HiTAC technology combined with HRS burners in a walking beam steel reheating furnace

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Abstract

Lately due to increasing competition in the steelmaking industry all companies have had to reduce production costs. This drives steel manufacturers to exert pressure on technology suppliers to reduce fuel consumption and energy costs. Additionally, the newest, very restrictive emission limits of pollutant gases (for example: NOx, CO_2, CO) and a continuous increase in ecological consciousness result in great interest of the industry in applying the newest combustion technology.

Heavy industry customers shun field–testing of new technologies. Thus, every type of new combustion technology has to guarantee reduced energy consumption of the process, low pollutant emissions, a furnace capacity increase, the combustion process and product quality improvement and, at the same time, reliability and dependability in industrial conditions.

All the conditions and targets which were listed above can be reached by using the High Temperature Air Combustion (HiTAC) technology combined with the High-cycle Regenerative System (HRS) technology. This solution has been invented recently and already successfully adapted and proven in hundreds of different industrial applications. Over two thousand HRS burner pairs have been installed throughout the last twenty years in several industry applications, mainly in Japan. Using this technology, it is possible to achieve low emission of NO_X and CO, uniform temperature profiles as well as heat flux in the furnace.

Sample application of the HiTAC combustion technology combined with HRS burners utilizing a special type of heat regenerative bed, called “the honeycomb” is a walking beam steel reheating furnace of a rolling mill plant. This project covered a revamp of the reheating, walking beam furnace with a new combustion system. The revamped furnace is a part of reinforcement bar production line where carbon steel is rolled. Investor’s expectations of lowering fuel consumption, improving product quality and boosting furnace throughput were successfully met by the HRS burner system.

This paper presents advantages of using this technology and experiences which come from over two years of furnace operation – a fuel consumption reduction by 27%, a capacity increase by 33% (from 15.0 t/h to 20.0 t/h) and product quality improvement. It must be noted that all the mentioned effects were attained without furnace shell modification.

Key words

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

Introduction

Due to increasing competition in the steelmaking industry and the newest, very restrictive emission limits of pollutant gases (for example: NO_X, CO_2, CO) all companies have to reduce production costs and emission levels by applying the newest combustion technology. Additionally, heavy industry customers shun field–testing of new technologies.

This drives steel manufacturers to exert pressure on technology suppliers to deliver a new combustion technology which guarantees reduced energy consumption of the process, low pollutant emissions, a furnace capacity increase, combustion process and product quality improvement and at the same time reliability and dependability in industrial conditions [1, 2].

All the conditions and targets which were listed above can be reached by using the High Temperature Air Combustion (HiTAC) technology combined with the High-cycle Regenerative System (HRS) technology.

This paper presents advantages of using this technology in a walking beam steel reheating furnace and experiences which come from over two years of furnace operation.

HiTAC Technology and HRS Burners

The HiTAC technology was introduced into the market by NFK company (Nippon Furnace Kogyo). Main features of this combustion technology are propagation of the combustion process over large volume (usually almost the total furnace volume) and carrying out the combustion process with low oxygen concentration. Therefore, the HiTAC is often called “volumetric combustion” or “flameless combustion” [3].

The volumetric character of this technology is achieved by injection of fuel and combustion air into the combustion chamber at a high velocity and through separate nozzles. The nozzles are located at a proper distance from each other.

Application of the HiTAC technology provides the following advantages [4, 5, 6, 7, 8, 9]:

- flat heat flux distribution,
- flat temperature distribution,
- low emission of NO_x due to lack of temperature peaks,
- possibility of decreasing fuel consumption,
- lower average temperature in the zone, due to propagation of the combustion process over large volume,
- ability to increase zone capacity, due to making possible an increase in the zone temperature,
- higher refractory lining lifetime due to lack of temperature peaks,
- low noise,
- possibility of burning fuel with very low heating value (LHV).

The unique features of the HiTAC combustion technology have been successfully applied in the special HRS Burners.

In the HRS burners / HRS combustion systems several techniques are applied in order to achieve the required advantages (Fig. 1). The techniques are as follows [1]:

- 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 through separate nozzles at furnace temperature over the fuel auto-ignition point,
- proper distance between nozzles and its location,
- special way of the burner control in the system.

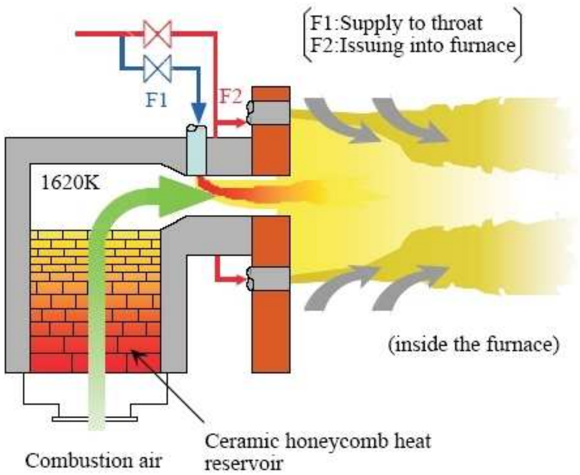


Fig. 1. Scheme of the NFK-HRS-DL type burner (NFK Direct Firing System) [10]

The HRS burner concept depends on the High Temperature Air Combustion with high performance regenerative heat exchangers. The wide range of HRS burners used in industrial furnace applications opened a series of the HRS-DL burners. This type of burners is installed in furnaces where energy flux is exchanged directly between flue gas and heating charge. The idea behind the system is that two burners work alternatively (Fig.2). When burner A works as a burner (the firing mode), burner B sucks the exhaust gas from the combustion chamber (the regenerative mode). The burners change their functions after the switching time. Burner maximum thermal efficiency for such regenerators is achieved during 30-second switching time [5, 6].

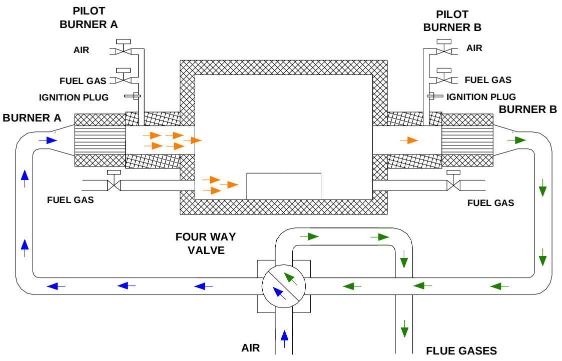


Fig. 2. Scheme of the HRS burners pair operation [11]

The burners enclose a regenerative bed called “the honeycomb”, made of ceramics resistant to high temperature of flue gas. The high performance heat exchanger allows combustion air of ambient temperature to preheat up to the temperature close to the sucked flue gas temperature during the the regenerative mode of the burner [1]. The arrangement of a pair of the HRS burners is presented in Figure 3.

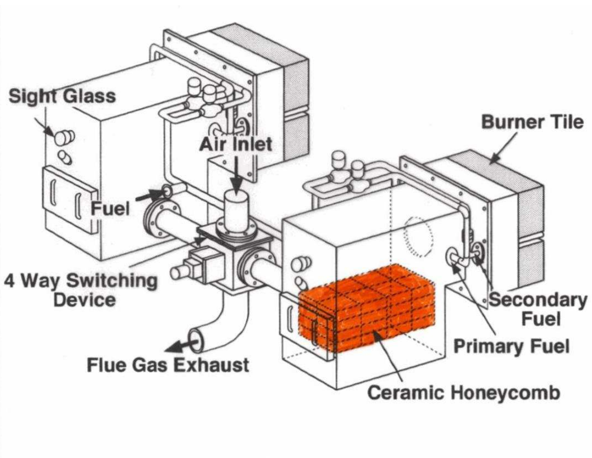


Fig. 3. HRS burners pair DL- series [12]

The HRS burner system may operate in two ways: the conventional high velocity combustion mode (F1) and the HiTAC mode (F2). A schematic drawing of the F1 and F2 combustion modes are shown in Figure 4.

During the heat-up the furnace burner works in the F1 mode, however, always as a regenerative burner. When combustion chamber temperature exceeds 800˚C, gas is supplied through F2 nozzles and the burner starts to work in the F2 mode [1].

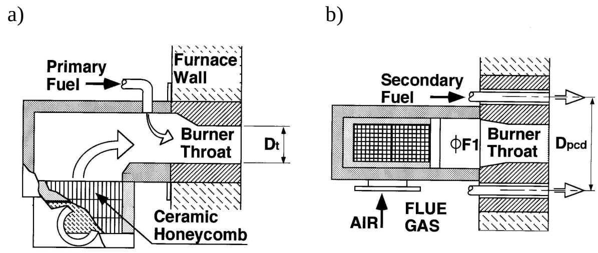


Fig. 4. Scheme of HRS burner typical work during a) F1 mode and b) F2 mode [12]

The regenerative heat exchanger used in the HRS burners is made from ceramic honeycombs (Fig.5). A typical honeycomb used as a regenerative medium has 100 cells per square inch. This great number of cells per square inch ensures the following features of the regenerative heat exchanger (Fig. 6) [13]:

- high specific surface area equal to 1307 m^2/m^3, about 7 times bigger than in the case of the ball type (a ball diameter – 20 mm)
- high equivalent heat transfer rate per volume equal to 165 $kW/m^{3}\cdot K$, about 5 times bigger than in the case of the ball type,
- 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 causes that burners are compact and easy to install, especially during furnace revamping.
- short optimum switching time equal to 30 s - the time where the highest regenerative efficiency is obtained. It is about 2 to 4 times lower compared to 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 the construction of the honeycombs (lack of flow dead zone)

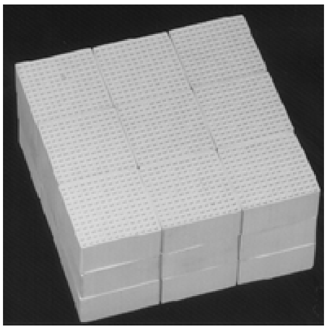


Fig. 5. Square type of ceramic “honeycomb” regenerative heat exchangers [14]

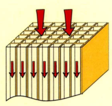
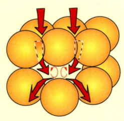
Regenerator	Honeycomb (100 cell/in2)	Ball (20mm dia.)
		
1. Heat transfer surface area per vol.	$1307 m^2/m^3$ (7 times)	$186 m^2/m^3$
2. Heat transfer coefficent@1.5Nm/s	$126 W/m^2.K$ (0.7 times)	$174 W/m^2.K$
3. Equivalent heat transfer rate per vol.	$165 kW/m^3.K$ (5 times)	$32 kW/m^3.K$
4. Temperature efficiency	90~96%	70~85%
5. Pressure loss@1.5Nm/s, 300mmL	88mmH_2O (0.3 times)	289mmH_2O
6. Weight	$500 kg/m^3$ (0.35 times)	$1430 kg/m^3$

Fig. 6. Comparison of ceramic honeycomb and ball [12]

High efficiency of the honeycombs results in fuel saving after the revamp of furnaces. The savings can reach even about 50% (Fig. 7). The highest level of fuel saving takes place when the furnace before revamping is equipped with a poor recovery system or even does not have one [1, 5, 6].

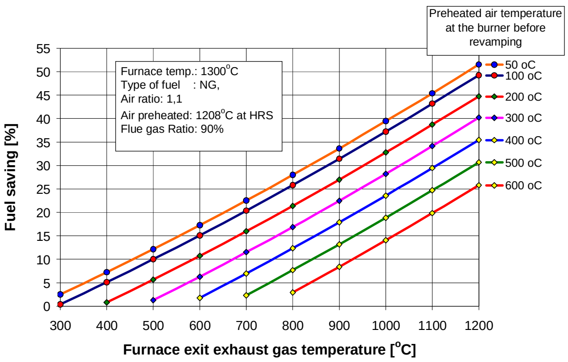


Fig. 7. Fuel saving as a function of furnace exhaust gas temperature [2, 5]

The fuel savings for the typical furnaces are on the range of 20% - 35% because of standard preheated air temperature is on the range of 300˚C - 450˚C and furnace exit exhaust gas temperature is on the range of 900˚C - 1100˚C.

Description of the installation

The first Polish industrial application of the HiTAC technology combined with HRS burners in a walking beam steel reheating furnace was installed in Rolling Mill Plant Ferrostal Sp.z o.o. in Gliwice in Poland. Ferrostal is a steel reinforcement bar manufacturer located in southern Poland, which is a part of the Złomrex Group. The installation was commissioned in March 2008. The Project covered the revamp of the reheating walking beam furnace with a new combustion system. The revamped furnace is a part of bar production line where carbon steel is rolled.

The installation consists of the following elements:

- 4 x HRS DL5 burners (2 pairs) – 2300.0 kW per burner pair, inside with refractory lining, equipped with fuel lances and a regenerative bed called “the honeycomb”.
- 6 x HRS DL4S burners (3 pairs) – 1550.0 kW per burner pair, inside with refractory lining, equipped with fuel lances and a regenerative bed called “the honeycomb”.
- 3 x TermJet burners – 879.0 kW per burner,
- walking beam type steel reheating furnace

The installation consists of five pairs of the HRS regenerative burners. Two pairs of the HRS DL5 burners are installed in the furnace heating zone and 3 pairs of the HRS DL4S burners are installed in the furnace soaking zone. The three conventional TermJet burners are used for the furnace cold start and heating up to temperature over 800˚C (at this time the HRS burners are in the stand-by mode). When temperature achieves a certain level (800°C), the HRS burners are started. All the HRS DL type burners (Figs.8, 9) are natural gas fired units equipped only with the high temperature mode (F2 mode).

Fig. 8. Furnace sidewall installation - HRS burners

Fig. 9. HRS DL4S burners

In the installed system, the burners work alternatively in pairs. When one burner works as a burner (the firing mode), the second burner sucks the exhaust gas from the combustion chamber (the regenerative mode). After 30-second switching time burners switch their functions. The burner pairs in the heating zone work in “parallel mode”. It means that two burners from different burner pairs and located on the same side of the furnace operate simultaneously in the same mode (firing or regenerative mode). The burner pairs in the soaking zone work in “stagger mode”, it means that there is 10-second delay time between switching of the burner pairs. To avoid switching the burners from different zone at the same time, 2.5-second delay time between switching of the zones was implement to the control system.

Application of such solutions causes that natural gas, combustion air and flue gases are intensively mixed in the furnace. As a result the homogenous furnace atmosphere and uniform temperature profile in the furnace are obtained. Additionally, the proper switching sequences make possible keeping a stable pressure in the main installations of natural gas, air and flue gases. The final installation is shown in Figure 10.

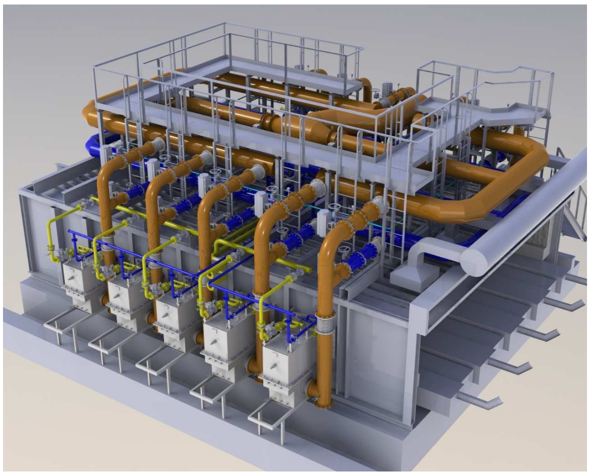


Fig. 10. Installation – design stage

Aims of the project

Main aims of the project and characteristics of the combustion system before and after revamping are presented below.

<u>The aims of the project were:</u>

- to increase furnace capacity,
- to reduce unit fuel consumption,
- to improve product quality.

<u>The furnace and combustion system before revamping:</u>

- Furnace type:
  - o walking beam type steel reheating furnace,
  - o top firing zone only, two sections without typical dark zone,
  - o maximum production rate 15.0 t/h.
- Furnace internal dimensions:
  - o length:11,150.0 mm (the working length - till center of discharge window is 10,000.0 mm),
  - o width: 7,540.0 mm,
  - o height: 1,500.0 mm.
- Type of material:
  - o bars: 100×100 ÷ 140×140 mm,
  - o length 6.000,0 mm,
  - o carbon steel.
- Combustion system type:
  - o heating zone: 8 roof burners, 814.0 kW each, average zone temperature 1250˚C,
  - o soaking zone: 8 roof burners, 442.0 kW each, average zone temperature 1250˚C,
  - o average air temperature before the burners 230˚C.
- Energy consumption:
  - o average production rate 12.15 t/h,
  - o average fuel consumption: 52.56 Nm^3/t.

The old furnace and combustion system before revamping are presented in Figure 11.

Fig. 11. Furnace before revamping

<u>The furnace and combustion system after revamping:</u>

- Furnace type:
  - o walking beam steel reheating furnace,
  - o top firing zone only, two main sections without typical dark zone,
  - o maximum production rate 20.0 t/h.
- Furnace internal dimensions:
  - o the same as before revamping.
- Type of material:
  - o the same as before revamping.
- Combustion system type:
  - o heating zone: 2 pairs of the HRS DL5, 2300.0 kW per burner pair, design zone temperature 1250˚C,
  - o soaking zone: 3 pairs of the HRS DL4S, 1550.0 kW per burner pair, design zone temperature 1350˚C,
  - o additional soaking zone: 3 TermJet burners, 879.0 kW per burner, design zone temperature 1350˚C,
- Energy consumption:
  - o average production rate 13.39 t/h,
  - o average fuel consumption: 38.37 Nm^3/t.

The new HRS combustion system is presented in Figure 12.

Fig. 12. Furnace and combustion system after revamping

Results and discussion

In order to analyse furnace operation, the archival data from the control system were downloaded. On the basis of the obtained data, a relationship between unit energy consumption [MJ/kg], unit fuel consumption [Nm^3/h] and a production rate [tone/h] was prepared (Fig. 13).

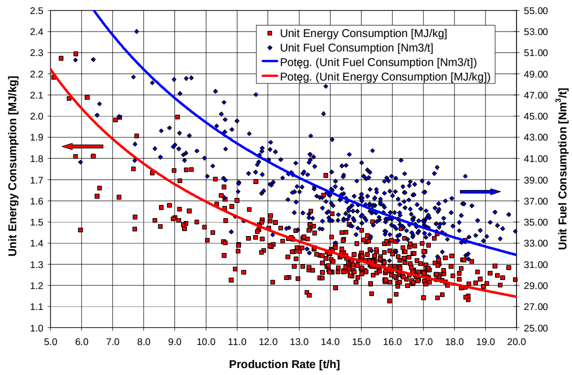


Fig. 13. Relationships between unit energy consumption, unit fuel consumption and a production rate

As shown in Figure 13, the unit energy consumption and unit fuel consumption fall down along with an increase in the production rate. For the nominal furnace capacity (20.0 t/h – tone steel per hour) energy consumption is about 1.2 MJ/kg. The unit energy consumption for the average production rate (13.39 t/h) is 1.38 MJ/kg. However, unit fuel consumption for the nominal furnace capacity is about 33.0 Nm^3/t and 38.37 Nm^3/t for furnace average production. The presented results were calculated based on the average shift (8 hours) fuel consumptions and production rates. The average values include furnace operation period (maximum 7.5 hours) and also furnace hot stand-by period (when production line after the furnace is adjusted, minimum 0.5 hours). If the furnace works continuously, the achieved results will be better.

Additionally, it needs to be pointed out that changes of the furnace production rate from the minimum to nominal furnace capacity have significant influence on reduction in the furnace unit energy consumption. Therefore, the obtained results will be even better if the furnace average production rate increases to the nominal capacity. Now the furnace average production rate (13.39 t/h) is only 67% of the nominal furnace capacity (20.0 t/h).

Obtained results are compared to the unit fuel consumptions (52.56 Nm^3/t) achieved when old furnace worked with small production rate (average 12,15 t/h). If the old furnace worked with higher production rate (20.0 t/h), its unit fuel consumption would be significantly higher and the slabs overheated would probably occur.

During the furnace operation, heating zone temperature is usually about 1200˚C and soaking zone temperature is about 1250˚C. Temperature distribution in the furnace is much even in comparison to the previous combustion system, which has significant influence on even heating of bars. In the previous system bars in certain parts were usually overheated.

On the basis of previous experiences and observations of the furnaces using the HiTAC technology, it can be claimed that NO_X emission is very low.

The obtained effects resulting from furnace and combustion system revamping are excellent in comparison to the previous system. In some cases these effects are better than the design assumptions.

Conclusion

On the basis of over two-year observation of the furnace operation, in comparison to previous system the following advantages were noticed:

- much even temperature distribution in the furnace
- substantial improvement of the final product quality,
- reduction in scale production,
- increase in the maximum furnace capacity from 15.0 t/h to 20.0 t/h, **that is by 5.0 t/h (33% relatively),**
- reduction in the unit fuel consumption from 52.56 Nm^3/t to 38.37 Nm^3/t, **that is by 14.19 Nm^3/t (27% relatively)** for the average production rate, **for the nominal furnace capacity unit fuel consumption is about 33.0 Nm^3/t,**
- CO and NO_X emission decreased.

It needs to be pointed out that all the above results were achieved by applying the High Temperature Air Combustion (HiTAC) technology combined with the HRS combustion system. It also must be noted that all the mentioned effects were obtained without furnace shell modification.

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