KAWASAKI STEEL TECHNICAL REPORT
No.46 (JUNE 2002)
"Environment-friendly Steel Products" and
"Environment Preservation Technology"

Advanced Heating Technologies Applying Regenerative Heat Exchange Systems to Energy Saving

Kazunari Andachi, Tsuguhiko Nakagawa, Masamitsu Obashi

Synopsis :

For the prevention of global warming and the improvement of quality of steel products, Kawasaki Steel has developed a regenerative burner and heating technologies by the use of regenerative heat exchanger system. A regenerative radiant tube burner was developed first. A direct-fired regenerative burner heating system was developed and applied to a reheating furnace for a wide flange beam mill, which was the first application for a large scale industrial furnace in the steel industry in Japan, and it has spread to reheating furnaces for hot strip mills, plate mills and seamless pipe mills. A non-oxidizing heating system using high temperature nitrogen jet, a ladle heating system synchronized with the steelmaking converter operation, and a rotary regenerator adopted heating system were also developed. These systems were applied to tundishs of continuous casting machines, to steelmaking converters and to continuous annealing lines respectively. Total energy saving of 733924GJ is achieved, that is equivalent to 94513t of CO_2 reduction a year, and improvement of steel product quality was achieved as well.

The body can be viewed from the next page.

Advanced Heating Technologies Applying Regenerative Heat Exchange Systems to Energy Saving*


Kazunari Andachi
Manager, Thermal & Fluid Technology Sec., Equipment Technology Dept., Mizushima Works


Tsuguhiko Nakagawa
Dr. Eng., Staff Manager, Planning Sec., Planning Dept., Mizushima Works


Masamitsu Obashi
General Manager, Planning Dept., New Energy Foundation

Synopsis:

For the prevention of global warming and the improvement of quality of steel products, Kawasaki Steel has developed a regenerative burner and heating technologies by the use of regenerative heat exchanger system. A regenerative radiant tube burner was developed first. A direct-fired regenerative burner heating system was developed and applied to a reheating furnace for a wide flange beam mill, which was the first application for a large scale industrial furnace in the steel industry in Japan, and it has spread to reheating furnaces for hot strip mills, plate mills and seamless pipe mills. A non-oxidizing heating system using high temperature nitrogen jet, a ladle heating system synchronized with the steelmaking converter operation, and a rotary regenerator adopted heating system were also developed. These systems were applied to tundishs of continuous casting machines, to steelmaking converters and to continuous annealing lines respectively. Total energy saving of 733 924 GJ is achieved, that is equivalent to 94 513 t of CO_2 *reduction a year, and improvement of steel product quality was achieved as well.*

1 Introduction

The importance of environmental protection on a global scale has discussed in recent years. Suppression of the apparent global warming, due to increase in the CO_2 concentration in the atmosphere, is in particular one of the most important issues in the iron and steel industry which consumes approximately 11% of the energy in Japan and uses coal as the major energy sources.

Kawasaki Steel has promoted various energy saving measures to reduce the global environmental load for many years. Furthermore, as a new heating system capable of meeting the above-described needs, we have developed various high efficiency advanced heating technologies applying regenerative heat exchange systems and have made these technologies practically usable. We developed regenerative radiant tube burners and installed them in cold rolling continuous annealing furnaces for the first time in Japan. Furthermore, we have advanced the development of direct-fired regenerative burners for practical applications. We applied these burners to large scale reheating furnaces for the first time in the iron and steel industry of Japan. At the same time, we promoted the introduction of these burners to reheating furnaces for hot strip mills and reheating furnaces for plate mills in Mizushima Works and also to reheating furnaces for seamless pipe mills in Chita Works. We have also developed various original heating technologies such as the following examples. The first is a heating system using high temperature nitrogen jets which is capable of non-oxidizing heating of tundishes in continuous steel casting machines. The second example is a ladle heating system which is capable of efficiently heating ladles by synchronizing it with the operation of converters. The third is high efficient heating technologies using rotary regenerators. We have made them practically usable for steelmaking tundishes, steelmaking ladles and cold rolling continuous annealing furnaces.

This article describes the high efficient heating tech-

* Originally published in *Kawasaki Steel Giho*, 32(2000)4, 292–299

nologies at Kawasaki Steel which have been making a large contribution toward energy saving and ultimately toward reducing CO_2 emission.

2 Principles of the Regenerative Heat Exchange System

Regenerative heat exchangers (or regenerators) have been in use in various kinds of high temperature furnaces such as hot stoves for blast furnaces, coke ovens and open hearth furnaces for many years. As shown in **Fig. 1**, the principle of this type of heat exchangers is to exchange heat using a solid as the heating medium by alternately flowing high temperature gas to heat the medium and low temperature gas to be heated by the medium. The efficiency is approximately 80%, much higher than that of recuperative heat exchangers (or recuperators) of which efficiency is approximately 45%. As shown in **Fig. 2**[1], the type of regenerative heat exchanger is operated either of two methods to switch the value periodically or to rotate the heat reservoir itself.

The regenerative burners[2] originated in the U.K. in 1986 are of such a design that the regenerative heat exchanger and the burner are integrated in a unit. The heating system is composed of a pair of regenerative burners as shown in **Fig. 3**. In other words, exhaust gas from the furnace is led to a thermal accumulator on the unburnt side and transfers its heat to a heat reservoir, while combustion air passes through the thermal accumulator on the fireside which has accumulated heat and

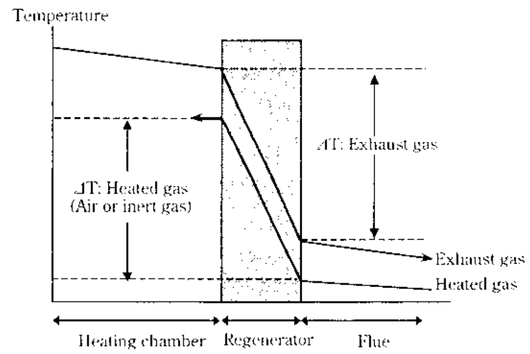

Fig. 1 Concept of regenerative heat exchanger

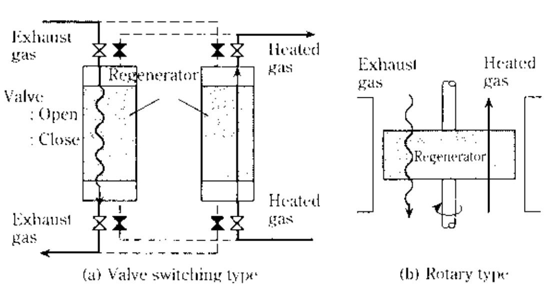

Fig. 2 Type of regenerative heat exchanger

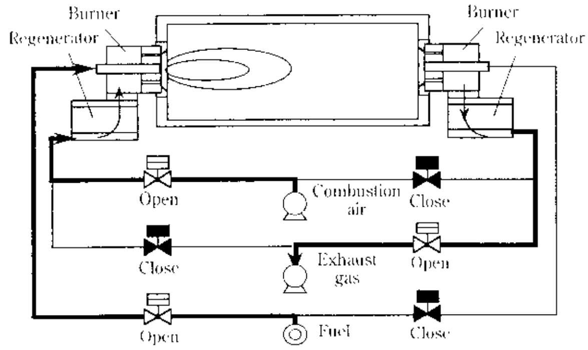

Fig. 3 Schema of regenerative burner heating system

is heated to a high temperature for combustion use. By switching operation between burning and exhaust modes in a short cycle of 30-90 s, a highly efficient system is realized in a compact design. Two types of regenerative burners are present. The first is the regenerative radiant tube (RT) burner which indirectly heats the object of heating and the second is the direct-fired regenerative burner which directly heats the object.

3 Regenerative RT Burner System

Although regenerative burners have been known to have high efficiency, these burners had several problems including high NO_X concentration due to the high temperature of the combustion air and the low reliability of the apparatus. In order to solve these problems, studies to develop regenerative RT burners[3] were conducted in Kawasaki Steel.

3.1 Outline of the Regenerative RT Burner System

Figure 4 outlines the regenerative RT burner system developed. A burner coupled with a heat reservoir is fitted at each end of a radiant tube. A couple of burners is used alternately in that, the fuel is burnt at a burner while the combustion gas is exhausted through the other burner. The alternation of combustion and exhaust is repeated every 40-60 s.

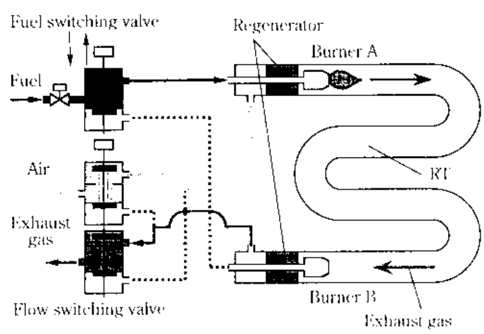

Fig. 4 Schema of regenerative RT burner

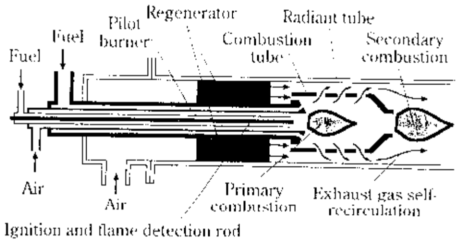

Fig. 5 Structure of developed regenerative RT burner

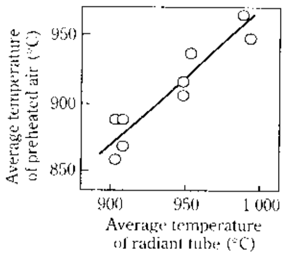

Fig. 6 Preheated air temperature of developed burner

3.2 Basic Design of the Developed Burner

As shown in **Fig. 5**, the burner itself consists of a two-step combustion system[4)] with an exhaust gas self-recycle type which has application to high temperature annealing finances in Kawasaki Steel. By re-optimizing the design of the combustion tube corresponding to the raised temperature of the combustion air, the NO_X generation could be significantly reduced. Furthermore, by arranging a pilot burner in the center and by making use of the cooling effect of the fuel gas, the life of the flame detection rods and the reliability of flame detection were improved.

3.3 Performance of the Regenerative RT Burner System

3.3.1 Thermal efficiency

With the developed regenerative RT burners, the relationship between the average temperature of RT and the average temperature of preheated air is shown in **Fig. 6**. When the average RT temperature is 960°C, the combustion air can be preheated up to 930°C and as a result, more than 80% of the sensible heat of the exhaust gas can be recovered as sensible heat of air with burners of this design.

3.3.2 NO_X generation properties

The ratio of the primary combustion to the secondary combustion as well as the circulated volume of exhaust gas were optimized by changing the shape of the combustion tubes and the design of the dispersion flame hole. Thereby, as shown in **Fig. 7**, an NO_X concentration below 120 ppm, when converted to the O_2 content of exhaust gas of 11% was achieved at a burner capacity of 502 MJ/h and a preheating air temperature of 900°C.

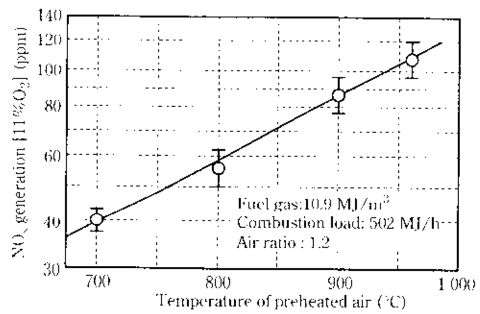

Fig. 7 NO_X generation of developed burner

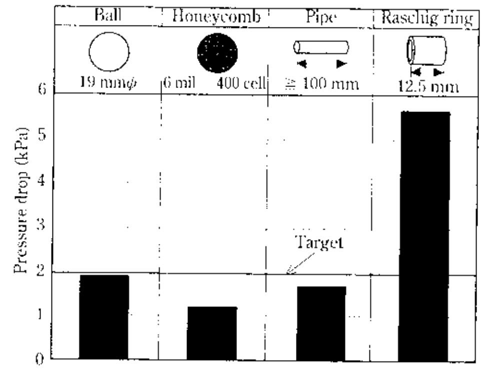

Fig. 8 Comparison of pressure drop of regenerator

3.3.3 Structure of the heat reservoirs

In selecting the solid medium of the heat reservoirs, comparison tests were carried out to determin shape and materials under the same temperature conditions as those in commercial units. The points considered for the comparison were (1) low pressure-loss, (2) strong structure to bear weight and (3) ease of replacement and repair. Through comparing the pressure losses in regenerators, it was found that pressure loss in each type of heat reservoir is in the order shown in **Fig. 8**:

Honeycomb packing < Pipe < Ball
≪ Raschig ring

However, the honeycomb type model was broken while testing after approximately only 50 h of operation and its repair was found to be difficult, therefore, the ball type or pipe type design was selected. For the burners developed this time, a structure with high purity alumina balls or pipes stuffed in a heat resisting steel casing was adopted considering ease of replacement and repair so that the heat reservoir can be easily replaced even if damaged. Furthermore, after conducting endurance tests under the same conditions as commercial units, it was confirmed that the life span of the heat reservoir is expected to be longer than three years.

3.3.4 Design and life span of the switching valve

With RT burners, since the installation space is

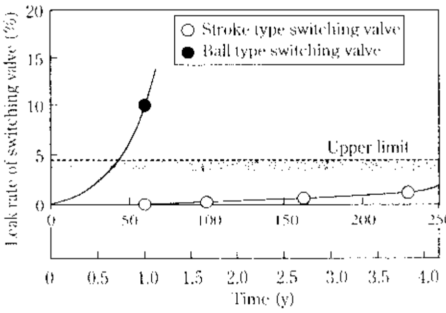

Fig. 9 Life of switching valuc

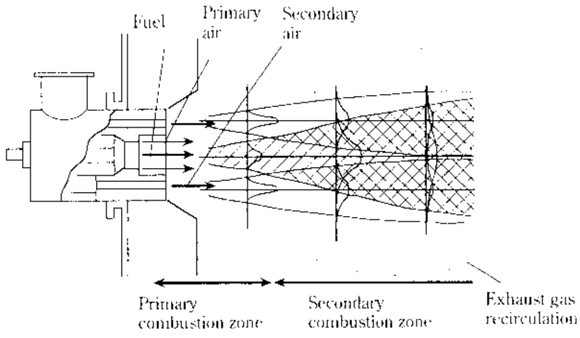

Fig. 10 Concept of NO_X reduction of applied burner

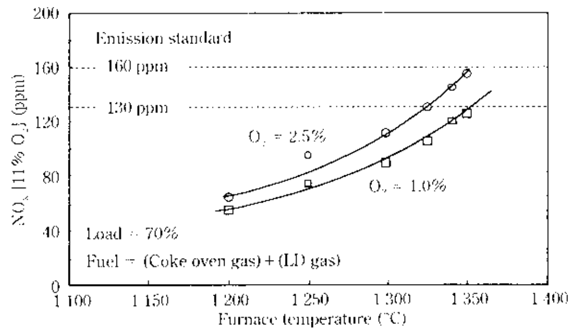

Fig. 11 Characteristics of NO_X generation

restricted and the number of burners is large, it is necessary to employ the compact switching valve and also to reduce the total installation number. For these reasons, stroke type hexagonal valves were adopted. The stroke type switching valves and ball type switching valves adopted were continuously used under exactly the same conditions and were evaluated on the basis of their rate of combustion air leaking into the exhaust gas. Thus, it was confirmed that the span of life of stroke type valves is longer than four years as shown in **Fig. 9**.

3.4 Results of Application to Commercial Units

Three sets of burner systems developed were installed in the soaking zone tunnel of the No. 2 cold rolling continuous annealing furnace in Mizushima Works and were continuously operated from December 1993. Since then, no leakage has occurred in the switching valves and no damage has been found in the heat reservoirs, thus the reliability of the burner system as a whole can be confirmed.

4 Direct-fired Regenerative Burner System

4.1 Establishment of Application Techniques to Commercial Units

4.1.1 Background of development

The application of direct-fired regenerative burners to commercial units had also been delayed because problems such as high NO_X concentration due to raised combustion air temperature became obstacles. Jointly with Chugai Ro Co., Ltd., Kawasaki Steel conducted combustion tests in 1993 using by-product gas (M gas) produced from ironmaking process and planned to establish technologies for application of direct-fired regenerative burners to commercial units.[5,6]

4.1.2 Special features of direct-fired regenerative burners

(1) Basic Design of Low NO_X Concentration Burners and NO_X Generation Behaviors

As the measures to achieve low NO_X concentration, two methods were adopted which can be realized only with the burner structure design of device and without any special control system. The first is to apply a two-step combustion system by means of two-step air injection. The second is to adopt a diffusion lean combustion method by means of high speed gas ejection. In the two-step combustion system, as shown in **Fig. 10**, the combustion space is composed of a fuel-excessive primary zone and a secondary zone which has a low oxygen concentration owing to self-recycling of exhaust gas. By virtue of this combustion process, it becomes possible to achieve low NO_X concentration. Furthermore, flame is stabilized by raising combustion air temperature, therefore, it becomes possible to blow out air and fuel gas at high velocities and to achieve diffusion lean combustion and as a result, NO_X generation can be suppressed.

The relationship between the NO_X concentration and the furnace temperature when M gas is burned is shown in **Fig. 11**. M gas is a mixed gas of coke oven gas and LD gas. At 1 300°C, the highest temperature employed usually for reheating furnaces, the value of NO_X concentration could be reduced to a level below 130 ppm, which satisfies the upper limit of NO_X content specified by the law (160 ppm, converted to 11% O_2). Since then, efforts were made to further reduce NO_X concentration and burners with an NO_X concentration of lower than 50 ppm are now in use in several furnaces including the No. 3 reheating furnace for hot strip mills which will be described later in this article.

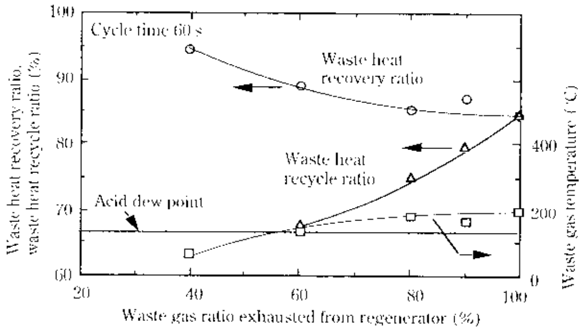

Fig. 12 Characteristics of waste heat recovery

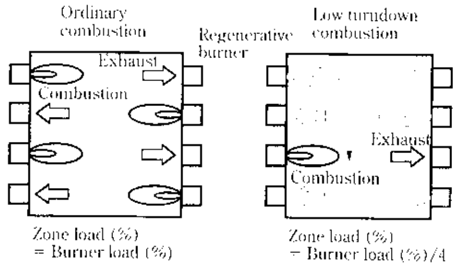

Fig. 13 Concept of high turndown ratio combustion system

(2) Selection of Heat Reservoirs

High purity alumina balls were adopted as heat transfer medium which bore the function of waste heat recovery. It is less expensive than structured bodies such as honeycombs, and its life has longer because of high resistance against thermal expansion and thermal shock. Furthermore, this construction has superior maintainability. For example, replacement of heat reservoirs can be accomplished simply by dumping these alumina ball into the regenerator.

(3) Waste Heat Recovery Behavior

In other to investigate the optimum operation conditions for regenerative burners, the waste heat recovery behavior was experimentally investigated. As shown in **Fig. 12**, high waste heat recovery ratios exceeding 80% can be obtained in the heat reservoir (Here, the waste heat recovery ratio is defined as the quotient obtained by dividing the "increase of heat-capacity of air due to passing through the heat reservoir" by the "heat capacity of the exhaust gas passing through the heat reservoir"). Furthermore, as the waste gas ratio exhausted from the regenerator decreases, the waste heat recovery ratio increases while the exhaust gas exhausted through the heat reservoir decreases, therefore, the waste heat recycle ratio decreases (Here, the waste gas ratio exhausted from the regenerator is defined as the quotient obtained by dividing the "exhaust gas volume passing through the heat reservoir" by the "combustion exhaust gas volume of the regenerative burner" and the waste heat recycle ratio is the rate of recycling waste heat obtained by multiplying the "waste heat recovery ratio" by the "waste gas ratio exhausted from the regenerator"). In addition, if the exhaust gas temperature drops below the dew point of sulfuric acid, there arises the possibility of corrosion in the pipe because of condensation of the sulfur oxide in the exhaust gas. As explained above, it is advantageous for direct-fired regenerative burners to increase the percentage of waste gas exhausted from the regenerator within the range permitted for heat resistance of switching valves and suction fans.

(4) Furnace Temperature Distribution

The furnace temperature distribution is an important factor which affects the uniformity of steel temperature in furnaces. Regenerative burners of this type make the furnace temperature distribution uniform within a wide range of combustion loads and have been confirmed to have superior uniformity in heating performance even at low loads.

4.1.3 Control system for direct-fired regenerative burners

In consideration of the operability of direct-fired regenerative burners when applied to commercial furnaces, a new control system was developed in addition to the combustion control common to conventional burners.

(1) Safe Switching Combustion System

Since the regenerative burners repeatedly fire and unfire, stable and safe switching combustion was established using various means, including automatic firing and unfiring control of pilot burners, flame surveillance, open and closed condition surveillance for switching valves.

(2) High Turndown Ratio Combustion System

A high turndown ratio combustion system was developed for commercial use. This system makes thinned-out control of each pair of burners facing each other possible within a control zone formed by a plural number of regenerative burners, thus the turndown ratio can be made larger than that of a single burner (Here, the turndown ratio is defined as a ratio of the minimum and the maximum amount of fuel that can be burned by a burner or a combustion system). As shown in **Fig. 13**, the zone load is equal to the burner load when all pairs of burners are in use. On the other hand, the zone load can be set to 1/4 of the burner load when each pair of burners are rotated through combustion/regeneration and pause with only one of the four pairs of burners in combustion. When this method is combined with the 1/5 turndown ratio of each burner, it becomes possible to reduce the zone turndown ratio down to 1/20 and as a result, it becomes possible to secure combustion load control over a wide range and uniformity of furnace tempera-

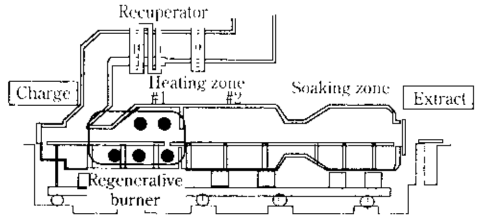

Fig. 14 Setting position of regenerative burner

ture under low load operation.

(3) Control of the Waste Gas Ratio Exhausted from the Regenerator

A control method was developed that makes the exhaust gas temperature at the exhaust side of the regenerator higher than the acid dew-point and at the same time, achieves high heat recovery, by controlling exhaust gas flow through heat reservoirs.

(4) Burner Switching Pattern Control

When regenerative burners are simultaneously switch-operated, temperature and pressure in reheating furnaces do not stabilize. Therefore, a switching pattern control was designed.

4.1.4 Results of practical application

On the basis of the above-described knowledge and findings, the direct-fired regenerative burners were applied to continuous reheating furnaces in Large Section Steel Works, Mizushima Works in September, 1994 the first time in Japan for large scale continuous reheating furnaces.[7] Since then, the system has been in operation and has been making a contribution toward energy saving by reducing the fuel consumption by approximately 15%.

4.2 Introduction of Direct-fired Regenerative Burners to Continuous Reheating Furnaces

Kawasaki Steel has applied the direct-fired regenerative burners to the above-described large-scale reheating furnaces and has installed the burners to reheating furnaces for hot strip mills and reheating furnaces for plate mills in Mizushima Works and to reheating furnaces for seamless pipe mills in Chita Works. The application of this type of burner is expanding.

4.2.1 Reheating furnace for hot strip mills

(1) Purpose of Introduction

The regenerative burners were introduced to the No. 3 reheating furnace for hot strip mills in Mizushima Works for the purposes of expanding productivity through enhancing the reheating ability, reducing fuel consumption through improving the waste heat recovery ratio, and reducing the environmental load through reducing the CO_2 and NO_X emission.

(2) Outline of the Introduced Facility

As shown in **Fig. 14**, the regeneration burners in this reheating furnace were installed on the upper and lower parts of the No. 1 heating zone because application of these burners at these points was estimated to make it possible to effectively enhance the reheating capacity and reduce fuel consumption.[8] The burner capacities were made 25.2 GJ/h and 24.1 GJ/h for the upper part and for the lower part respectively. Two pairs and three pairs of burners were installed on the upper and lower parts, respectively. In consideration of the expected life span, 13 mm diameter ceramic ball was used for the heat reservoir medium and a L-shape value of simple structure was adopted for the switching valves due to ease in the maintenance. The combustion switching interval was set to 40~60 s.

(3) Effects of Installation

The effects on the enhancement of the reheating capacity are listed in **Table 1**. Due to increase of sensible heat of hot air heated at the heat reservoir, the total heat capacity injected into the No. 1 heating zone increased by approximately 18%. Furthermore, through introduction of regenerative burners, the heat recovery ratio of the exhaust gas passing through the heat reservoir exceeded 80% and the fuel consumption was reduced by 10.2% as shown in **Fig. 15**. The CO_2 reduction is estimated to be approximately 23 597 t/y. In addition, by adopting the two-step combustion system of exhaust gas self-recycling type using high temperature injection, the NO_X concentration in the exhaust gas was significantly reduced from the previous value of 120 ppm to 77 ppm.

Since staring operation in April, 1999, this regenerative burner system has successfully operated and significantly contributed to reducing the environmental load as well as improving the slab quality due to a decrease of skid marks and so on.

Table 1 Comparison of available heat

(GJ/h)

	Conventional burner	Regenerative burner
Combustion heat of fuel	120	120
Sensible heat of fuel	5	5
Sensible heat of air	25	52
Total heat	150	177

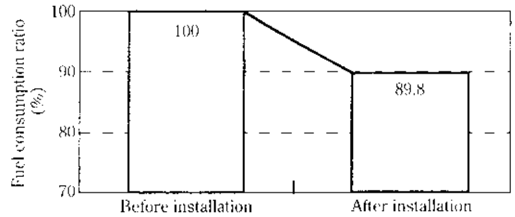

Fig. 15 Comparison of fuel consumption

4.2.2 Reheating furnace for seamless pipe mills

(1) Purpose of Introduction

The Small Diameter Seamless Pipe Works that is

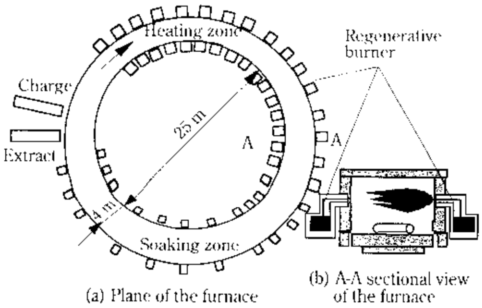

Fig. 16 Rotary furnace with regenerative burner

one of the major facilities in Chita Works consumes the largest amount of energy in this works. Since the reheating furnace has the largest amount of energy consumption among its facilities. It was intended to introduce the regenerative burners to this furnace and by changing the fuel from heavy oil to natural gas in order to save energy, to made exhaust gas clean and to improve the product quality though improving the unifomity of steel temperature distribution.

(2) Outline and Features of the Burners Installed

All burners used in this reheating furnace were replaced with regenerative burners using ceramic ball heat reservoirs and 54 burners were installed in 27 pairs as shown in **Fig. 16**. In this modification, the combustion capacity was reduced from 232 to 204 GJ/h without sacrificing productivity. In the past, waste heat was recovered in three steps consisting of material preheating, recuperator and waste heat boiler. However, it was intended at this modification to simplify the facilities by recovering waste heat only by the regenerative burner system and to improve the waste heat recovery ratio. It should be worth mentioning that it was the first case in the iron and steel industry to modify reheating furnace for seamless pipe mills to use regenerative burners. This furnace is a ring-shape tunnel furnace with a narrow cross section of a width of only 4 m, as shown in Fig. 16. Regenerative burners are generally designed for slow combustion for suppression of NO_X generation, as a result, the flame tends to become longer than that of ordinary burners. Since an important point of technological development for this modification was to apply large capacity burners to a narrow combustion space, experimental studies and numerical analyses were carried out prior to the modification work. Based on these studies technologies have been successfully developed which make low NO_X concentration compatible with complete combustion by means of control of the mixing state in the furnace through optimization of the nozzle arrangement and of discharge velocity of the fuel gas.[9] Using this technology application of large capacity regenerative burners (11.5 GJ/h, 8 burners in 4 pairs) to a narrow space with a maximum zone length of 10.1 m and a furnace width of 4 m has been established.

Table 2 Result of installation

(%)

	Before installation	After installation
Thermal efficiency	48	64
Waste heat recovery	45	70

(3) Effect of Installation

As shown in **Table 2**, the waste heat recovery ratio was increased from 45% to 70% by this modification, leading to an energy saving of approximately 20%. Consequently, Chita Works as a whole could achieve a 14 656 t/y reduction of CO_2 emission and a 40% reduction of SO_X emission through fuel conversion. Thus, the modification made a large contribution toward improvement of the environment. In addition, the modification also contributed to stabilizing the quality of alloy steels through improving success percentages of the targeted heating temperature and soaking degree for steel materials. This regenerative burner system installed on the reheating furnace started its operation in March, 1999[10] and the above-described performance has been continuing.

5 Non-oxidizing Heating System using High Temperature Nitrogen Jets

5.1 Background of Development

The system adopted for the No. 4 continuous casting facility of Mizushima Works alternately uses two tundishes in high temperature atmosphere in order to reduce the cost of refractories and to improve productivity. With this system, however, reoxidation of the remained steel in tundishes had occurred while waiting, deteriorating the quality of bottom slabs due to contamination of molten steel at the beginning of casting-in. For this reason, studies were required to develop a heating method which enables maintaining the condition of the tundishes while waiting at a high temperature by keeping these tundishes under a non-oxidizing or reducing condition. Therefore, studies were conducted jointly with Chugai Ro Co., Ltd. to develop a non-oxidizing heating system using high temperature nitrogen jets (N_2 jet heater).[11]

5.2 Principle and Outline of the N_2 Jet Heater

The developed N_2 Jet heater heats objects by raising the temperature of N_2 gas up to 1 500°C using a pair of heat reservoir integrating heaters and blowing high temperature gas against the objects. The principle of non-oxidizing tundish heating with this unit is shown in **Fig. 17**. Each heater has two modes of operation and repeats operation in "combustion mode" and "N_2 jet mode" alternately at a cycle of 30–100 s. In the combustion mode, the N_2 jet heater heats the heat reservoir to a high temperature by the combustion exhaust gas and by N_2

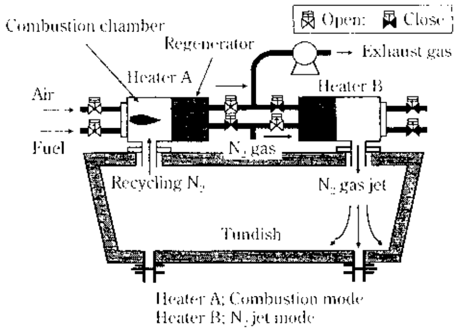

Fig. 17 Tundish equipped with N_2 jet heater

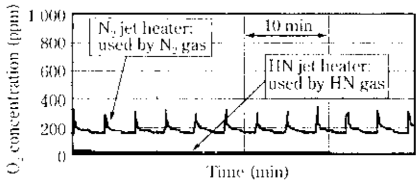

Fig. 18 O_2 concentration in tundish

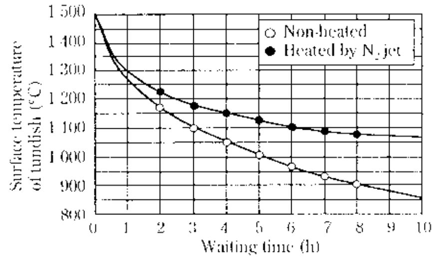

Fig. 19 Effect of N_2 jet heating on tundish temperature

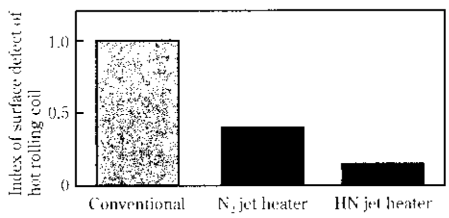

Fig. 20 Comparison of surface defect of hot coil

gas which is recovered after heating the tundish. In the N_2 jet mode, heat energy kept in the heat reservoir is converted to sensible heat of high temperature N_2 gas by passing N_2 gas through the hot heat reservoir, and hot N_2 gas is blown into the tundish. Consequently, it becomes possible to heat the inside of a tundish in a non-oxidizing atmosphere through convective heat transfer of high temperature N_2 gas jet. Furthermore, reduction heating is also possible by using HN gas with a hydrogen concentration of approximately 1–3% by adding a small amount of H_2 to the N_2 gas before heating.[12]

5.3 Performance of the N_2 Jet Heater

5.3.1 Tundish non-oxidization performance

Figure 18 shows the oxygen concentration in a tundish while using the N_2 jet heater. As heating medium gas for the N_2 jet heater, N_2 gas alone and HN gas made by adding a small amount of H_2 to the N_2 gas were used. By using N_2 gas alone, the O_2 concentration in the tundish can be kept below 300 ppm on an average and heating can be accomplished in a almost non-oxidizing condition. When using HN gas, the O_2 concentration in the tundish can be made perfectly zero. In addition, the H_2/H_2O ratio, which indicates the iron's reduction atmosphere zone can be maintained above 1.5, and it has been confirmed that reduction heating is also possible.

5.3.2 Tundish heating capacity

Figure 19 shows one effect of N_2 jet heating that it deters the dropping of the inside surface temperature of the tundish. The figure indicates that by N_2 jet heating, the inside surface temperature of the tundish after waiting for 8 h could be kept at a temperature of approximately 180°C higher than that of a conventional non-heated tundish. As a result, even after waiting for 20 h, tundishes can be kept at a temperature of above 900°C which is the temperature condition required before casting.

5.4 Effect of Using the N_2 Jet Heater

Figure 20 shows a comparison of surface defect admixing indices for coils made by hot rolling bottom slabs at the beginning of casting and then treated by surface pickling. The comparison is made between three methods (without preheating, with N_2 jet heating and with NH jet heating) taken for waiting tundishes which are repeatedly used continuously. By introducing this N_2 jet heater, surface defects could be reduced to less than 1/2 those of conventional non-preheating tundishes. Furthermore, when adopting reduction heating using NH gas, surface defects could be reduced to less than 1/4[13] and this system has significantly contributed to energy saving through improving the yield rate.

6 Ladle Heating System Synchronized with Converter Operation

6.1 Background of Development

The No. 1 Steelmaking Works of Mizushima Works is designed to produce many kinds of products in small lots, therefore, many ladles are in use according to the regulations for using ladles which are determined from restrictions in the kinds of steel, etc. For this reason, the waiting time of ladles becomes longer than in ordinary steelmaking works and the temperature of the refracto-

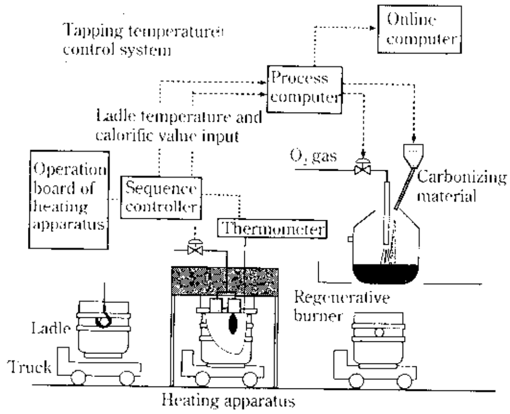

Fig. 21 Outline of the online ladle heating system

ries of ladles before receiving molten steel decreases, therefore, the temperature of molten steel received from a converter significantly drops in these ladles. In order to overcome this problem, an off-line heating system using direct-fired burners had been installed for ladle refractories, however, its effect was lower than expected because of large heat radiation due to too long required time from finish heating to steel receiving. Therefore, efforts were made in the No. 1 Steelmaking Works to develop a system to heat up ladles in a short time immediately before receiving steel aimed at suppressing the drop of the steel tapping temperature by deterring a temperature drop of molten steel in ladles.[14]

6.2 Outline of the Ladle Heating System

Figure 21 outlines the ladle heating system introduced in the No. 1 Steelmaking Works. A ladle fully prepared to receive molten steel is put on a truck by a crane, transferred to a heating apparatus by the truck and then heated. The ladle is heated for about 20 min. Until smelting in the converter is completed, thus the heat radiation loss after heating is suppressed to the minimum by limiting the time from completion of heating to tapping to 5 min. Furthermore, by calculating the heat input to the ladle refractories at all times while heating and by transmitting heating information to a process computer, decrease of the converter's tapping temperature drop is achieved. Furthermore, regenerative burners, which are capable of rapid heating and high heat recovery are used for burners of the heating apparatus. The features of this heating system are summarized as two points. One is that the conventional system, which consists of lengthy off-line heating and transferring of a ladle to a truck by crane, was replaced to a new system of on-line rapid heating on a truck. The other is that the tapping temperature of molten steel from converters is controlled according to the heat input to the ladle by synchronizing ladle heating to smelting in converters.

6.3 Performance of the Ladle Heating System

On-line heating of a ladle on a truck is restricted by

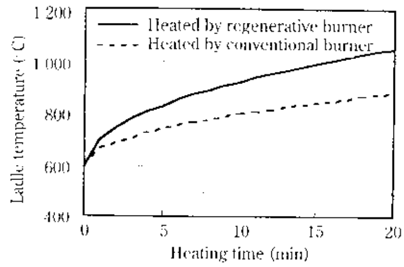

Fig. 22 Effect of regenerative burner heating on ladle temperature

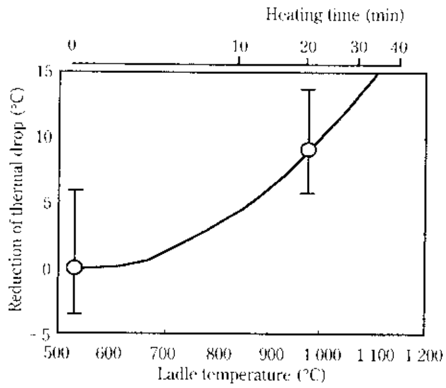

Fig. 23 Reduction of temperature drop of molten steel in ladle

heating time according to the tapping cycle of converters and by the required time for secondary smelting after tapping. Therefore, it becomes necessary to supply sufficient heat to ladle refractories within the limited heating time.

Figure 22 shows changes in refractory surface temperature when heating a ladle using a regenerative burner and a conventional burner having the same combustion capacity. By adopting the regenerative burner, the ladle can be heated up above 1 000°C in 20 min. And the ladle temperature can be raised at a temperature of approximately 150°C higher than that with conventional burner heating. In addition, the ladle heating efficiency is approximately 80% when the regenerative burner is used and is improved by approximately 1.6 times that of a conventional burner (Here, the ladle heating efficiency is defined as the quotient of the "heat input to ladle refractories" divided by the "fuel gas combustion calories"). Furthermore, as a heating system as a whole, including heat radiation loss from heating completion of ladle heating to steel receiving, the heating efficiency of this system was improved by more than 10 times that of off-line heating due to the effect of on-line heating.

6.4 Effects of Introduction of the Ladle Heating System

This ladle heating system was introduced in May 2000, and the effect of this introduction on reducing the converter molten steel tapping temperature is shown in

Fig. 23. By virtue of rapid on-line ladle heating, the ladle temperature rose to approximately 1 000°C from approximately 550°C of conventional systems and the temperature drop of the molten steel in the ladle could be reduced by approximately 9°C. Thereby, it became possible to lower the tapping temperature at converters by approximately 9°C and consumption of charcoal used for raising the tapping temperature could be significantly reduced. Furthermore, fuel gas consumed for ladle heating could be reduced to approximately 40% of that of conventional off-line ladle heating, resulting in a great energy saving.[15]

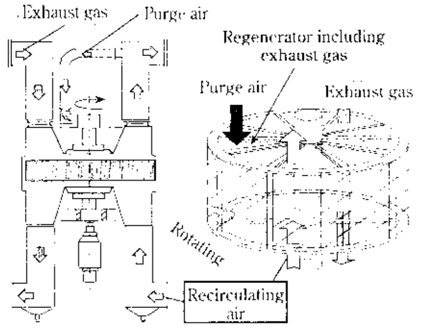

Fig. 25 Purging method of regenerator

7 High-efficiency Heating System Using a Rotary Regenerator

7.1 Background of Development

The No. 2 cold rolling continuous annealing furnace (2CAL) of Mizushima Works, whose features are high-temperature annealing and chance-free, has been in operation for production of high value-added steel at low cost, however, further improvement of productivity and cost reduction had been required in response to intensified cost competition in recent years. Therefore, by applying a rotary (Jüngstrom) type regenerative heat exchanger adopted heating system to the preheating section of 2CAL, it was planned to enhance the heating capacity in the preheating section, to raise the production capacity through stable annealing operation in the furnace, to reduce the repair costs by extending the life span of fixtures in the furnace and to reduce fuel consumption.

7.2 Outline of the Heating System

Figure 24 outlines heating system in which the rotary type regenerative heat exchanger was applied to the continuous annealing furnace.[16] In the rotary type regenerative heat exchanger, heat exchanging takes place from high temperature (650°C) exhaust gas discharged from the heating section to recirculating air in the preheating section. Heated recirculating air is blown against strips

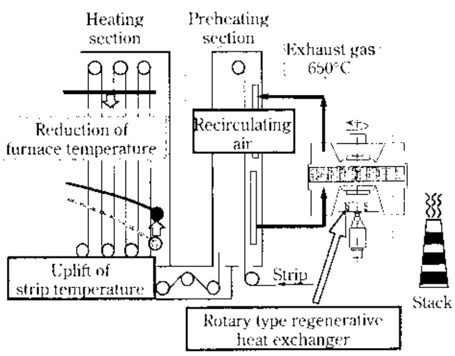

Fig. 24 Schema of installed regenerative heat exchanger

from a chamber in the preheating section and the strips are heated up to a predetermined temperature. With this heating system, the heat recovery efficiency can be double that of a conventional recuperator system and the plate temperature on the outlet side of preheating section can be raised. As a result, steady annealing in the furnace due to decreasing in the temperature difference between strips and rolls (thermal crown) can be achieved together with extending the life span of fixtures in the furnace by simultaneously reducing the combustion load in the heating section and reducing the average furnace temperature.

7.3 Application Technology of the Rotary Type Regenerative Heat Exchanger to Annealing Furnaces

Rotary type regenerative heat exchanges were traditionally used for example, for the low temperature exhaust gas of hot stoves for blast furnaces; however, the following technologies were developed in order to apply heat exchangers of this type to continuous annealing furnaces.

(1) In order to prevent deterioration of the surface quality of strips due to leakage of combustion exhaust gas to recirculating air, a purging method was developed as shown in **Fig. 25** to purge exhaust gas in the heat reservoir by circulating air and thereby the mixing of exhaust gas with recirculating air was made zero.

(2) In order to evaluate the effect of heating strips up to a high temperature using hot recirculating air on the quality of the strip surface, strip heating tests were carried out using a hot jet stream. The oxidization and reduction properties as well as the chemical conversion treatment performance of strips were evaluated. Based on the test results obtained through these tests, strip-heating temperatures in the preheating section were optimized.

(3) In order to improve the reliability of the rotary type heat reservoir when high temperature (650°C) exhaust gas is injected, the heat reservoir was designed in consideration of the high temperature heat resistance of the entire heat reservoir as a whole by adopting elements as heating medium that make leads to high

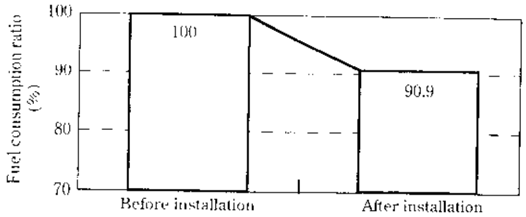

Fig. 26 Comparison of fuel consumption

temperature heat resistance, low pressure loss and small size in dimension of the system.

By taking these measures, the rotary type regenerative heat exchanger has been successfully used for a continuous annealing furnace for the first time.

7.4 Effect of the Introduction of the Heating System

As a result of adapting the rotary type regenerative heat exchanger to the preheating section of 2CAL[17], the raising performance of strip temperature in preheating section was enhanced by approximately 45°C and the thermal crown of the heating section was decreased by approximately 15°C, thus the production capacity increased by approximately 17%. Furthermore, the combustion load of the heating section was reduced, and since the optimum heating pattern which maximizes the heat transfer quantity was accomplished, and as a result, the average furnace temperature of the heating section was lowered by approximately 11°C. The life span of various fixtures such as radiant tubes is estimated to prolong approximately 1.7 times accordingly.

In addition, the heat recovery was doubled by using the adopted regenerative heat exchanger, and together with the effect of optimizing the combustion load on the heating section, the efficiency of the annealing furnace was improved by approximately 10%. With these achievements, fuel consumption was reduced by 9.1% as shown in **Fig. 26** and installment of this heating system has been making a great contribution to energy saving.

8 Conclusions

Kawasaki Steel developed and has practically adopted various regenerative heat exchange systems applied heating technologies which can contribute to deterring global warming due to the increased CO_2 concentration in the atmosphere. These heat exchange systems have confirmed the capabilities as expected since applied to steelmaking processes and as a result, an energy saving of 733 924 GJ/y or 94 513 t/y as converted of CO_2 emission amount has been achieved and at the same time, is also contributing toward improving the quality of products.

The technologies described in this article are considered extremely effective for reduction of the environmental load through energy saving and the application of these technologies is expected to expand in the future.

Introduction of regenerative burners to the reheating furnace for hot strip mills and reheating furnace for plate mills in Mizushima Works and that to the reheating furnace for the seamless pipe mills in Chita Works were approved and subsidized by the New Energy and Industrial Technology Development Organization as a part of the High Performance Industrial Furnace Introduction Field Test Project and that to the steelmaking ladle heating system in Mizushima Works was approved and subsidized by the same organization as a part of the Leading Energy Using Rationalized Facility Introduction Model Project.

References

1) H. Obana: "Netsukoukanki Sekkei Handbook", (1974), 219, [Kougakutosho Ltd.]
2) M. Gettings: *Gas Warme Int.*, **35**(1986)5, 292
3) T. Nakagawa, Y. Kodama, N. Eguchi, N. Hanazono, Y. Abe, and T. Yuri: *CAMP-ISIJ*, **9**(1996), 1048
4) T. Nakagawa, M. Obashi, K. Nuta, Y. Naitou, H. Kuramoto, and R. Kaihara: *CAMP-ISIJ*, **5**(1992), 504
5) J. Ozaki, M. Fukui, J. Shimizu, and Y. Fujimoto: *CAMP-ISIJ*, **9**(1996), 112
6) The 98th Netsu Keizai Gijutsu Bukai, ISIJ, (1996), Netsu 98-Tou-4
7) Y. Fujimoto, T. Tokumaru, J. Ozaki, K. Yahiro, S. Sakamoto, and K. Nagai: *CAMP-ISIJ*, **9**(1996), 1046
8) I. Sugimoto, M. Furukawa, K. Karube, and K. Andachi: *CAMP-ISIJ*, **12**(1999), 1110
9) Kawasaki Steel Corp.: Jpn. Application 2000–39214
10) M. Syouji: Heisei 11 Nendo Shou Energy Yushu Jirei Zenkoku-Taikai, Toukai-Chiku Taikai Jireishu, (1999), 185
11) T. Nakagawa, K. Hara, J. Hasunuma, H. Osanai, R. Yamaguchi, and S. Hashimoto: Steelmaking Conf. Proc., ISS, 80(1997), 307
12) K. Hara, T. Nakagawa, S. Yuhara, H. Osanai, T. Abe, and Y. Wakatsuki: *CAMP-ISIJ*, **13**(2000), 72
13) T. Abe, K. Hara, T. Nakagawa, K. Kadota, T. Fujimura, and H. Nomura: *CAMP-ISIJ*, **13**(2000), 73
14) Kawasaki Steel Corp.: Jpn. Application 11–242005
15) K. Hara, K. Andachi, H. Nomura, N. Goto, and D. Takahashi: *CAMP-ISIJ*, **14**(2001), 220
16) Kawasaki Steel Corp.: Jpn. Application 10–088245
17) K. Karube, K. Andachi, T. Nakagawa, Y. Kishida, Y. Kodama, and K. Hirohata: *CAMP-ISIJ*, **13**(2000), 1072