OVER DECADE OF THE INDUSTRIAL EXPERIENCES IN HIGH TEMPERATURE AIR COMBUSTION APPLIED WITH HRS REGENERATIVE BURNERS

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ABSTRACT
A continuous competition among manufacturers lays behind the development of new technologies. One of the technologies which has been invented recently is High Temperature Air Combustion (HiTAC). Low emission of NOₓ and uniform thermal fields as well as heat flux in the combustion chamber of the furnace is possible to achieve by using this method. Combined with unique features heat regenerative bed, called "honeycomb" HiTAC ensures high thermal efficiency of combustion processes and low emission of pollutants like NOₓ and CO₂.

This paper outlines areas of applications of High-cycle Regenerative System (HRS) and types of presently used burners.

Over two thousand HRS burner pairs have been installed throughout last fifteen years in several industry applications. It has been done in new furnaces as well as in revamped systems. HRS burners are used successfully to modernize existing furnaces, because the applied regenerator beds are compact which means that vast heat exchange surface is enclosed in a small volume and light weight. Designing new furnaces operating with HRS burners allow to decrease volume of the furnaces while retaining the same productivity in comparison with conventional furnaces and firing systems. Moreover, HRS burners are used in some heating zones of existing furnaces to increase productivity.

There are three types of the HRS burners designed for different applications. In the first place are burners for the direct firing heating applications e.g.: in reheating furnaces, heat treatment furnaces, etc. Secondly, indirect flame burners are used in radiant tube applications, mainly in heat treatment furnaces. The continuous, direct-firing, single-flame burners are used in processes demanding constant temperature during specified period of operation.

KEY WORDS: High Temperature Air Combustion (HiTAC), Regenerative Burners, Heat Recovery Systems, High-cycle Regenerative System (HRS), Energy Saving, Low NOₓ Combustion Technology.

INTRODUCTION
Since the beginning of 90-ies or even late 80-ies of the last century a lot of publications regarding the idea of HiTAC have been already presented all over the world. For this reason it could be assumed that the idea of HiTAC combustion is known well. Such advantages of HiTAC like low NOₓ emission or flat temperature and heat flux distributions inside furnaces has been reported in many documents [2, 4]. Other advantages of HiTAC like low noise [17] or possibility to burn fuel
with very low heating value can be found in many papers too [1].

Along with HiTAC combustion technology HRS is discussed/introduced by many authors [9, 4, 2]. Apart from the interesting features of HiTAC an additional advantage is pointed out in these publications but in regard to HRS. It is high heat recovery ratio or in other words very high fuel saving in comparison with the conventional heat recovery systems [6].

Apart from investigations made by many researching institutions [1, 3, 2], laboratory centers or researching and development departments in different companies [4, 5, 8, 17, 19] in the field of HiTAC and HRS the technologies could be observed by the users. This is because almost 800 furnaces has been revamped or built as new units using the regenerative burners in Japan since the beginning of the 90-ies.

About half of them, it means about 400 furnaces, utilized the HRS regenerative burners with HiTAC combustion technology invented and developed by Nippon Furnace Kogyo Kaisha Ltd. (NFK).

First industrial application that used HRS burners took place in 1992. Since that time HRS system has been applied for example in the following areas:

- reheating furnaces – 56 applications with installed firing power up to 93 MW (38 pairs of HRS DL burners),
- ladle furnaces – 6 applications with installed firing power up to 3,2 MW (2 pairs of HRS DL burners),
- annealing, tempering, carburizing and other heat treatment furnaces – 61 applications with installed firing power up to 15,6 MW (180 pairs of HRS RT burners),
- furnaces for ceramics – 8 applications with installed firing power up to 1,7 MW (50 pairs of HRS U_1 burners),

Basing on the big number of the application of the HRS technology it is possible to confirm that the fuel saving obtained in many application is over 50% and the same time the NO_x emission is in the range from 30 up to 70 ppm corrected to 11% of O_2.

ADVANTAGES OF HITAC AND HRS TECHNOLOGY

With reference to the responses form the users of HRS burners the following main advantages of using HRS (HiTAC) can be seen [11]:

- In case of open flame technology applied, for example, in reheating furnaces:
  - decreasing of the unit fuel consumption,
  - reduction of the scale loss or dross
  - improvement of inner quality of products
  - enhancement of steel soaking
  - extension of life time of refractories
  - improvement of productivity (yield)
  - reduction of the repair cost
  - mitigation of production limit
  - reduction of the NO_x
  - improvement of the furnace temperature uniformity

- In case of indirect heating systems (Radiant Tubes) such as heat treatment furnaces:
  - improvement of inner quality of products,
  - decreasing of the unit fuel consumption,
  - speed up of the heating temperature,
  - enhancement of steel soaking,
  - extension of radiant tube life time,
  - extension of life time of refractories,
  - improvement of productivity (yield),
  - improvement of the scale property,
  - reduction of the soot amount,
  - reduction of the scale loss or dross,

All the advantages mentioned above can be generally grouped in four areas:

- reduction of fuel consumptions,
- improvement quality of products,
- increasing of the life time of the equipments,
- reduction of pollutions,

The advantages come from the following main features of HiTAC and HRS technologies:

- high efficiency of the regenerative heat exchanger (bed of honeycombs),
- flat temperature and heat flux distributions,
- flat distributions of flue gas composition,
- low pollution emissions including NO_x emissions,

Regenerative heat exchanger efficiency

The high efficiency of the regenerative heat exchanger (bed of honeycombs) could be
defined by the use of so-called temperature efficacy of regenerative heat exchanger [15].

\[
\eta = \frac{T_{AO} - T_{AI}}{T_{FGI} - T_{AI}} \cdot 100 \ [\%]
\]

Where: \( T_{AI} \): Inlet air temperature, \( T_{AO} \): Outlet air temperature, \( T_{FGI} \): Inlet gas temperature

This efficiency can even reach the level of 96.5%, whereas in the case of central recuperative systems this efficiency is no greater than 50%. The level of temperature efficiency of 96.5% means that temperature of the air after regenerative heat exchanger (honeycombs) is almost on the same level as the temperature of the flue gases that are sucked from the furnace during regenerative mode.

High efficiency of the honeycombs results in fuel saving after revamping furnaces. The savings can reach about 50% (Fig. 1). The highest level of fuel saving takes place when the furnace is equipped with poor or even has no heat recovery system before revamping.

In the typical reheating furnaces flue gasses temperature at the exit of the furnace is on the level between 800°C and 1000°C. Temperature of the preheated air before the burner ranges from 300°C to 400°C (the temperature efficiency of the recuperative system is below 50%). In such case installing HRS burners can result in fuel saving between 20% and 30%. In such typical application of HRS 90% of flue gases is usually sucked through the honeycombs therefore the temperature efficiency of the regenerative heat exchanger is about 93%.

The regenerative heat exchanger used in the HRS burners is made from ceramic honeycombs (Fig. 2).

A typical type of honeycomb used as a regenerative media has 100 cells per square inch. This great number of cells per square inch ensures the flowing features of the regenerative heat exchanger (fig. 3) [13]:

- high specific surface area equal to 1307 m²/m³, about 5 times greater than in the case of the ball type (ball diameter – 20 mm) as equivalent heat transfer rate per volume,
- low unit weight - about 3 times less that in the case of the ball type,
- low unit volume - about 5 times less that in the case of the ball type. This factor makes that burners are compact and easy to install, especially during furnace revamping,
- short optimum switching time equal 30 s - the time where the highest regenerative efficiency is obtained. It is about 2 to 4 times lower compared to what is possible in the case of the ball type. Short switching time results in small fluctuation of the preheated air temperature,
- low pressure drop, about 3 to 4 times lower than in the case of the ball type,
- no problem with plugging due to construction of the honeycombs.
Fig. 3. Comparison of ceramic honeycomb and ball

**Flat distribution of the temperature, heat flux and composition of the flue gases inside the furnace**

Temperature distribution inside the furnace affects heating quality in a great degree. However, it is widely known that heating quality directly influences the quality of products therefore it is important to keep heating quality on the required level. Consequently the temperature distribution inside the furnace is one of the key points of the good technology [10].

In HRS burners / HRS combustion systems several techniques are applied in order to achieve flat temperature distributions (Fig. 4). The techniques are as follow:

- very high injection velocity of the fuel gas,
- very high injection velocity of the preheated air,
- air and fuel are injected directly into the furnace from separate nozzles at furnace temperature over 800°C,
- the proper distance between nozzles and its location,
- the special way of the control of the burners in the system.

A separate injection of fuel and preheated air into the combustion chamber results in the fact that the fuel as well as the air is mixed with flue gases before combustion process takes place (internal flue gas recirculation). This results in lowering of the peak temperature because of the two main reasons. Firstly, the oxygen level in the oxidizer is lowered. Secondly, fuel is burned partly before main combustion process takes place. The flue gases usually include some amount of the oxygen. The power of the internal flue gas recirculation is controlled by the injection velocity of the preheated air and fuel (design parameters) as well as the location of the nozzle.

Fig. 4. Description NFK

Higher injection velocity results in faster internal flue gas recirculation and swirl the gas volume. It is similar with the location or distance between nozzle of fuel and air. Higher distance between them results in faster internal flue gas recirculation [7].

In a furnace or in a zone some pairs of burners are usually installed. The burners in pair work alternatively it is meaning that every burner has to be firing 30 s per cycle. However the pairs must not be switched simultaneously what results in an additional mixing process inside the furnace.

High internal flue gases recirculation, high injection velocity and the way of controlling the burner results in not only proper temperature distribution but also in heat flux and flue gases composition. In some cases almost the whole combustion chamber is filled up with combustion process. The difference between peak temperature and furnace temperature in HRS Combustion Technology is about 5 – 7 times smaller [19] compared to the conventional technology. Similar situation is with the heat flux - decrease of temperature peak results in decrease of heat flux peak.

**Low emissions of the pollutants**

The HRS Combustion System ensures particularly low emissions in comparison with the conventional technology regarding carbon dioxide (CO₂) and nitrogen oxides (NOₓ) [12]. Reduction of the first pollutant (CO₂) is in the same ratio as reduction of energy consumption. Each kilogram of saved fuel decrease certain numbers of kilograms
of CO₂. Since the efficiency of the regenerative heat exchanger applied in the HRS burners is very high, it is possible to reduce emission of CO₂ even more than 50%. However, the exact reduction depends on the application.

Reduction of the second pollutant (NOₓ) ranges form 50% up to almost 90% and sometime higher. The reduction of NOₓ very much depends on the NOx emission before installation of the HRS system (Fig 5). NOx emission for non HRS technology can be on the level of 200 ppm (0% of O₂) but also close to 1000 ppm (0% of O₂).

The typical NOₓ emission from HRS Combustion System in the reheating furnaces is on the level from 50 ppm (0% of O₂) up to 120 ppm (0% of O₂) and depends mainly on the furnace temperature and the type of fuel. However in some application the NOx emission can be even on lower level.

The ultra low NOₓ emission obtained in HRS Combustion System is possible thanks to HiTAC combustion technology. Proper control of temperature distribution as well as the composition of flue gas makes that there are no temperature peak with high fraction of radicals (OH, CH,…). Both temperature and the amount of radicals plays important role in all NOₓ creation mechanisms. Therefore by applying HiTAC, that is avoiding the peak temperature that appears in the conventional combustion technology and high concentration of radicals, NOₓ creation is very low. It has to be noticed that temperature of the preheated air in the HRS burners is on very high level close to the furnace temperature.

THREE TYPES OF HRS BURNER AND ITS APPLICATIONS

There are three HRS-series burners:
- Direct firing HRS burners (DL, DS, U1 series)
- In-direct HRS burners (RT series)
- Single flame direct firing HRS burners (Ux series)

Direct firing HRS burners – DL series

The HRS burners concept depends on High Temperature Air Combustion with high performance regenerator heat exchangers. The wide range of HRS burners used in industrial furnace applications opened the HRS-DL series burners. This type of burners is installed in furnaces were energy flux is exchanged directly between flue gas and heating charge. The idea behind the system is that two burners work alternatively. When one of them works as a burner (firing mode) the second sucks the exhaust gas from the combustion chamber (regenerative mode). Maximum thermal efficiency for such regenerators is achieved during 30 seconds switching time. The burners enclose regenerative bed called “honeycomb”, made from ceramic resistant to high temperature of flue gas. High performance heat exchanger allows combustion air with ambient to preheat up to the temperature close to the sucked flue gas temperature during regenerative mode of burner. Figure 6 shows the arrangement of a pair of the HRS burners.
The HRS burner system may operate in two ways: conventional combustion mode (F1) and HiTAC mode (F2). Figure 7 shows schematic drawing of F1 and F2 combustion modes. During heat up the furnace burner works in F1 mode, however always as a regenerative burner. When combustion chamber temperature exceeds 800°C gas is supplied by F2 nozzles and the burner starts to work in F2 mode.

The Fuel and preheated air is fed to the combustion chamber through separate nozzles. Both media are mixed with flue gases and unburned gases in the combustion chamber. This way a combustion take place in a zone were is low oxygen molar concentration.

The HRS-DL burners are used in the furnaces were temperature in heating zone ranges from 800°C (600°C) to 1350°C (1400°C). Minimum working temperature is limited by investment costs and energy saving whereas maximum operating temperature is limited by technical restrictions.

The HRS DL burners are produced in a wide capacity range. The smallest burner in DL-series is HRS-DL2, its capacity is equal to 150 kW. The capacity of biggest unit HRS-DL9 is 5810 kW.

The HRS (DL, DS, U1) burners have been installed mainly in the following types of the furnaces:

- in common butch type furnaces for the following process of the metals:
  - billet reheating, plate reheating, ingot heating, casting heating (aluminum), soaking pit,
  - annealing,
- in batch type furnaces such as:
  - bogie type heat treatment, gas heat treatment,
  - car bottom typo heat treatment,
- continuous type furnaces such as walking beam, pusher type for the following process of the metals:
  - continuous billet reheating (also for copper), slab re/heating, heating, plate reheating,
  - continuous annealing, heat treatment, tempering,
- ladle heaters,
- others types of furnaces and process:
  - indirect gypsum firing kiln,
  - ceramic firing furnace, ceramic baking furnace,
  - roller hearth kiln
  - ferrite firing furnace
  - edge heating,
  - coil annealing furnace, open coil annealing
  - pipe annealing furnace,
  - W/B sheet spring heating,

Examples of the application

Slab reheating walking beam furnace

One of the main target applications of HRS-DL series burners are slab reheating walking beam furnaces (fig. 8). As a good example of the HRS technology in use is furnace with a maximum throughput of 100 t/hour utilizing 16 pairs of HRS burners (fig. 9) [15].

The billets are fed into the furnace at ambient temperature and are discharged at a temperature in the region of 1100°C, whereas the average furnace temperature of soaking zone is 1250°C. At a throughput of 78 t/hour, the energy consumption unitary was 0.88 GJ/ton, as show in figure 10. The specific energy consumption level for furnaces of this type with high efficiency conventional recuperative burner system is normally about 1.1 GJ/ton. NOx emission was found to be generally bellow 60 ppm (at 11% of oxygen) over a wide range of burners capacity.
Temperature difference over the width of the heating zone was less then 20°C. It means that a more uniform temperature profile was achieved than is possible with a conventional burner system.

**Ladle preheaters**

The HRS burners are also used in steel manufacturing in ladle preheaters. Modernization of two sets of existing ladle preheaters with 50 tons/charge firing kerosene by the use of HRS-DL U type burner is described below (fig. 11) [16]. In an existing system, a conventional air atomizing type burner of the designed capacity 2,3 MW, is installed eccentrically on the top of the ladle cover. The ladle is preheated by the burner up to approximately 1273 K as an equilibrium state before receiving molten steel. Before revamping the flue gas of around 1273 K has been released through the flue on the ladle cover without heat recovery. For the retrofitted ladle, a pair of the HRS burners, each burner as shown in figure 12 is connected with a 4 way valve, are mounted on the ladle cover.

The designed capacity is 1,6 MW per each burner. The Flue gas outlet and preheated air calculated temperatures are respectively 502 K and 1170 K at flue gas inlet temperature of 1273 K, at which the temperature efficiency is 89%.

Figure 13 shows the comparison of heat-up curve and fuel firing rate, as a function of time measured for the HRS and the conventional burner. The heat-up curve for each burner is almost the same but fuel firing rate with HRS is significantly lower which results in 84% of waste heat recovery rate and 54% fuel saving rate. Annual fuel saving rate is 19,344 GJ which is equivalent to 547 000 l of kerosene per ladle. Fuel cost is up to 10 million yen a year, which makes that the payout period is as short as 2 years. NOx content in the flue gas during firing at full load, that is 1,6 MW, while the ladle is in atmospheric temperature was measured as low as 32 ppm (for 11% vol. of oxygen in dry flue gas) which is equivalent 30% of value achieved by conventional burner.
Temperature profiles inside the walls of the ladle at conventional and HRS burners operation were also investigated. Maximum temperature differences between the HRS and the conventional burners in all measuring points were 24 K and 58 K, which proved that HRS combustion is more uniform than that of conventional burner. In addition, under the same inside atmospheric temperature of 1273 K, average combustion temperatures for HRS and the conventional burner were respectively 1095 K and 1023 K - temperature with HRS burner is higher by 72 K. This also means that heat flux with HRS is higher than that from the conventional burner and that heat flux by high temperature air combustion with HRS is higher than that from conventional combustion. Temperature uniformity on the refractories extend lifespan and significantly reduce re-building cost of the refractories. The compact and light weight of HRS with ceramic honeycomb is another advantage compared with heavy ball-type regenerative burner in these down firing application.

Ceramic industry.

A new shuttle kiln furnace with designed charge of 5.8 ton using 4 pairs of HRS-DF burners, 200 kW each, firing natural gas, is described below as an example of new combustion technology in ceramic industry [16]. Ceramic tiles which are designed for exterior applications in building or housing are charged on the car from the inlet door of the furnace and heated up to 1473 K at the maximum, in accordance with the heating curve, as shown in figure 14. The regenerative burner must fulfill the requested features which are the capability of both oxidizing and reducing firing.

Each burner is installed in the furnace wall so that the flame pass through the racks of the ceramic tiles. During the reduced firing, excess air ratio is controlled and kept at 0.8 which is equivalent to dry CO concentration of 4 to 6%. As a result 13.3% fuel saving ratio, where waste heat recovery rate was 68.9 and temperature efficiency was 96%, was obtained. NOx average emissions during reduced firing was 37 ppm (for 11% vol. of oxygen in dry flue gas) which was nearly 50% less compared with an existing continuous tunnel kiln furnace of the same capacity. Because of soot in flue gas, smoke number of Bacharach was reduced to less than 1.0 (0.06 g/Nm³) at excess air ratio of 0.8 and yet the ceramic honeycomb regenerator was clean after 3 months operation. Figure 15 shows the effect on Bacharach smoke number on excess air ratio for the HRS burner and a conventional regenerative burner.

In addition to that, the maximum temperature difference of 15 K, which was one of the targets, in the furnace was attained, and
firing time in one batch could be shortened from 30 to 25 hours.

**Non-ferrous industry.**

A new continuous and non-oxidized copper billet reheating furnace with a designed maximum throughput capacity of 20 tons/h utilizing 9 pairs of HRS-DF burners, firing LPG, is discussed below. The burner firing capacity ranges from 120 kW to 580 kW. The copper billets are charged into the heating zone and are transported through soaking zone on the walking beam mechanism. The billets are fed into the furnace at ambient temperature and discharged at a temperature ranging from 973 K to 1123 K, where non-oxidized atmosphere at excess air ratio of 0.9 is being kept and average furnace temperature of soaking zone is 1273 K. As a result 68.5% of fuel saving rate, where waste gas heat recovery rate was 70.9%, was obtained compared with the conventional reheating system. Such system was usually composed of direct fired type preheating furnace with conventional burner and induction heater for soaking. Figure 16 shows NO\textsubscript{x} emissions measurement results at furnace temperature in a test furnace. The measurements were carried out for two cases; mixed firing, that is for F1 and F2 modes at low temperature, and for F2 mode firing at high temperature under non-oxidizing atmospheric condition no free oxygen is admitted in the normal oxygen analyzer. In the designed operation conditions at F2 firing mode in the new furnace NO\textsubscript{x} emissions were recorded as 19 ppm (at 11%vol. oxygen in dry flue gas) [6] on average.

**In-direct HRS burners – RT series**

The HRS-RT burner series is designed for indirect applications where flue gas can not get in contact with heating charge. These types of burners are installed in radiant tubes. A schematic drawing of the HRS-RT series radiant tube burner is shown in figure 17.

![Fig. 17. View of HRS Radiant Tube System](image)

The HRS-RT operate on the same idea as DL-series burners. All burners are equipped with high efficient thermal regenerative heat exchangers. This solution compared to conventional recuperative burners allows achieving fuel savings up to 30%.

The temperature profile of the tube surface along the tube length is shown in figure 18. It presents profiles obtained with recuperative (conventional burner) and regenerative (HRS-RT burner). The temperature profile obtained from regenerative system is much more uniform and symmetric - the maximum temperature difference measured on tube does not exceed 25°C.

![Fig. 18. Radiant tube skin temperature distribution](image)

The HRS-RT burners are manufactured for firing output ranging from 23 kW up to 140 kW. The High-cycle Regenerative System RT burners are usually applied in the
furnaces with services temperatures from 500°C up to 1150°C.

The HRS RT burners have been installed mainly in the following types of the furnaces:

- in batch type furnaces for the following processes and metals and non-ferrous metals like aluminum and cooper:
  - heating/reheating, heat treatment, vacuum preheat,
  - austempering, intruding, non-oxidation annealing, non-oxidation normalizing, brazing, annealing, bright annealing,
  - carburizing, gas carburizing, sulphurizing & nitriding,
- continuous type furnaces for the following process of metals:
  - heating/reheating, heat treatment, vacuum preheat
  - continuous heat treatment, atmosphere heat treatment, bolt tempering
  - continuous annealing, non-oxidation annealing, soot-continuous annealing, spheroidizing annealing, soot-continuous baking, non-oxidation quenching, coil tube annealing, normalizing quenching, quenching, sintering, non-oxidation normalizing
- others types of the furnaces/processes:
  - electrode baking,
  - glass-ling furnace,
  - mesh-belt furnace
  - powder continuous baking

Examples of the application

Continuous annealing furnace

The figure 19 shows two pairs of HRS-RT burners installed on Continuous Galvanizing and Annealing Line Furnace in rolling mill with maximum throughput of 140 t/h. On the line there are installed 52 burner pairs which single burner capacity is 140 kW (fig. 20). The highest temperature achieved in heating zone was 950°C. Line revamping include replace the conventional radiant tube burners having recuperative heat exchangers with HRS-RT burners having high efficiency and high thermal response. As the result, unit fuel consumption rate was decreased and the improvement of steel sheet temperature uniformity was achieved. Owing to the advantage of regenerative burners, the temperature distribution of the tubes are homogenized and thus it extends the life of tubes.

Fig. 19. Two pairs of HRS-RT burners installed on Continuous Galvanizing and Annealing Line Furnace

Fig. 20. Overview of furnace equip with 52 pairs of HRS-RT

NOx emission which target is less 120 ppm corrected to 11% oxygen in flue gas was achieved to be 118 ppm by adding flue gas external recalculation. The waste heat recovery rate after modernization was increased from 45.4% to 80.3% which led energy saving of 25.5%.

Batch type gas carburizing Furnace

The HRS burners are also dedicate for small scale heating treatment systems. As a example of this application will be describe Batch type gas carburizing furnace present in drawing 21. There is two pairs of HRS-RT burners supplied to 5 inches W-type radiant tube vertically installed at each side wall on the roof of the furnace. The throughput of the furnace, in which mainly motor parts and bolts nuts and nuts are carburized, is 600 kg/charge. Operating furnace temperature is 93°C. As a result of modernization 23% of fuel saving was achieved compared to the same throughput capacity of a conventional single-end type radiant tube furnace, or 61% of fuel saving compared to the same throughput capacity for an electric heater type furnace. NOx
emission was obtained as 94 ppm at 11% of oxygen in flue gas. Temperature profile of the tube surface are very uniform and symmetric at the center of a tube and the maximum temperature difference was 25°C at average furnace temperature of 930°C.

Fig. 21 HRS-RT mounted on batch type gas carburizing furnace

**Single flame direct firing HRS burners – Ux series**

There are heating systems where process without alternative combustion must be assured, with very uniform temperature profile in the combustion chamber. In order to meet such requirements NFK have designed HRS-Ux burners. There is a schematic of HRS-Ux burner in figure 22.

Fig. 22. Schematic diagram of the HRS-Ux burner

Four parallel ceramic honeycomb regenerators are installed around the fuel nozzle. In operation condition the flue gases are sucked through three regenerators whereas air is traveling across one. After 5 to 9 seconds there is a change in the way of supply air to the combustion chamber. The fuel, however, is fed continuously. The advantages of HRS-Ux burners are size compactness, and that they are easy to be adopted to single burner system.

The HRS-Ux burners are made in different capacities from 120 kW up to 2200 kW. The optimum application of the HRS-Ux burners reaches up to 1100 – 1200°C

The HRS-Ux burners are destined for the following area:

- small size heating/reheating furnaces,
- small size heat treatment furnaces,
- hydrogen generators,
- petrochemical furnaces
- others ....

**Small-sized industrial heating production equipment**

An example of application of this burner is a small sized hydrogen production equipment commercialized by joint development with other companies.

Fig. 23. View of the HRS-Ux burner installed on hydrogen reformer system

The HRS-Ux burner application in a hydrocarbon installation is shown in figure 23. The required combustion system is based on a down firing method. Uniform heating in a modified tube, high thermal recovery rate gained without using recuperator or convection, are essential to this system in order to enhance hydrogen production efficiency. Apart from that low NOx emission and space saving is achieved.

This is one of the most promising burners which can be applied in a great number of
small sized heating systems including small sized ladle furnaces, small sized heating medium heater, and small sized hot air generator, in addition to the above-mentioned application. In all these examples of application space saving plays an important role especially when adopting the down firing method as one of the most vital features of this system.

**European application of HRS combustion technology**

Commercial success of the HRS Combustion Technology in Japan awoke great interest from European industries. Because of constantly raising prices of fuel, and more and more restrictive pollutants emission policies as well as thanks to fiercer competition very high quality products were obtained. Particularly big interest in the HRS has been observed recently in Europe. However, despite this fact there are still few HRS application in this continent.

One of the recent projects that are being realized is revamping of the upper preheating zone in the pusher furnace whose capacity is 150 t/h at CORUS, Llanwern Strip Works. The HRS combustion system in this case will consist of two HRS-DL9 burner pairs. The total firing power of the system is 11,6 MW. The installation will be commissioned at the beginning of 2006.

Despite few systems realized all types of the HRS burners found application in Europe. The exemplary installations are:

- 2 pairs of the HRS DS1 burner with firing power 100kW each are installed in the semi-industrial furnace in laboratory at Royal institute of Technology (KTH), Stockholm, Sweden [2],

- 1 pair of the HRS RT burner with firing power 140kW is installed in the semi-industrial furnace in laboratory at Royal institute of Technology (KTH), Stockholm, Sweden [14],

- 1 pair of the HRS DL4 burner with firing power 1000kW is installed in the test furnace in the laboratory of the International Flame Research Foundation (IFRF), IJmuiden, The Netherlands [5, 8],

- 1 HRS DL burner with firing capacity 200kW in the test furnace in the laboratory of the Gaz de France–Research Department, France [4, 18],

- 1 pair of the HRS RT burner with firing power 140kW is installed in the laboratory of R&D of CORUS, IJmuiden, The Netherlands,

- 1 HRS U x burner with firing power 220kW is installed in the test furnace in laboratory of Poznań University of Technology, Poland

**CONCLUSION**

Basing on the results from HRS burners combustion systems application in industry the following main advantages can be drawn:

- After revamping furnaces using the HRS burners basic on high performance heat regenerators allow to achieve even over 50% fuel reduction in comparison with conventional burners.

- Revamping of burner system allow to reduce emission of NOx pollutants at least 50%.

- Application of the HRS burners is simple way to improve the product quality.

- Uniform temperature of radiant tube wall decrease thermal stress and extend of live time due to applying of the HRS RT burners

- Using of the HRS burners during designing procedure give possibility to decrease furnace volume (about 25%) and reduce cost of new installation.

Almost 15 years of the industrial experience and thousands of sold burners as well as good relationships with the final users of the HRS system resulted in the optimum construction of the HRS burners for different type of the applications.

The HRS burners which are environmental friendly technology applied in European industry is one of way to realize the Kyoto Protocol task.
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