Low NO$_x$ HTB Burners for reheating furnaces

Low NOX HTB Burners for reheating furnaces

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W KILKU SŁOWACH

Ciągły wzrost wymagań dotyczących ochrony środowiska oraz dążenie do obniżenia kosztów energii skutkuje rozwojem coraz bardziej wydajnych i proekologicznych technologii wśród wszystkich branż przemysłu. Jednakże, nie tylko obniżenie emisji zanieczyszczeń (np. NOX) czy zużycia energii, ale także wysoka jakość produktów, niezawodność urządzeń, jednolity profil temperatury, odpowiedni strumień ciepła i bezpieczeństwo są niezwykle istotne. Wszystkie te kwestie są kluczowe dla przemysłu ciężkiego w obszarze procesów spalania.

Powyższe aspekty zostały dokładnie sprawdzone i potwierdzone w technologii HiTAC podczas wieloletnich badań, a wyniki opisane w wielu publikacjach. Palnik HTB (ang. High Temperature Burner – palnik wysokotemperaturowy) wykorzystuje technologię spalania HiTAC oferują znacznie więcej korzyści niż te, które zostały wymienione powyżej. Palnik HTB jest wytrzymałym, wysokiej jakości produktem, umożliwiającym łatwe dostosowanie do istniejących warunków zabudowy i pracy pieca. Ponadto umożliwia on wykorzystanie istniejącego systemu rekuperacji oraz pozwala pracować z różnymi rodzajami paliw. Palnik HTB charakteryzuje się prostą konstrukcją, co sprawia, że jest praktycznie bezobsługowy. Zastosowanie palników HTB pozwala też na zmniejszenie kosztów operacyjnych poprzez wzrost żywotności wyłożenia ogniotrwałego komory spalania/pieca uzyskiwany dzięki wyeliminowaniu powstawania tzw. pików temperatury.

Niniejszy artykuł opisuje zalety palników HTB w kontekście redukcji emisji zanieczyszczeń, obniżania kosztów operacyjnych oraz podniesienia jakości produktu w systemach spalania opartych o palniki HTB. Opis systemu przygotowany jest w oparciu o piec grzewczy pokroczny o wydajności projektowej równej 300t/h wykorzystujący wyłącznie palniki HTB (poza palnikami sufitowymi).

SUMMARY

The continuously increasing standards of environmental protection and the drive to reduce energy costs result in the development of more efficient and environmentally friendly technologies across all sectors of industry. However, lowering levels of pollutants emissions (like NOX) and power consumption are as crucially important as high product quality, reliability, uniform temperature profile, appropriate heat flux, and safety. All these factors are of key significance for the heavy industry with regard to combustion processes.

The abovementioned aspects had been thoroughly examined and proven over many years in studies employing the HiTAC technology (High Temperature Air Combustion). The results appeared in numerous publications. HTB (High Temperature Burner) utilizes the HiTAC combustion technology, offering an even wider range of advantages than those listed above. It is a heavy-duty high-quality product which can be easily adapted to an existing installation. Furthermore, HTB can utilise an existing recuperative system and is suitable for use with a variety of different fuels. Owing to the simple design, the burner is virtually maintenance-free. It should be also stressed that using HTB can provide cost savings, as eliminating temperature peaks improves the life of the combustion chamber refractory lining.

The following article discusses the advantages of HTB-type burners with regard to reducing pollutants emissions, decreasing operating expenses, and improving product quality in HTB-based combustion systems. The description is based on the walking beam reheating furnace with the design capacity of 300 t/h using almost exclusively HTB burners (with the exception of roof burners).

Fig. 1. Photo of the HTB burner

with burner piping during erection

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A continuous increase in authorities' demands regarding the environmental protection and striving for reduction of energy costs result in development of more efficient and more ecological technologies amongst all industrial branches. However, not only lowering of the emission of the pollutants (for example NO$_x$) and the power consumption, but also high quality of the product, reliability, uniform temperature, heat flux and safety are of the highest importance. All the mentioned matters are key factors for heavy industry in the area of combustion processes.

These aspects have been widely examined and proved by HiTAC technology (High Temperature Air Combustion) for many years and described in many papers (1, 2, 3, 4, 5, 6, 7, 8).

HTB (High Temperature Burner) utilizes the HiTAC combustion technology and gives more advantages than mentioned above. The HTB (Fig. 1) is a heavy duty, high-tech product that allows easy adjustment to existing furnace conditions, using the existing recuperative system and a possibility of working with different types of fuels(9). Moreover, the HTB burner is easy to operate and is almost maintenance free. Finally, the HTB burner can decrease operating costs thanks to an increase in combustion chamber refractory lining lifetime due to avoiding temperature peaks.

This paper describes and proves the advantages of the HTB burners in the context of pollutant emission reduction, lowering of the operating costs and an increase in the product quality in the HTB systems. The description is based on the walking beam reheating furnace with design capacity of 300 t/h using almost only HTB burners.

Background

The HiTAC combustion technology has been incorporated in hundreds of industrial applications mainly in Japan over the last decades. It has been introduced into the market by the Japanese company called NFK (Nippon Furnace Kogyo), since the beginning of the 90 s or even late 80 s of the last century. The general principle of the technology is to carry out a combustion process at high temperature in the whole chamber with a significantly lowered oxygen level in the area where the combustion process takes place due to intense internal flue gas recirculation. Therefore, the HiTAC is referred to as "volumetric combustion" or sometimes as "flameless combustion" due to diluted flame in the combustion process(9, 10, 11).

The HiTAC combustion technology provides many advantages(4, 5, 8, 11, 12, 13, 14, 15, 16, 17):

1. Flat heat flux distribution,
2. Flat temperature distribution,
3. Low emission of NO_x due to lack of temperature peaks,
4. Possibility of decreasing of fuel consumption,
5. Lower average temperature in the zone, due to carrying out of the combustion process in large volume,
6. Ability to increase zone capacity, due to making possible an increase in zone temperature,
7. Higher refractory lining lifetime due to lack of temperature peaks,
8. Low noise,
9. Possibility of burning fuel with very low heating value (LHV).

The HiTAC technology has been successfully applied in the HTB burners in cooperation between ICS and NFK company.

The advantages of the HTB burners resulting from the HiTAC technology can be grouped in four areas:

1. Improvement in final product quality,
2. Increase in equipment lifetime,
3. Reduction in pollutants,
4. Reduction in fuel consumption.

All these features are available together with reliability and safety(9).

The HTB burners (Fig. 2) have a very simple construction and consist of the following main components:

- Metal casing lined internally with refractory insulation,
- Air nozzle located in the centre of burner serving as a burner throat,
- Fuel F1 lance (option),
- Fuel F2 lance(s) located at a specific distance from the air nozzle,
- Pilot burner (option).

Fig. 2. 3D visualization of the HTB burner with burner piping

The HTB burner can work from ambient temperature in the conventional mode called the F1 mode or low temperature mode. The F1 mode is achieved by mixing of combustion air and fuel inside the burner and ignition of the mixture by the pilot burner before the outlet into the combustion chamber. This is used for gradual heating up of the combustion chamber. After the temperature reaches the fuel auto-ignition point the burners can be switched to the HiTAC mode called the F2 mode or high temperature mode. In this mode the fuel and combustion air are injected directly into the combustion chamber by separate nozzles. This principle stands behind the HiTAC combustion technology. High velocity of the air flow injected through the centre of the burner and a specific F2 fuel lance(s) location from the air nozzle result in gradual mixing of the combustion process reactants (air, fuel, and flue gases) through internal recirculation inside the combustion chamber(9, 11). The schematic idea of the HTB burner operation principles is presented in Fig. 3.

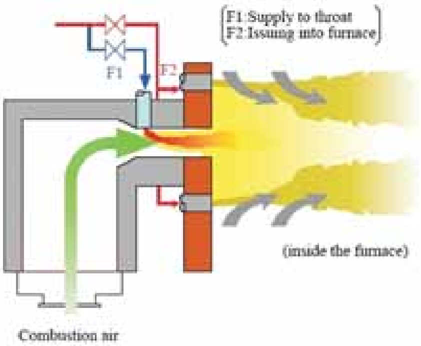

Fig. 3. Schematic HTB burner operation principles (14)

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The internal recirculation leads to dilution of air and, as a result, to reduction of the local oxygen concentration in the area where the combustion process takes place. This, together with high temperature of the combustion process, leads to very uniform temperature and heat flux, prevents temperature peaks, and reduces NO_X emission(9, 18, 19). The graph showing comparison of NO_X curve for the conventional and HiTAC combustion is presented in Fig. 4.

Compared to the conventional burners, the temperature peaks are even 5 to 7 times lower for HTB burners(20). This significantly influences the heat flux peaks which decrease with peak temperature lowering.

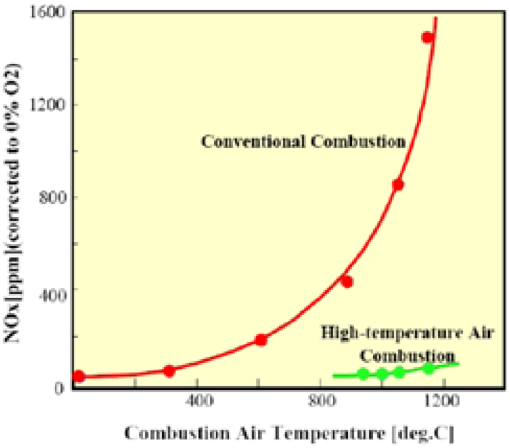

Fig. 4. Conventional combustion and HiTAC combustion – NO_X profile (21)

Since the HTB burners can be equipped with pilot burners (F1/F2 mode burner), there is no necessity to install additional external burners in order to bring the furnace into the high temperature at which the HiTAC mode can operate. The furnace can be equipped with burners capable of working in the F2 mode only, in the F1 and F2 or as a combination of both types of the burners.

Installation

The example of the HTB burners application is the revamp of the combustion system at the reheating furnace in SSAB Tunnplåt AB, Borlänge, Sweden, which is a part of SSAB Group, a global producer of high strength steel. The revamped furnace is a part of a steel sheet production plant where steel slabs are rolled. The sketch of the furnace is presented in Fig. 5.

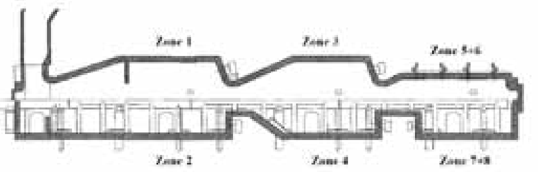

Fig.5. Layout of the reheating furnace, SSAB

The combustion system has been designed by ICS company. The system works on propane or LPG fuel with the combustion air preheated up to 600°C by a central recuperative system. The control temperature of the zones is between 1,100°C–1,320°C during normal operation. The furnace where the burners are installed is a walking beam type furnace with design capacity of 300 t/h. The photo of a part of the HTB burners installed in SSAB is presented in Fig. 6 .

Fig. 6. Photo of the HTB burners, zone 3, SSAB

The combustion system was revamped two times. In 2006 two zones were rebuilt, Zone 1: 8 HTB-DL3.5 burners, each with firing power rate capacity of 3.5 MW and Zone 2: 9 HTB-DL3.8 each with firing power rate capacity of 3.8 MW. The total firing power rate of both zones was 62.7 MW. The investor's expectation was to reduce the NO_X emission originating from Zone 1 and Zone 2 down to 65 ppm (normalized to 5% of O_2). In 2008 four remaining zones were revamped: Zone 3 (8 HTB-DL2.8 – 2.8 MW), Zone 4 (9 HTB-DL2.7 – 2.7 MW), and Zone 7/8 (in total 9 HTB-DL1.2 – 1.2 MW). The investor's expectation was to reduce the NO_X emission down to

62 ppm (excluding Zone 5/6) to meet the current authorities' demands. The total firing power rate of the rebuilt zones in 2008 was 56.8 MW. After both installations the total firing power rate of the units designed by ICS is 119 MW, that is, 92.8 % of the total heating power of the combustion system installed at the furnace. The remaining 7.21% (9.28 MW) of the total heating power comes from the roof burners from Zone 5 and Zone 6 where due to the location it is not possible to install the HTB burners. It has to be emphasized that in both cases the installation was revamped without lowering the overall firing capacity of the furnace and production capacities. The values of power rates for particular burners and zones in Furnace 301 are presented in Table 1.

Zone no.	HTB burners per zone	Burner power rate [MW]	Zone power rate [MW]	Zone power rate to total furnace power rate	Revamp year
1	8	3.50	28.0	21.7%	2006
2	9	3.85	34.7	26.9%	2006
3	8	2.80	22.4	17.4%	2008
4	9	2.68	24.1	18.7%	2008
5	16	0.29	4.64	3.60%	–
6	16	0.29	4.64	3.60%	–
7	4	1.15	4.60	3.57%	2008
8	5	1.15	5.75	4.47%	2008

Tab. 1. Burner and zone power rates

Results and discussion

The objective for the revamp of Zone 1 and Zone 2 in 2006 was to reduce the NO_x emission down to 65 ppm from these particular two zones. The NO_x emission from Zone 1 and 2 was calculated by a difference between the total emission and emissions from Zone 3 to 8 according to the equation below:

$$x_{NO,1-2}=\frac{x_{NO,1-8}\,\lambda_{1-8}\,\dot{m}_{FG,1-8}-x_{NO,3-8}\,\lambda_{3-8}\,\dot{m}_{FG,3-8}}{\lambda_{1-8}\,\dot{m}_{FG,1-8}-\lambda_{3-8}\,\dot{m}_{FG,3-8}}\,[ppm]$$

where:

$x_{NO,i}$ – NO in [ppm] in corresponding points,
$\dot{m}_{FG,i}$ – mass flow of LPG in [kg/h] for corresponding zones,
λ_i – excess air number in corresponding points,
$O_{2,i}$ – O_2 in [%] at corresponding points.

The goal was fully achieved. Moreover, the performed installation resulted in the total furnace NO_x emission reduction from about 134 ppm down to less than 93 ppm. This reduces the initial NO_x release by about 31%.

The NO_x contribution from the revamped Zone 1 and 2 was proven to be very low. The emissions from the particular zones are shown in Fig. 7. The NO_x net production in Zone 1 and 2 was calculated according to the mathematical algorithm(1) and the result is shown by the green line. The NO_x emission from Zone 3 to 8 is presented by the red line, while from all zones by the blue line. The NO_x emission for Zone 1 and 2 is well below 50 ppm most of the time. One can observe that in many cases the calculated values for Zone 1 and 2 are below zero. It is due to reduction of NO_x from the other zones by the reburning process occurring in Zone 1 and 2. However, it can be also possible due to measurement discrepancies originating from the measurement of the local NO_x emission in the furnace.

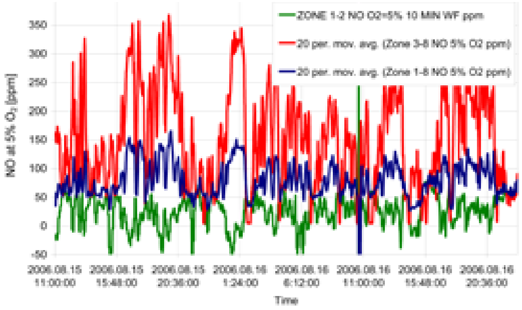

Fig. 7. NO_x emission after the first revamp of Zone 1 and 2 in 2006

The guarantee level for the second revamp in 2008 was to achieve NO_x emission reduction down to 62 ppm for the whole furnace excluding NO_x emission from Zone 5 and 6. The total NO_x emission from the total furnace except Zone 5 and 6 was determined by a difference between total emission and emissions from Zone 5 and 6 according to the equation below:

$$x_{NO,\,TOT}=\frac{x_{NO,1-8}\,\lambda_{1-8}\,\dot{m}_{FG,1-8}-x_{NO,5-6}\,\lambda_{5-6}\,\dot{m}_{FG,5-6}}{\lambda_{1-8}\,\dot{m}_{FG,1-8}-\lambda_{5-6}\,\dot{m}_{FG,5-6}}\,[ppm]$$

where:

$x_{NO,i}$ – NO in [ppm] in corresponding points,
$\dot{m}_{FG,i}$ – mass flow of LPG in [kg/h] for corresponding zones,
λ_i – excess air number in corresponding points,
$O_{2,i}$ – O_2 in [%] at corresponding points.

The guarantee test was fully performed as well. Moreover, the NO_x emission was reduced from 93 ppm to around 62 ppm for the whole furnace including Zone 5 and 6 which is 33% less compared to the initial levels.

After both revamps the complete obtained emission reduction amounted to over 50% com-

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pared to the emission before installation of any HTB burners. All the obtained outcomes are corrected to 5% of oxygen in flue gases. The overall firing capacity of the furnace and production capacities remained unchanged. The graphical presentation of averaged NO_X levels before and after the performed revamps is shown in Fig. 8.

The presented data originate from the period of 24 months of continuous operation after the first installation of HTB burners in 2006. In the case of results concerning the second revamp, the data originate from the period of 15 months after the end of the assembly. However, due to the furnace stoppage connected with the global crisis at the market the given value of the averaged NO_X emission is calculated on the basis of the results from 10-month periodical furnace operation.

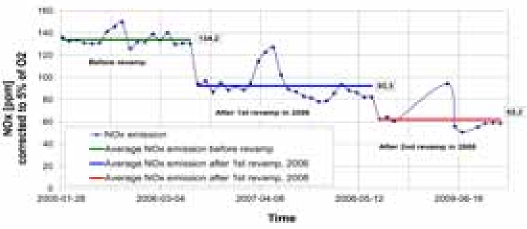

Fig. 8. NO_X emissions before and after HTB burners assembly

One can observe a high peak after the first revamp and a high peak after the second revamp in Fig. 8. The first peak corresponds to the time of an unfortunate breakdown of the furnace roof. An uncontrolled amount of leakage air was forced into the furnace due to the necessity of using a low furnace pressure. As an effect, higher than usual NO_X levels were obtained due to much higher oxygen quantities in the furnace. The second peak corresponds to the heating up procedure after the longer furnace stop. The heating up procedure is operated with using the low temperature mode of operation. This mode is operated with relatively high local combustion temperature and relatively high local oxygen concentration compared to the HiTAC mode, leading to higher NO_X emissions. Therefore, the average NO_X level for the HiTAC combustion would be even smaller if the peak data were excluded.

The phenomenon of the nitrogen oxides emission increase as an effect of the O_2 content increase in flue gases is shown in Fig. 9. The data come from$^{(22)}$ and concern laboratory tests of which conditions are briefly described below. The graph shows nitrogen oxides emission as a function of O_2 content in the oxidizer for propane and methane which were injected into the combustion chamber in a cross-flow pattern.

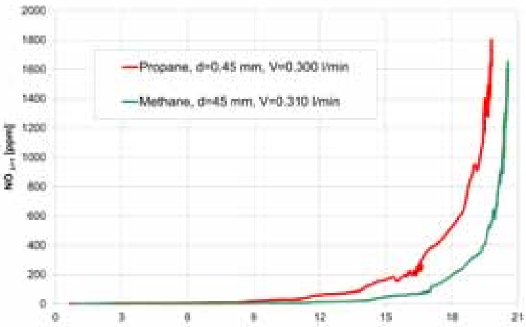

Fig. 9. NO_X emissions in relation to O_2 concentration in oxidizer$^{(22)}$

The data show that the higher O_2 content in the oxidizer (over about 12-15%) causes a significant increase in nitrogen oxides generation, since it results in higher content of radicals and combustion temperature. Both these factors influence simultaneously the increase in laminar velocity of combustion as well as creation of nitrogen oxides, which is reflected in Fig. 9 as a NO_X peak in the curve after the first revamp in 2006 $^{(22)}$.

Another data analysis coming from the time before and after the erection in 2008 shows the influence of the HTB burners on a temperature distribution of the slabs released from the furnace and rolled at the mill. These data are presented in a graphical form in Fig. 10 .

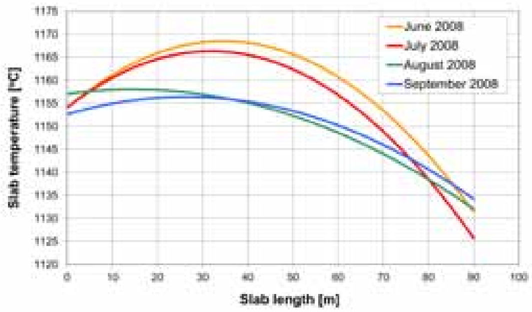

Fig. 10. Slab temperature distribution after the rolling mill before and after the revamp in 2008

The data come from June and July 2008 before the revamp of Zone 3, 4, 7 and 8 and from August and September the same year after the new installation was built. As it can be observed before new burners were installed (the red and orange line) the temperature distribution in the slab is much more inhomogeneous compared to the slab temperature distribution after the assembly of the HTB burners (the blue and green line). For slabs after the revamp in 2008 there are no significant temperature differences along the elements compared to the slabs temperature differences before the revamp. Much better temperature homogeneity over the slab length proves better temperature homogeneity inside the furnace. This is an effect of "volumetric combustion"(10) which takes place in the whole volume of the combustion chamber due to diluted flame. The conventional burners do not posses this advantage. Thus, in case of the conventional burners the temperature close to the furnace walls can have much lower temperature compared to temperature in the middle of the furnace (Fig. 10).

Better homogeneity of the slab temperature which results from better furnace temperature uniformity is also a consequence of easy adjustment of the firing power rate of a particular burner due to separate regulation valves for a particular burner and its wide, effective turn down ratio. Therefore, the outside zone burners located closer to the furnace wall can be adjusted to higher firing power rates. On the other hand, the burners which are more responsible for the heating up of the middle part of the furnace can be regulated to lower firing power rates, since it is easier to heat up the internal furnace part than the area around the walls.

Heating with a more uniform temperature profile can give an important economical advantage. Due to the even temperature in the furnace any point or region of the discharging slab have sufficient temperature for rolling and none of the points are overheated. With less energy used, the lower average temperature of the extracted slab is obtained. In fact, the lower average temperature of the slab could need more power for slab thickness, reduction, due to higher average resistance. On the other hand, a more uniform and reliable temperature profile gives a lot better situation to deal with quality related problems, such as thickness and with the control and material properties of steel. This in turn makes possible correct performance of steel slabs processing for the first time which saves both time and energy.

Improvement of slab heating can be observed in Fig. 11 and Fig. 12. The slabs according to rolling treatment at the mill can be divided into three parts: the head, the body and the tail, of which temperatures are measured by the UV temperature meter at different spots of the transfer bar. The division of the slab is the following: the head is approx the first 10%, the body is next 80% in the middle and the tail is the last 10%.

Fig. 11. Presentation of temperature at different parts of the slab

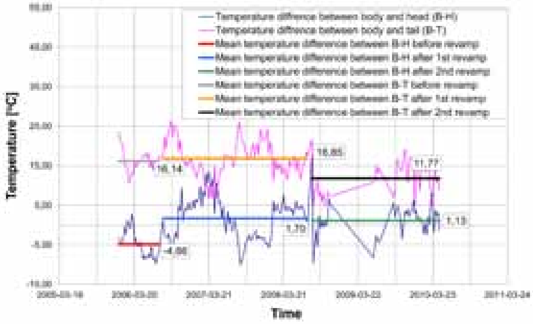

Fig. 12. Presentation of temperature uniformity assessment factors

There are two important factors that are taken into consideration regarding slab temperature homogeneity assessment. First, it is important that a temperature difference between the body and the head ("body – head") as well as the body and the tail ("body – tail") is consistent in time. It has to be noticed that in the case of the consistent slab heating process the pre-settings of the mill are reliable and accurate. Second, the differences between certain slab parts should not be as small as possible, but close to zero for "body – head" and approx "+10" for "body – tail". Then the slab is considered to be evenly heated in the furnace. During the rolling, the tail becomes cooler compared to the body due to longer time before reaching the rolling mill. Calculations of average values of the temperatures differen-

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ces “body – head” and “body – tail” for periods before and after the first revamp and after the second revamp show superiority of the HTB burners over conventional ones. For the calculation purposes, in order to avoid influence of extreme samples (out layers), 5% of the samples with the highest and with 5% the lowest values were rejected from the series. The calculated average values for temperature differences “body – head” are: -4.88; 1.70; 1.13 for particular periods respectively. One can observe significant improvement of this factor: the temperature difference is very close to “0” after the second revamp, especially in comparison to the value before any revamp was done. The average values for the difference “body – tail” are the following: 16.14; 16.85; 11.77 for particular periods respectively. One can also observe significant improvement of this factor, which as an assumption for the good temperature homogeneity is close to “+10”. The very good result for the second revamp is caused by the fact that it concerns the revamp of both heating and soaking zones revamp, which have much bigger influence on the slab temperature uniformity than preheating zones (Zone 1 and 2).

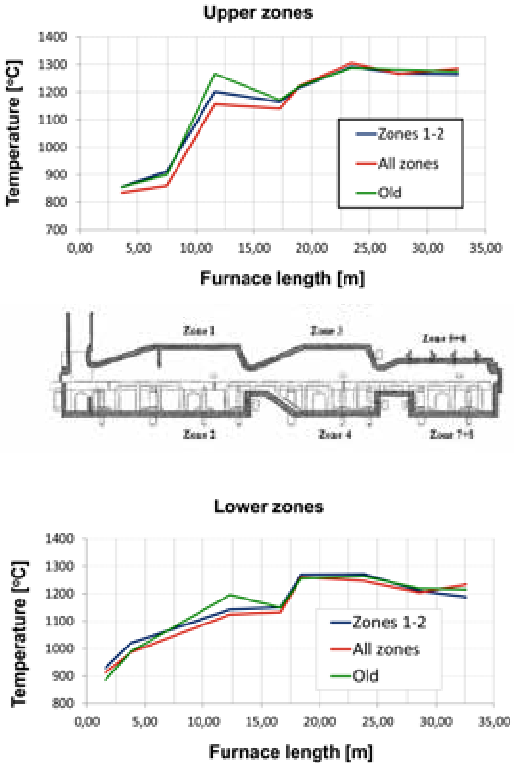

Fig. 13. Zone temperatures before and after the revamp in 2006

The comparison of temperature profiles along the furnace measured by thermocouples on furnace walls are presented in Fig. 13. The data come from the time before the revamp (the green line), after the revamp of Zone 1 and Zone 2 (the blue line) and after revamp of all zones (the red line). For zones 3 – 8 the lines are generally overlapping, since no modifications have been made at the installation in 2006. However, one can observe a trend of lowering the temperature close to the burner area in Zone 1 and Zone 2. This is a positive trend resulting in longer lifetime of the refractory lining around the burners, which is not exposed locally to very high temperatures. On the other hand, the temperature in the further area from the burner wall is higher in Zone 2. This means better uniformity of the temperature in these two zones compared to the situation when conventional burners were installed. This is important from the controlling point of view. It is better and easier to control the furnace where the temperature is more uniform, as there are no or there are less areas with higher or lower temperature (better temperature homogeneity).

At the given graph the difference between the temperature at about the seventh meter can be observed between the Zone 1 (lower temperature) and Zone 2 (higher temperature). It is caused by a special barrier which protects against radiation.

Referring to refractory lining lifetime, the graph presenting the steam production in the walking beam cooling system before and after the revamp of the burners in the furnace is shown in Fig. 14 .

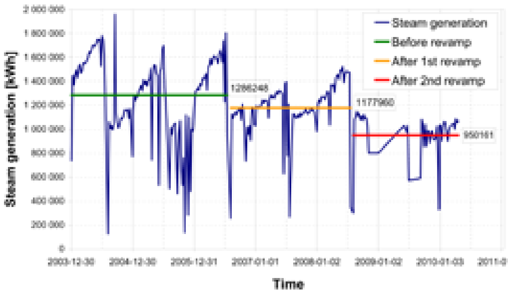

Fig. 14. Graph presenting the steam production in the walking beam cooling system

One can observe that the average steam production before HTB burners installation (the green line) is at the level of 1,286,248 kWh. After the first revamp in 2006 when the burners in two Zones 1 and 2 were changed this value is lower by

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about 9% giving 1,177,960 kWh. The lowest steam generation is recorded after the second revamp in 2008 when burners in four zones were replaced. The value of steam generation dropped down to 950,161 kWh. One can observe that the slopes of the curve for the time before the revamp are big while for the time after the first revamp get smaller to be almost flat for the time after the second revamp. These data prove that the refractory lining covering the beams was in a worse condition in comparison to the situation after the revamps, and dropped over time resulting higher steam production. It must be emphasized that working conditions for example production capacity or furnace temperature are comparable for the cases. These data prove that when the HiTAC technology is used, the refractory has longer lifetime. Additionally, the lower fuel consumption can be observed, which is important from the economical point of view.

Conclusions

The reference installation that belongs to SSAB group located in Borlänge in Sweden is a very good example of the supremacy of the HiTAC combustion and the HTB burners over the conventional combustion systems, especially as it is not a laboratory or semi-industrial application, but a real plant with the capacity of 300 t/h. Based on that and a number of performed tests and observations several conclusions can be drawn:

1. Very low NO_x emission, even far below 62 ppm.
2. Improved furnace temperature – very even temperature distribution in the zones.
3. Increase in lifetime of the combustion chamber refractory.
4. Improvement of the product quality.
5. No necessity to modify or rebuild existing recuperative systems.
6. Simple construction of the burners allows easy adjustment to the furnace conditions.

These advantages of the HiTAC and the HTB burners allows to draw a general conclusion that the HiTAC/HTB burners are a state of the art technology.