.1 Changes in exhaust gas properties during sintering

4.1.1 Exhaust gas temperature

The exhaust gas temperature in each wind leg during sintering was greater after introducing the exhaust gas recirculation technology, as shown in **Fig. 6**. Particularly in the latter half of the sinter strand, the exhaust gas temperature rose, and the high-temperature range expanded. This may be explained as follows. The temperature of the recirculating gas drawn into line B2 from the first half of the sinter strand was about 170°C. The sensible heat of the gas slowed the cooling rate of the red-hot zone in the sinter bed and caused heat accumulation in the lower part of the sinter bed. This phenomenon signifies an extension of the time when the sinter cake is held at high temperatures. This in turn increases the shatter index (SI) of the sinter.

4.1.2 Exhaust gas moisture content

The exhaust gas moisture content levels measured along the sinter strand before and after the introduction of the exhaust gas recirculation technology are shown in **Fig. 7**. The data measured before the introduction of the exhaust gas recirculation technology showed some variability, but the data measured after the introduction changed as originally expected. With the new exhaust gas recirculation technology, when the gas drawn into the sinter bend became relatively high in moisture, the moisture emission pattern did not appreciably differ from that for the previous technology. It is therefore obvious that recirculation did not concentrate the moisture of the recirculating gas in line B2. As a result, the exhaust gas moisture content was about 3.6% in line B1 and about 2.4% in line B2. These data may be taken to mean that the moisture content has little or no effect on the operating range of the exhaust gas recirculation system.

4.1.3 Exhaust gas SO_x content

The exhaust gas SO_x content levels measured during the progress of sintering before and after the introduction of the exhaust gas recirculation technology are shown in **Fig. 8**. These SO_x distribution patterns may be explained as follows. When the SO_x contained in the drawn gas passed through the sinter bed, it accumulated in the sinter bed's red-hot zone and dry zones. When the SO_x reached near the bottom layer of the sinter bed as sintering progressed, it was expelled. The recirculation of the exhaust gas moved the SO_x emission start positions three to five wind boxes ahead, raised the maximum SO_x concentration, and accentuated the SO_x concentrated emission tendency. As a result, the exhaust gas drawn through No. 26 to No. 31 wind legs into line B2 relatively decreased in SO_x content. The exhaust gas drawn

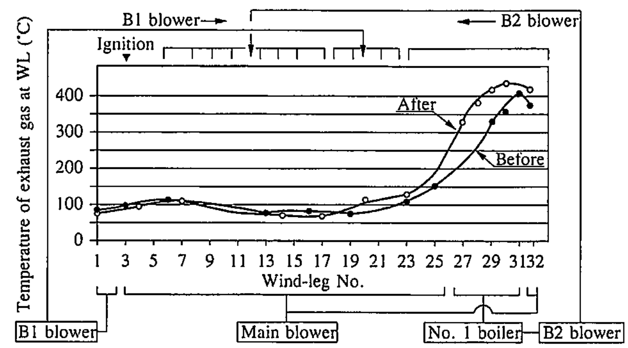


Fig. 6 Temperature distributions along sinter strand before and after introduction of exhaust gas recirculation technology

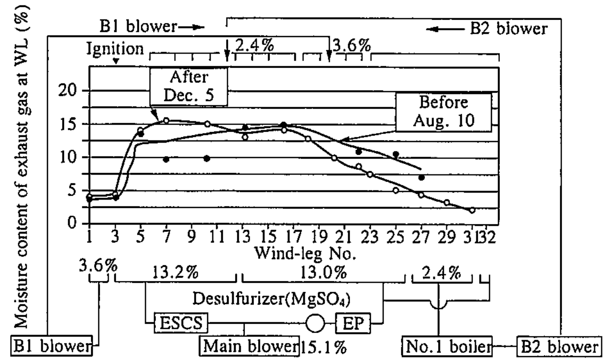


Fig. 7 Moisture distributions along sinter strand before and after introduction of exhaust gas recirculation technology

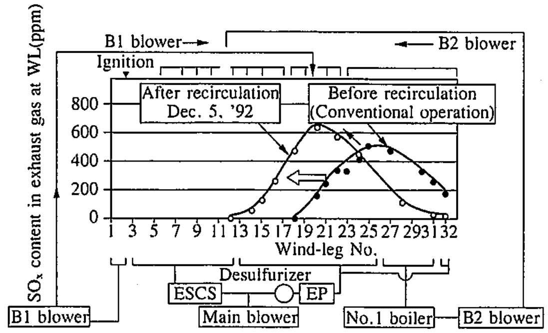


Fig. 8 SO_x distributions along sinter strand before and after introduction of exhaust gas recirculation technology

through the last No. 32 wind leg by the main blower to ensure the desired exhaust gas temperature also decreased in SO_x content. The concentration of SO_x emissions after recirculation is considered to have reduced the SO_x emissions from the stack and improved the overall desulfurization ratio. This was achieved without any additional equipment at the Tobata No. 3 sinter plant, where partial desulfurization is undertaken.

4.2 Changes in sintering operation data

4.2.1 Sintering energy consumption

Fig. 9 details the operating data of the plant before and after its major repairs during which the exhaust gas recirculation system was installed. Since the major repairs, the exhaust gas recirculation ratio (volume of recirculated air/volume of air drawn through the sinter bed) has hovered around 25%, and the plant has continued to operate smoothly and has met the blast furnace sinter requirements. The stack gas emissions decreased by an amount corresponding to the exhaust gas recirculation ratio. This made it possible to close one electrostatic precipitator.

The changes in the operating performance data for the Tobata No. 3 sinter plant before and after the new technology are summarized in **Table 2**. The energy required to fire the raw sinter mix was successfully reduced from about 1,500 to about 1,400 MJ/t-sinter. The total energy consumption, including electric power consumption and steam production from recovered waste energy, was lowered from 1,662 to 1,570 MJ/t-sinter.

4.2.2 Sinter quality

The time when the upper layer of the sinter cake was held at high temperatures was prolonged by the sensible heat of the recirculated gas. As a result, the sinter improved by about 0.5 in SI, but changed little in reduction degradation index (RDI).

4.2.3 Sinter yield

The sinter yield distributions in the top, middle, and bottom layers of the sinter bed before and after the introduction of the exhaust gas recirculation technology are shown in **Fig. 10**. Immediately after the installation of the new technology, the sinter yield rose in the middle layer but fell in the lower layer of the sinter bed. The porosity distributions in the sinter bed height direction before and after the new technology are shown in **Fig. 11**. The exhaust gas recirculation did not appreciably change the +5-mm porosity in the top and middle layers, but reduced the +5-mm porosity in the lower layer by about 20%. One probable cause was the decrease in the balling tendency of the low-moisture raw mix, which was employed as a corrective measure against excessive moisture condensation in the sinter bed's wet zone. After exhaust gas recirculation, the moisture condensation in the wet zone increased by only about 1%, and it was confirmed that no abnormal moisture condensation occurred in the wet zone. To promote the granulation of the raw mix, the moisture content of the raw mix was returned to the original level before the exhaust gas recirculation technology was installed. As shown in **Fig. 12**, this improved sinter bed permeability, raised the yield in the lower layer, and increased the product yield.

5. Conclusions

The major benefits derived from undertaking exhaust gas recirculation at the Tobata No. 3 sinter plant may be summarized as follows:

(1)The exhaust gas volume (or volume of exhaust gas emitted from the stack) was successfully reduced to an amount corresponding to an exhaust gas recirculation ratio of 25 to 28%.

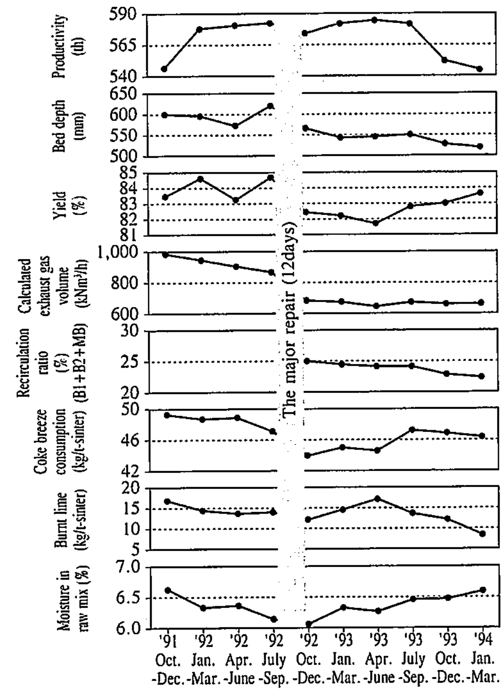


Fig. 9 (a)Changes in operating data

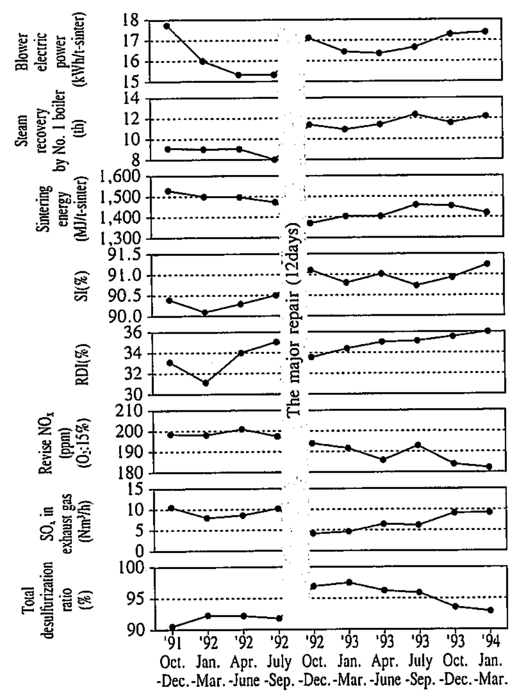


Fig. 9 (b)Changes in operating data

Table 2 Comparison of operating performance before and after introduction of exhaust gas recirculation technology

			Actual performance: Before recirculation (Oct. '91-Sep. '92)	Actual performance: After recirculation (Oct. '92-Jun. '93)	Improvement ratio %
Exhaust stack gas characteristics	Exhaust gas emission rate (Nm^3/h)		925×10^3	665×10^3	▽28
	Dust	Concentration (mg/Nm^3)	50	30	▽56
		Emission rate (kg/h)	46	20	
	SO_x	Concentration (ppm)	9	5	▽63
		Emission rate (Nm^3/h)	8	3	
	NO_x	Concentration (ppm)	199 (at:O_2=15%)	199 (at:O_2=15%)	▽ 3
		Emission rate (Nm^3/h)	179 (at:O_2=act)	173 (at:O_2=act)	
Energy savings (MJ/t-sinter)	Sintering energy		1,498	1,400	▽ 7
	Total energy consumption		1,662	1,570	▽ 6

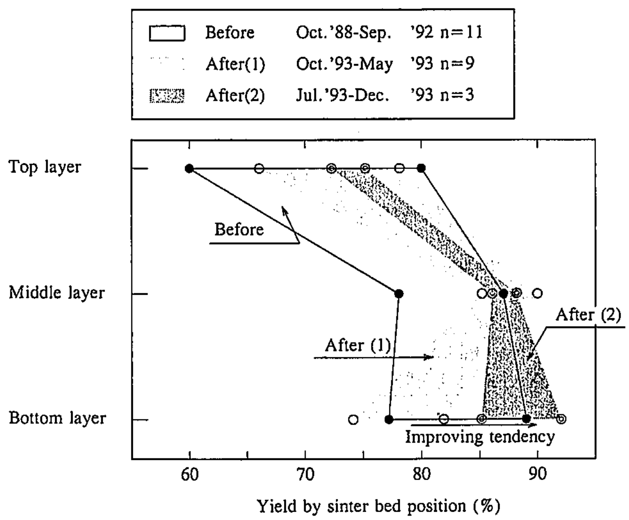


Fig. 10 Yield distributions in sinter bed depth direction before and after introduction of exhaust gas recirculation technology

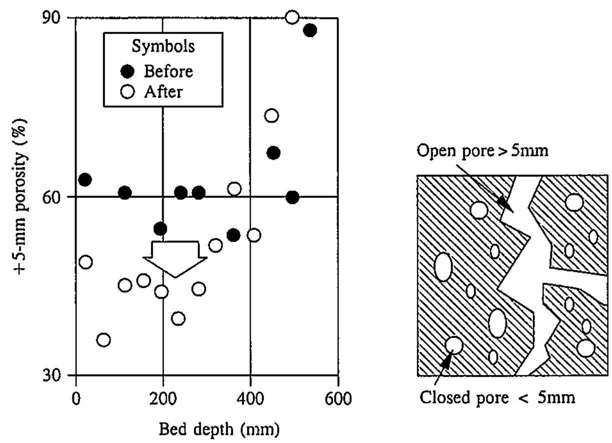
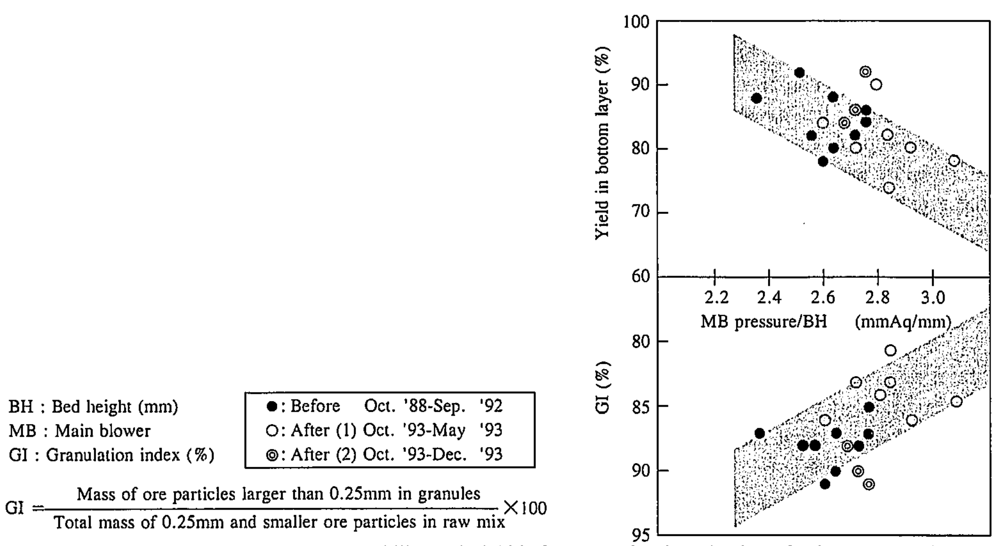


Fig. 11 Porosity distributions in sinter bed depth direction before and after introduction of exhaust gas recirculation technology



$$GI = \frac{\text{Mass of ore particles larger than 0.25mm in granules}}{\text{Total mass of 0.25mm and smaller ore particles in raw mix}} \times 100$$

Fig. 12 Relationship between sinter bed permeability and yield before and after introduction of exhaust gas recirculation technology

(2)The dust and SO_x emissions from the stack were sharply cut.

(3)The SI of the product sinter improved.

(4)The energy required for firing the raw sinter mix was reduced.

It was also established that ensuring appropriate permeability in the bottom layer of the sinter bed is extremely important in improving the yield of the product sinter, but this greatly depends on the granulation tendency of the raw mix.