Eco-friendly Regenerative Burner Heating System Technology Application and Its Future Prospects

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The environmental friendly, ceramic honeycomb regenerative burner system is worth noting as innovative technology, for its effect of low energy consumption and NOx emission. It is recognized as one of concrete measures to prevent global warming and to solve environmental problems. NKK and Nippon Furnace Kogyo have jointly developed the system and succeeded in starting its practical operation. In NKK, this technology has been already applied to eleven furnaces. NKK has achieved over 30% energy saving effect and over 50% NOx reductions. This system ensures to provide the world with an effective countermeasure for the global greenhouse effect and the acid rain.

1. Introduction

The Toronto Congress was held in 1988, fifteen years after the First Oil Crisis, and was the first official meeting to declare the need for action in terms of global warming issues. Since then, another fifteen years have passed. During this time, the World Environmental Technology Development Congress adopted the United Nations Framework Convention on Climate Change in 1992. This was enforced in March 1994. In addition, the Kyoto Protocol, which was adopted at COP3 (the Kyoto Protocol to the United Nations Framework Convention on Climate Change) in 1997 to determine the detailed targets associated with the reduction of CO_2 emissions for individual developed countries by 2010. These were determined on the basis of 1990 levels and have been successfully adopted by developed countries by 2002 except for the U.S.A. In Japan during the thirty years since the Oil Crisis, there have been many energy saving actions and efforts against global warming (i.e. reducing COThroughout the period, NKK has been promoting company-wide efforts on the basis of energy saving actions by all employees at both the Keihin and Fukuyama Works.

was recovered at 100 m^3/t or larger volume), as well as sensible heat recovery, and
9) saving energy such as by continuous casting and annealing achieved by eliminating process steps and by achieving continuous process operation.
As a result, all possible measures had been taken and completed by the late 1980's.

As for environmental issues, the measures needed to respond to the Air Pollution Control Law and the Water Pollution Control Law, which were enforced in 1970, have apparently been completed for the first stage of the works. After that, methods have been successively introduced to deal with the newly emerged problems of global warming (CO_2 emission), increases in NOx (nitric oxides) emissions from urban mobile sources, the issues of SPM, waste, dioxins, and endocrine disrupters. The Life Cycle Analysis evaluation method was finally introduced for these issues where one countermeasure leads to the need for further countermeasures. For further action associated with energy saving and global warming to be undertaken under such circumstances, it is vital that new subjects be explored and new technology developed through a comprehensive approach to the challenges of environmental problems. Based on this concept, NKK has shifted its focus on new energy saving activities to improving the quality of efficiency in terms of increasing the quantity of energy saving. For instance, NKK has promoted exclusive technology development that concentrates on the method of supplying quality energy (i.e. calorific value, temperature, etc.) by responding to each energy use level in terms of heat recovery method without degrading the energy quality, as well as the environmental problems.

NKK has developed an eco-friendly regenerative burner heating system in partnership with NFK(Nippon Furnace Kogyo Kaisha) Ltd. This technology has been successful in solving issues related to energy and the environment, or ultimate heat recovery and reduction of NOx emissions. These issues could not be achieved simultaneously through conventional technologies[1). This paper describes the development, practical applications, and technological outlook for this eco-friendly regenerative burner system. This technology was adopted as a base technology by the National Project, "High Performance Industrial Furnace Project", which ran from 1993 to 2000. The project addressed the national policy for improving energy saving, and has been recognized as a base technology in terms of developmental results from Japanese-based technologies.

2.

diluting the fuel in the air.

The technology was examined in detail by the National Project, and as a result a new sector was created, termed “highly preheated air combustion”, in the field of combustion science. The introduction of dispersed heat recovery technology and highly preheated air combustion technology to the industrial heating furnace technology, which was thought to have matured, has led to the eco-friendly regenerative burner heating system. This is an innovative technology in the heating furnace sector that achieves 30% energy savings and 50% reduction in NOx emissions.

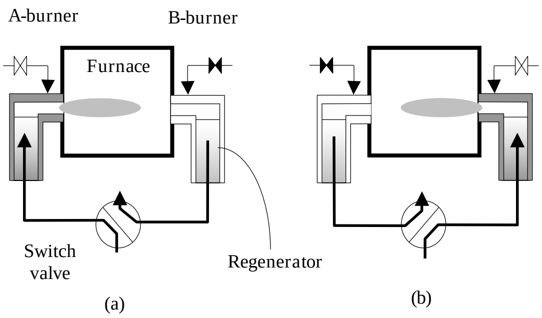


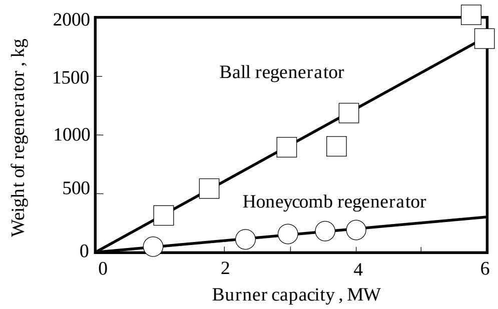
Fig.1 Regenerative burner system

2.2 Ultimate heat recovery (Regenerator optimization)[4)-6)]

Developing a regenerative burner entailed the potentially conflicting issues of maximizing heat recovery capacity within the regenerator, and compact design. The honeycomb regenerator has solved the problem. The honeycomb regenerator is the optimal heat exchanger when compared with other heat exchangers such as balls, owing to the geometrically large specific surface area contained within a honeycomb design. The honeycomb regenerator is superior also in terms of pressure drops and the preheated air temperatures. The relationship between the combustion capacity of the burner and the necessary weight of the honeycomb regenerator is calculated based on the energy balance. For example, **Fig.2** shows the relationship between the calculated weight of the regenerator (solid line) and the actual weight of the regenerator for a burner in a continuous slab-heating furnace at the Fukuyama Works’ hot-rolling mill.

Compared with the weight of ball regenerators discussed in other papers, the honeycomb regenerator is significantly lighter. Furthermore, compact designs are available for the burner body. A regenerative burner using a honeycomb regenerator will attain a maximum preheated air temperature of 1570 K (50 K lower than the furnace temperature). The preheated air temperature obtained by using ball regenerators is expected to be about 150 K lower than the furnace temperature, based on experimental data. In case of conventional metal-tube heat exchangers, the preheated air temperature is about 900 K.

Achievable heat recovery obtained by the regenerative burner is in the range 70 to 90% (depending on fuel type). That obtained by metal-tube heat exchanger is in the range 40 to 50%. Energy saving is attained by increasing the preheated air temperature by recovering sensible heat from the flue gases.



2.3 Ultra low NOx emissions (Discovery of “highly preheated air combustion”)

Developing industrial burner that use highly preheated air emphasizes the suppression of NOx emissions generated by oxidation of nitrogen in the air, (thermal NOx). Zeldovich et al. studied the generation of thermal NOx and found that the generation of thermal NOx is determined by a function of temperature, oxygen concentration, and residence time. Accordingly, achieving low NOx combustion should result from: (1) the suppression of maximum flame temperature, and (2) the prevention of excess amounts of oxygen. To do this, NKK adopted a 2-stage fuel burner, which was brought into practical use by NFK, after modification for highly preheated air combustion use (as shown in **Fig.3**).

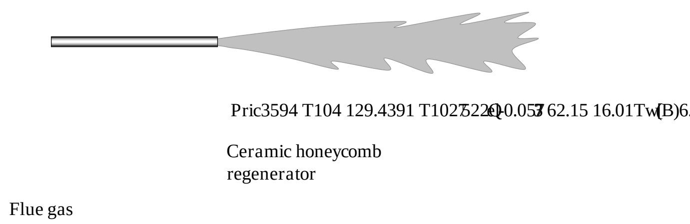


Fig.4 shows examples of experimental data from the developed burner in terms of flame temperature distribution, oxygen concentration distribution, and NOx concentration distribution observed during the combustion of by-product gases of steel works. **Fig.4**(a) shows the case the primary fuel ratio is 20%, and **Fig.4**(b) shows the case of 5%. The combustion load was 1.2 MW. This is equivalent to the capacity of a commercial burner. When primary fuel ratio was 20%, heat spots appeared in the temperature distribution. Oxygen concentrations in the heat spot were high, thus inducing the Zeldovich reaction, which resulted in a rapid increase in thermal NOx.

When primary fuel ratio was 5%, no heat spots appeared in the temperature distribution, and oxygen concentration decreased rapidly. In this case, raw NOx concentration was as low as 80 ppm (or 40 ppm converted to 11% O_2). The low NOx concentration presumably comes from the diffusion combustion of secondary fuel and highly preheated air being diluted by the intrafurnace combustion flue gases. Accordingly, the suppression of thermal NOx generation during combustion using highly preheated air can be attained by adequate diffusion and controlling the mixing of fuel with combustion air. To do this, an optimum design of burner is required. This would include the positioning of the fuel and air nozzles, the jet velocity of the fuel and air, and the secondary fuel ratio.

This technology was adopted as a core technology in the National Project of "Development of High Performance Industrial Furnaces", and was verified by many researchers including those in universities. In particular, the experimental results given by Hasegawa et al., shown in **Fig.5**, have been repeatedly cited as the data representing

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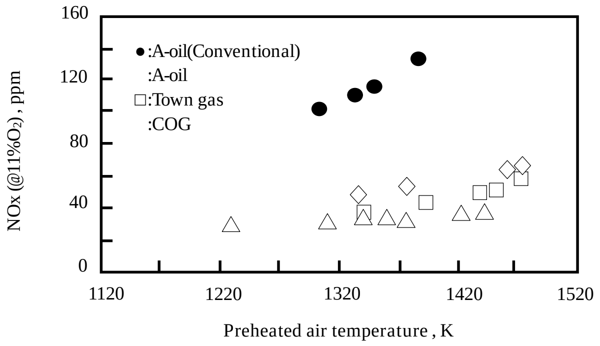


Fig.7 Comparison of NOx emission for various fuels

3. Application to iron and steel making processes

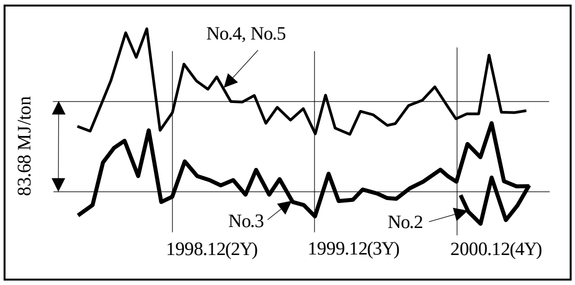
3.1 History of applying regenerative burners in iron and steel making processes

The first time regenerative burners were used in the iron and steel making processes was presumably in Europe during the 1980's as an energy saving technology. After that, the regenerative burner technology, using balls and nuggets as the regenerator, was introduced to Japan. In 1994, this technology was applied to a part of continuous slab reheating furnace at Mizushima Works to obtain energy savings. However, this technology had problems such that reduction of NOx emission remains small and the volume of the regenerator was still large.

3.2 Full-scale application to large continuous furnaces

The No.3 reheating furnace, a large-scale continuous slab reheating furnace, at NKK's Fukuyama Works' No.1 hot-rolling mill started operation in 1996, and totally applied the eco-friendly regenerative burner. For the first time in the world, both low NOx combustion and energy savings were achieved in the furnace. The No.3 reheating furnace attained the impressive result of a 25% reduction in energy consumption and a 80% reduction in NOx emissions when compared with conventional heating furnaces. Furthermore, the No.2 reheating furnace, which started operation in 2001, attained similar results to the No.3 reheating furnace, thus establishing the effectiveness of this technology.

Fig.8 compares unit fuel consumption between furnaces. Since the start of operations, the No.3 reheating furnace has sustained a lower unit fuel consumption than that of reheating furnaces Nos.4 and 5, which are renewed furnaces of a conventional type producing a preheated air temperature of 900 K. The difference in unit fuel consumption between these furnaces has stayed at about 80 MJ/t since operations began. The fluctuation in unit fuel consumption is caused by variations in production conditions, as well as by deterioration in the heat recovery rate resulting from the degradation of regenerator and increased leakage from the switching valves. Design standardization was conducted by applying measures to each of the causes. The No.2 reheating furnace, which started operation in January 2001, meets the standard design level of unit fuel consumption, producing a lower level (by about 80 MJ/t or more) than the levels of heating furnaces Nos.4 and 5. Thus, it is confirmed that the designed heat recovery rate is attained by adequate design and control of the regenerator and switching valves, as well as those of the furnace body.



Also in terms of the amount of NOx generated, the No.2 reheating furnace has achieved significant reductions, as much as 80%, owing to the synergistic effect of reductions in NOx concentrations in flue gases and reductions in flue gas amounts resulting from fuel saving. Furthermore, as a secondary effect, skid marks were reduced by more than 30%. As a result of these effects, the eco-friendly regenerative burner heating system that has been developed (see **Fig.9**), has proved to be an extremely effective technology in energy saving as well as environmental conservation aspects.

3.3 Partial application to large, continuous furnaces

The regenerative burner can be readily introduced to existing large, continuous slab heating furnaces. The method of introduction differs in terms of the intended use.

3.3.1 Increasing heating capacity through an additional regenerative burner

The plate mill at NKK's Keihin Works is intended to integrate two reheating furnaces into one by increasing the heating capacity of one of the reheating furnaces. This has been achieved by modifying the furnace by adding regenerative burners to the charge side of the furnace. Since the modification did not mean replacement of the existing burners, the recuperator could be used as part of the modification. Also in terms of the control system, the system for additional burners only, was added. By modifying the plant in this way, single-furnace operation became possible instead of a conventional two-furnace operation, thus improving the unit fuel consumption of the heating furnace by 13%. Furthermore, the furnace successfully keeps NOx generation below the regulated level while attaining increases in heating capacity. Since the environmental regulations are likely to become more severe in the future, heating furnaces will be forced to adopt the eco-friendly regenerative burner.

3.3.2 Attaining energy saving by replacing conventional type burners with regenerative burners

NKK's Fukuyama Works' plate mill has conducted modifications of continuous reheating furnaces by replacing the conventional type burners in the heating zone, whose burners consumed about 50% of the total heating furnace fuel, with regenerative burners, for energy saving purpose. In other words, the conventional burners were removed, and the regenerative burners were mounted in their place. Since the regenerative burner, which has a built-in honeycomb regenerator, is a compact burner, the regenerative burners could be mounted without changing the burner pitch. Through modification, the recuperator capacity should be decreased since the existing burners in the heating zone were removed. As for the control system, the existed control system was used while only the switching control for the regenerative burners was added. After modification, unit fuel consumption of the reheating furnace was improved by 9%. Furthermore, the adoption of the eco-friendly regenerative burner decreased NOx

4. Future prospects

4.1 Effects on industrial furnaces and applications to other fields

Since the sales of the eco-friendly regenerative burner began in 1992, NFK has led the sales activity mainly in the industrial furnace field, selling 1532 pairs to 263 facilities. About 50% of customers are from the iron and steel sector, 40% from the automobile and non-ferrous sectors, and 10% from the ceramics and other sectors. As described earlier, the National Project, "High Performance Industrial Furnace Project", which was promoted during the period 1998 to 2000, studied the increase in and clarification mechanism of performance in various industrial furnaces, such as, heat treatment furnace, and melting furnace, applying highly preheated air combustion technology using the eco-friendly regenerative burner heating system as well as adopting the optimal heating furnace design. As a result, the possibility of energy saving (by 30%), significant reduction of NOx (by 50%), reduction in noise, and compact design (by 20%) has been confirmed in reality as well as from a theoretical point of view. Following these studies, a field test project (FT Project) was planned to conduct verification tests at commercial furnaces using various types of industrial furnace, and to widely distribute this technology. These FT Projects have been conducted on 167 furnace units over the three years from 1998 to 2000. The test data has been accumulated for each furnace throughout the four years of continuous testing. At the point of proposing the testing of these 167 units, the expected effect was 160 thousand kl/y of reduction in fuel converted to oil.

In the view that such superior technology should also be applied to other combustion facilities, the five-year plan High Temperature Air Combustion Technology Project (HICOT Project) began in 1999. The target facilities for research and development are: (1) pulverized coal-fired boilers; (2) waste incineration furnaces, and (3) high temperature chemical reaction furnaces. Since the direct application of highly preheated air combustion technology to these facilities is not possible, individual issues resulting from practical application have been studied. NKK has studied the waste incineration furnace. In March 2002, NKK optimized the addition of hot air, thus attaining both lean air combustion, reducing the conventional air ratio of 1.7 to between 1.2 to 1.3, and the detoxification of flue gases, thus achieving energy savings of more than 30% and NOx reduction of more than 30%[7].

The application of highly preheated air combustion is not limited to the above fields. For instance, tests for wider application fields are underway by substituting hot air with a hot fluid and by substituting combustion with a chemical reaction[8]. A hot fluid generator using a honeycomb regenerator supplying hot fluid to the reactor, achieves a high temperature fluid at 1579 K with 87% heat efficiency ance verification tests of the NFK-made ceramic honeycomb regenerative burner are planned for France, Sweden, and Holland from 2001 to 2002. The test results will be evaluated within one to two years. In addition, Asian