HIGH-CYCLE REGENERATIVE SYSTEMS (HRS BURNERS)
AND HIGH TEMPERATURE AIR COMBUSTION TECHNOLOGY (HITAC)
– EUROPEAN INDUSTRIAL APPLICATION

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ABSTRACT
A continuous competition among the industrial burner manufacturers as well as the newest very low limits for the gases pollution (for example: NOx, CO2, CO) and rapid increase of the fuel prices results in 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 of heat regenerative bed, called “honeycomb” HiTAC ensures high thermal efficiency of combustion processes and low emission of pollutants like NOx and CO2.

Over two thousand HRS burner pairs have been installed throughout last fifteen years in several industry applications, mainly in Japan. 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 allows 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.

This paper presents basic information about High-cycle Regenerative System (HRS), High Temperature Air Combustion (HiTAC) and European Industrial Application of these technologies. Since up to now, the HRS in Europe is applied only in the reheating furnaces therefore only direct firing heating HRS burners will be discussed in the paper.

KEY WORDS: High Temperature Air Combustion (HiTAC), Regenerative Burners, Heat Recovery Systems, High-cycle Regenerative System (HRS), High Temperature Burners (HTB), 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 can be assumed that the idea of HiTAC combustion is known well. Such
advantages of HiTAC like low NO\textsubscript{x} emission or flat temperature and heat flux distributions inside furnaces have been reported in many documents [1, 2, 3]. Other advantages of HiTAC like low noise [4] or possibility to burn fuel with very low heating value can be found in many papers too [5].

Along with HiTAC combustion technology HRS is discussed/introduced by many authors [1, 2, 6]. Apart from the interesting features of HiTAC an additional advantage is pointed out in these publications 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 [7].

Apart from investigations made by many research institutions [1, 5, 8], laboratory centers or research and development departments in different companies [2, 4, 9, 10, 11, 12] 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, utilizes 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 [13]:

- 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\textsubscript{1} burners)

Basing on the big number of the applications 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\textsubscript{x} emission is in the range from 30 up to 70 ppm corrected to 11% of O\textsubscript{2}.

ADVANTAGES OF HITAC AND HRS TECHNOLOGY

With reference to the responses from the users of HRS burners the following main advantages of using HRS (HiTAC) can be seen [14]:

- In case of open flame technology applied, for example, in reheating furnaces:
  - decrease 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\textsubscript{x}
  - improvement of the furnace temperature uniformity

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

- reduction of fuel consumption
- improvement in quality of products
- increase in the life time of the equipment
- reduction of pollution

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\textsubscript{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 efficiency of regenerative heat exchanger [15].

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\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 drawn from the furnace during regenerative mode.

High efficiency of the honeycombs results in fuel saving after revamping furnaces. The savings can reach up to 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 typical reheating furnace flue gases 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 drawn 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 flow features of the regenerative heat exchanger (Fig. 3) [16]:

- 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 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 problems with plugging due to construction of the honeycombs.

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

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Fig. 1. Fuel saving as a function of furnace exhaust gas temperature

Fig. 2. Typical shape of ceramic “honeycomb” regenerative heat exchangers [17]

Fig. 3. Comparison of ceramic honeycomb and ball
inside the furnace is one of the key points of the good technology [18].

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 partially before main combustion process takes place. The flue gases usually include some amount of the oxygen. The power of the internal flue gases recirculation is controlled by the injection velocity of the preheated air and fuel (design parameters) as well as the location of the nozzles.

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 [19].

In a furnace or in a zone some pairs of burners are usually installed. The burners in pair work alternatively it means that every burner fires 30 s per cycle. However the pairs are not 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 [12] 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) [20]. 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 (NO\textsubscript{x}) ranges from 50% up to almost 90% and sometimes higher. The reduction of NO\textsubscript{x} very much depends on the NO\textsubscript{x} emission before installation of the HRS system (Fig 5). NO\textsubscript{x} emission for non HRS technology can be on the level of 200 ppm (0% of O\textsubscript{2}) but also close to 1000 ppm (0% of O\textsubscript{2}).

The typical NO\textsubscript{x} emission from HRS Combustion System in the reheating furnaces is on the level from 50 ppm (0% of O\textsubscript{2}) up to 120 ppm (0% of O\textsubscript{2}) and depends mainly on the furnace temperature and the type of fuel. However in some application the NO\textsubscript{x} emission can be even on lower level.

The ultra low NO\textsubscript{x} 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 peaks with high fraction of radicals (OH, CH,…). Both temperature and the amount of radicals plays important role in all NO\textsubscript{x} creation mechanisms. Therefore by applying HiTAC, that is avoiding the peak temperature that appears in the conventional combustion technology and high concentration of radicals, NO\textsubscript{x} 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.

**DIRECT FIRING HRS BURNERS**

The HRS burners concept depends on High Temperature Air Combustion with high performance regenerative 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 burner (firing mode) the second draws 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 material 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 drawn flue gas temperature during regenerative mode of burner. Fig 6 shows the arrangement of a pair of the HRS burners.

![Fig. 6. The HRS burners pair DL- series](image)

The HRS burner system may operate in two ways; conventional combustion mode (F1) and HiTAC mode (F2). Fig 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\textdegree 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 combustion takes pace in a zone with low oxygen molar concentration.

![Fig. 7. Schematic of typical work HRS burner during a) F1 mode and b) F2 mode](image)

The HRS-DL burners are used in the furnaces were temperature in heating zone ranges from 800\textdegree C (600\textdegree C) to 1350\textdegree C (1400\textdegree 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. Currently the HRS-DL10 burner with firing capacity about 7 – 8 MW is in design in order to meet the market requirements.

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

- in common batch 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,

EUROPEAN INDUSTRIAL APPLICATION

HRS Combustion System.

The first European Industrial Application of the HRS burners is located in CORUS in the Llanwern Works (United Kingdom). The installation has been done in the one of the reheating, pusher type furnace of the Llanwern Works with working capacity about 150t/h. Two pairs of the NFK-HRS-DL9 burners in the top preheating zone instead of the conventional longitude burners are in operation since April 2006 (Fig. 8)

The nominal firing power of the HRS-DL9 is 5.8MW (Fig. 9), therefore the total nominal firing of the installed system is 11.6MW. The nominal firing power is calculated as the flow rate of the natural gas multiply by low heating value of the natural gas. However the total nominal energy supplied to the zone is about 16.4MW (35% more) at nominal working condition of the zone due to energy supplied by the highly preheated air.

The calculated fuel saving for this zone is 25%, however based on the experimental data the fuel saving (energy saving, CO\(_2\) saving) for the whole furnace is between 4% and 7% due to usage of the HRS system. The actual fuel saving very much depends on the production rate and the operation
procedure of the furnace. Simply speaking, higher productivity is: more HRS system is used, bigger energy saving is obtained. It must be pointed out that HRS system is just installed in the top preheating zone (Fig. 10) as the first step of the revamping, after the full revamping of the furnace, expected fuel saying is between 20 – 25% for the whole furnace.

Besides of the energy saving which is one of the main reasons of this installation also following aspects have been noted/confirmed:

- reduction of NOx level
- reduction of the CO₂
- reduction of temperature of the flue gases before recuperator
- increase of the preheated air temperate before the conventional burners
- very even temperature distribution in the zone

The successful months of operation of NFK-HRS system in CORUS have proven the NFK-HRS System in full scale industrial application in Europe. In this application all European sub-suppliers (switching valves, refractories, control equipments, etc.) have been successfully proven as well.

**HTB Combustion System.**

The first European Industrial Application of the HTB burners is located in SSAB Tunnplåt AB in Borlange in Sweden. The HTB (High Temperature Burners) use the HiTAC combustion technology. It is the same combustion technology as it is applied in the HRS burners, however HTB burners are not equipped with regenerators. Therefore the HTB burners work continuously.

The HTB burners, as ultra low NOx burners are the best solution in order to reduce the NOx emission in the reheating furnace where the recuperative system is very efficient, like in SSAB where the temperature of the preheated air is over 600°C. In such level of the preheated air temperature the NOx emission from conventional burners became very high, beyond environmental regulations.

The HTB burners have been installed in one of the reheating, walking beam type furnaces (design capacity of the furnace 300 t/h) in top preheating zone (Zone 1) and bottom preheating zone (Zone 2), Fig 11, instead of the conventional longitude burners.

![Fig. 10. View of HRS instalaltion in CORUS, one side of the furnace, 2 HRS-DL9 burners with accessories](image)

![Fig. 11. Layout of the reheating furnace at SSAB](image)

![Fig. 12. View of HTB burners installed in the top preheating zone, 8 x HTB-DL3.5](image)
3.5MW each have been installed. Where in the bottom preheating zone, 9 of the NFK-HTB-DL3.8 burners have been installed with firing rate capacity 3.85MW each.

At normal operating conditions the preheated air temperature is about 600°C, where zone temperature is between 1100°C and 1250°C. As the fuel is this furnace Propane or LPG is used.

The HTB burners have a simple construction, therefore it is easy to adjust HTB burners to the furnace condition. The refractory on the furnace wall, which is a part of the burner is relative simple as well, Fig. 14.

The main aim of the revamping of these zones was to reduce the NOx level. Therefore, 3 days of the continuous guarantee test has been preformed after commissioning. Based on the results of this guarantee test, more then 30% of NOx reduction for whole furnace has been achieved. The level for NO from both preheating zones has been recorded on much more lower level then 65ppm at 5% corrected to 5% of O2 in the flue gases.

Beside of the NO reduction also very even zone temperature distribution has been confirmed. Since the system is under operation since the beginning of August, 2006 such advantages of using the HiTAC combustion technology as for example better quality of heated steel or longer lifetime of the refractory on the skid system has been not confirmed in this application yet.

CONCLUSION

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

- Revamping furnaces using the HRS burners with high performance heat regenerators allows to achieve even over 50% fuel reduction in comparison with conventional burners.
- Revamping of burner system allows to reduce emission of NOx pollutants at least by 50%.
- Application of the HRS burners is a simple way to improve the product quality.
- The HiTAC technology has been very successfully proven in the HTB burners.
- Using the HRS burners during designing procedure gives the possibility to decrease furnace volume (about 25%) and reduce costs 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.

Using the same knowledge that is the base of the HRS and HiTAC technology new type of the HTB burners has been successfully located on the market.

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