Copper blast furnace waste gas utilization system as a new field of HiTAC combustion technology

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Abstract

A continuous increase in ecological consciousness and high pressure to reduce the energy cost in many areas within the companies result in the high interest of industry in applying the newest combustion technology. This type of combustion technology has to ensure low pollutant emissions like NO_x and CO. It should also give the possibility of reducing energy consumption of the process or in the whole company and, at the same time, it must be a reliable, proven industrial combustion technology, because especially heavy industry customers shun field – testing of new technologies.

One of the technologies which has been recently invented and already successfully proven in hundreds of different industrial applications is the High Temperature Air Combustion (HiTAC). The low emission of NO_x and CO, uniform temperature profiles as well as heat flux in combustion chambers for different types of fuel are possible to be achieved by using this combustion technology.

Recently the unique features of the HiTAC combustion technology have also been successfully applied in a special type of HTB-DL-WG burners installed in the copper blast furnace waste gas utilization system. The HiTAC combustion technology besides, the typical advantages mentioned above: low NO_x and CO emission and good temperature distribution, gives one more very important feature. It is the insensitivity to the very low and fluctuating LHV and to the fluctuating flow rate of fuel gases.

The paper presents the advantages of the HiTAC combustion technology in the case of the industrial waste gases utilization system with the nominal capacity of 65,000.0 Nm^3/h of waste gases (with a range of LHV from 1.5 MJ/Nm^3 to 2.4 MJ/Nm^3), connected with a steam boiler with a design steam production rate of 41.0 t/h calculated for LHV of 2.0 MJ/Nm^3 (normally the steam boiler works with capacity of 38 t/h). It needs to be pointed out that the waste gases have high moisture content above the saturated point of the waste gas and carry relatively large quantities of dust particles.

The system presented in this paper, besides the typical clear environmental advantages showed above, provides also a number of other benefits like: extremely low support fuel consumption (natural gas), high flexibility of the system and the reduction in emission of other chemical components present in the waste gases by full oxidation of them.

Key words

High Temperature Air Combustion (HiTAC), High Temperature Burners (HTB), Low NOx Combustion Technology, Waste Gas Utilization System, Copper Industry, Shaft Furnace Off Gases.

Introduction

Since the beginning of the 90s or even late 80s 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 technology is well-known. Such advantages of HiTAC as low NO_x emission or flat temperature and heat flux distributions inside furnaces have been reported in many publications [1, 2, 3, 4, 5, 6, 7, 8]. Other advantages of HiTAC like low noise [9] or the possibility of burning fuel with very low heating value can be found in many papers too [10, 11, 12].

The unique features of the HiTAC combustion technology have been successfully applied in the HRS and HTB burners. The possibility of burning fuel with very low LHV (Low Heating Value) and other features of this combustion technology are used in the special HTB-DL-WG burners.

This paper presents the advantages of application of the HiTAC technology and HTB-DL-WG burners in the copper blast furnace waste gas utilization system.

HiTAC technology and HTB 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 [13].

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, 8, 11, 12]:

- 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).

During the long-term cooperation between NFK company and ICS company new HTB burners (High Temperature Burners) were designed and made. The sketch of HTB burner is presented in Figure 1.

In this special burners the unique features of the HiTAC combustion technology have been successfully applied. The HTB burners use the same combustion technology as the one applied in the HRS burners, however HTB burners are not equipped with regenerators. Therefore, the HTB burners work continuously and cooperate with central recuperative systems [14].

As a result of the evolution of HTB burners the special HTB-DL-WG burners was designed. In this burners the HiTAC technology is realized by a high temperature mode – the so-called F2 mode (Fig. 1). The low temperature mode (F1) is used for heating up the combustion chamber/furnace to the temperature over the fuel auto-ignition point. After that the F2 mode is started and the burner starts to work continuously in the mixed mode (F1 and F2). The conversion temperature between the F1 and mixed mode depends on a lot of parameters, for example: type of fuel and combustion air temperature.

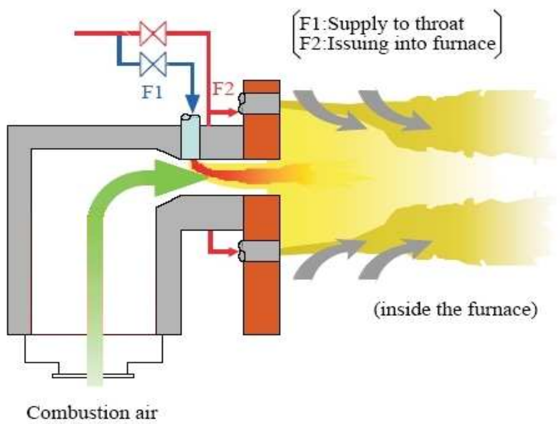

Fig. 1. HTB burner with F1 and F2 mode [15]

In the HTB burners / HTB combustion systems several techniques are applied in order to achieve the required advantages. The techniques are as follows [14]:

- very high injection velocity of the fuel gas,
- very high injection velocity of the preheated air,
- air and fuel are injected directly into the combustion chamber through separate nozzles at combustion chamber temperature over the fuel auto-ignition point,
- proper distance between nozzles and its location,
- special way of the burner control in the system.

A separate injection of fuel and preheated air into the combustion chamber results in the fact that the fuel and the air, are mixed with flue gases before the combustion process takes place (internal flue gas recirculation). This results in lowering of the peak temperature for two main reasons. Firstly, the oxygen level in the oxidizer is lowered. Secondly, fuel is burned partly before the main combustion process takes place, since the flue gas usually include some amount of 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 [14]. Higher injection velocity results in faster internal flue gas recirculation and swirls the gas volume. It is similar to the location or distance between the nozzles of fuel and air. Higher distance between them results in faster internal flue gas recirculation [16].

High internal flue gases recirculation, high injection velocity and the way of controlling the burner, results not only in proper temperature distribution but also in heat flux and flue gas composition. In some cases almost the whole combustion chamber is filled up with the combustion process. The difference between peak temperature and furnace temperature in the HTB Combustion Technology is about 5 – 7 times smaller [17] compared to the conventional technology. A similar situation occurs with heat flux – a decrease in the temperature peak results in a decrease in the heat flux peak.

The HiTAC Combustion System ensures particularly low emissions in comparison with the conventional technology regarding nitrogen oxides (NO_x) [18]. The typical NO_x emissions from the HiTAC Combustion System and the Conventional Combustion System in the reheating furnaces are presented in Figure 2.

The ultra low NO_x emission obtained in the HTB Combustion System is possible thanks to the HiTAC combustion technology. Proper control of the temperature distribution and the composition of flue gas cause that there are no temperature peaks with a high fraction of radicals (OH, CH,…). Both temperature and the amount of radicals play an important role in all NO_x creation mechanisms. Therefore by applying HiTAC, that is by avoiding the peak temperature and high concentration of radicals, which appears in the conventional combustion technology, NO_x creation is very low [14].

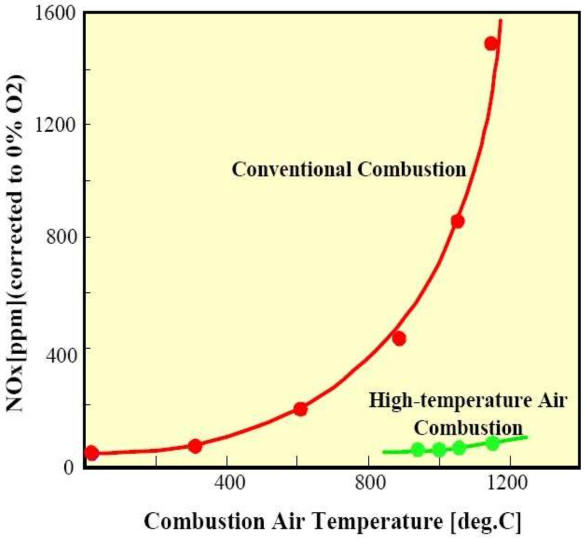

Fig. 2. NOx profiles for the conventional and HiTAC combustion [19]

Description of the installation

The first European industrial application of the copper blast furnace waste gas utilization system using the HTB-DL-WG burners was installed in Energetyka Sp. z o.o., in Głogów in Poland. Energetyka, located in western Poland, is a part of the KGHM Group. The installation was commissioned in July 2009.

The project covered replacing the old steam boiler and the old waste gas utilization system based on waste gas/coal co-firing with a new steam boiler equipped with waste gas/natural gas co-fired burners.

Due to low LHV (Low Heating Value) of 1.5-2.4 MJ/Nm^3, high moisture content and substantial solid particle contamination, the utilization of copper shaft furnace (blast furnace) waste gas is led through natural gas co-firing. In this system natural gas is used as a support fuel. Waste gas composition and low heating value are shown in Table 1.

Tab. 1. Waste gas composition and LHV

No	Component	Symbol	Unit	Min	Max
1	Methane	CH_4	%	0	0.97
2	Ethane	C_2H_6	%	0	0.08
3	Propane and higher hydrocarbons	C_3H_8	%	0	0.02
4	Hydrogen	H_2	%	1.13	6.44
5	Carbon monoxide	CO	%	9.22	13.66
6	Carbon dioxide	CO_2	%	6.44	11.28
7	Water vapour	H_2O	%	19.44	19.44
8	Oxygen	O_2	%	0.4	3.22
9	Nitrogen	N_2	%	50.0	62.54
10	Sulphur (VI) oxide (SO_2, CS_2, H_2S)	SO_2	g/Nm^3		33.25
11	Dust	-	g/Nm^3		0.1
12	Low Heating Value	LHV	MJ/Nm^3	1.5	2.4

The installation consists of the following elements:

- 3 x HTB-DL-WG15 burners, with the nominal power rate of 13,700.0 kW per burner, inside with refractory lining, equipped with: fuel lances, temperature sensors, flame scanners, pilot burners.
- semi-adiabatic combustion chamber, inside with refractory lining, equipped with temperature control system.
- steam boiler (waste-heat recovery boiler).

The HTB-DL-WG15 burners (Figs.3, 4) are double-fuel, three-stage combustion units, capable of low and high temperature operation (F1 and F2 mode).

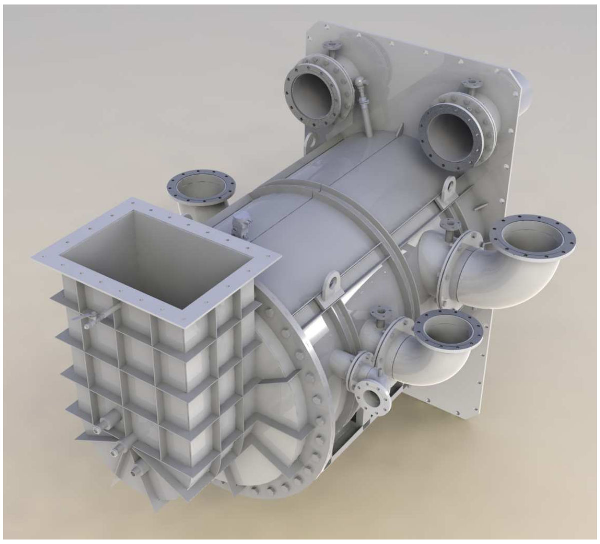

Fig. 3. HTB-DL-WG15 burner

The combustion process takes place in the semi-adiabatic combustion chamber (Fig.5). Waste gas and natural gas are delivered by three independent HTB-DL-WG15 burners. The nominal waste gas utilization system capacity is 65,000.0 Nm^3/h, in the nominal conditions natural gas consumption is 600.0 Nm^3/h.

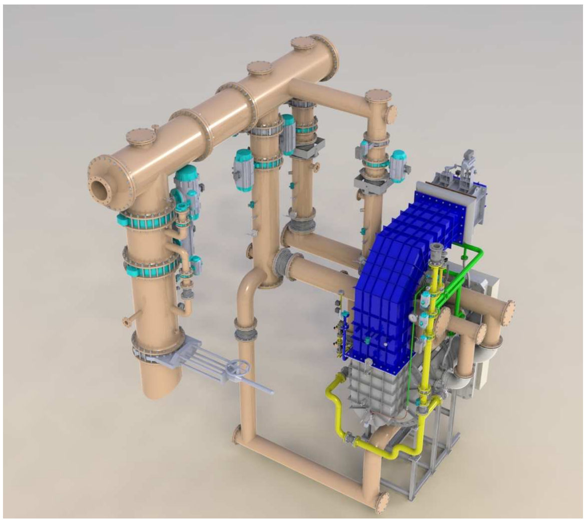

Fig. 4. HTB-DL-WG15 burner with fittings and piping

Natural gas consumption is directly related to waste gas parameters (Low Heating Value, moisture content, dust loading). If waste gas parameters deteriorate, the natural gas consumption increases to keep combustion chamber temperature at the set level.

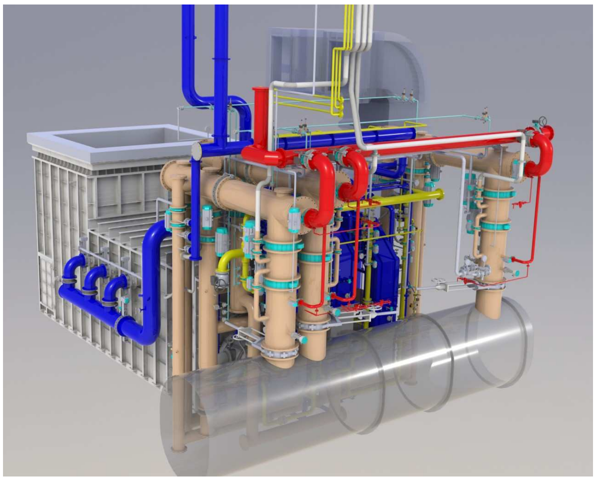

Fig. 5. Combustion chamber with burners and piping

Before waste gas is delivered, first the pilot burner is started, then natural gas is delivered to the main burner. The burners and the combustion chamber are heated up by natural gas.

When the combustion chamber temperature achieves a certain level (design conditions), the first stage of the waste gas F1 mode (the low temperature mode) is started and when temperature increases up to the next level, the second stage of waste gas F1 mode is initiated. The burner waste gas high temperature mode (the F2 mode) is activated when temperature in the combustion chamber reaches 900˚C. In order to achieve good quality of combustion process, the nominal temperature of the combustion process is from 950˚C to 1250˚C.

Exhaust gases energy produced in the combustion chamber by waste gas and natural gas co-firing is used for steam production in the next part of the installation (the steam boiler). Steam from the steam boiler is transported to steam turbines where electrical energy is produced. Low-pressure steam from the turbine is used for heat energy production and manufacturing processes.

The parts of the final installation are shown in Figures 6, 7 and 8.

Fig. 6. Part of the final installation – the main burner operating platform

Fig. 7. Part of the final installation – the combustion chamber

Fig. 8. Part of the final installation – the pilot burner operating platform

Aims of the project

The main aims of the project, the characteristics of the steam boiler and utilization system before and after revamping and results of the project are presented below.

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

- to increase waste gas utilization capacity,
- to increase steam production efficiency,
- to improve combustion process quality,
- to minimise CO and NO_x emission.

<u>The steam boiler and utilization system before revamping:</u>

- Boiler and utilization system type:
  - o typical steam boiler,
  - o utilization system based on waste gas/coal co-firing.
- Combustion system type:
  - o coal travelling grate,
  - o waste gas injection burner.
- System features:
  - o maximum capacity of waste gas utilization: 40,000.0 Nm^3/h,
  - o maximum capacity of steam production: 32.0 t/h,
  - o low efficiency of steam production: about 64%,
  - o relatively low quality of the combustion process,

- relatively high CO and NO_x emissions,
- high support fuel (coal) consumption about 50% of the total energy supplied.

<u>The steam boiler and utilization system after revamping:</u>

- Boiler and utilization system type:
  - new steam boiler (with tight walls),
  - utilization systems based on waste gas/natural gas co-firing.
- Combustion system type:
  - HTB-DL-WG15 burners using HiTAC combustion technology,
  - semi-adiabatic combustion chamber.
- System features:
  - maximum capacity of waste gas utilization: 65,000.0 Nm^3/h,
  - design capacity of steam production: 41.0 t/h, (normally the boiler works with capacity of 38.0 t/h).
  - high efficiency of steam production: 82% (Fig.10),
  - high quality of the combustion process,
  - extremely low CO and NO_x emission,
  - very low support fuel (natural gas) consumption, about 15% of the total energy supplied for nominal system capacity (Fig.11),
  - automatic system control.

Results and discussion

During the steam boiler and HTB utilization system operation (in Energetyka Sp. z o.o.) measurements of the emission of CO and NO_x were done. On the basis of the performed tests a relationship between CO, NO_x emissions and the ratio of waste gas input energy (Q_{WG}) to the total energy supplied (Q_{IN}) was prepared (Fig.9). The measurements were carried out in stable and possibly comparable conditions, in relation to combustion chamber temperature (950 - 970°C), combustion air temperature (250 - 320°C) and oxygen concentration in exhaust gases (usually 1.7 – 2.1%, for small capacities 3.7% - 6.3%).

As shown in Figure 9, if the ratio of waste gas input energy to the total energy supplied raises, CO emission is almost at the same level. System insensitivity to changes of the waste gas amount shows that the combustion process is of high quality and very stable.

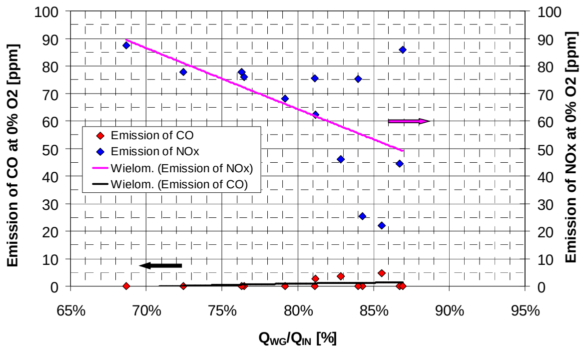

Fig. 9. Relationships between CO, NO_x emissions and the ratio of waste gas input energy (Q_{WG}) to the total energy supplied (Q_{IN})

A different situation occurs with NO_x emission. The NO_x emission slightly falls down along with an increase in the ratio of waste gas input energy to the total energy supplied. This ratio is high when burners work in the F1 and the F2 mode (the low and high temperature mode) with nominal capacity. Then due to influence of HiTAC combustion, NO_x emission is extremely low. During the utilization system operation with the nominal capacity about 50% of the total waste gas amount is burned in the pure HiTAC mode (the F2 mode).

When burners work only in the F1 mode, the ratio of waste gas input energy to the total energy supplied is low or burners work using natural gas only. In these conditions the NO_x emission is higher, due to two main reasons:

- HiTAC mode is not fully in operation,
- natural gas adiabatic combustion temperature is high, which has influence on NO_x creation mechanisms.

In this case to avoid high NO_x emission, the combustion process is operated with high excess air, which decreases the combustion process temperature and at the same time protects the combustion chamber from destruction.

Additionally, it needs to be pointed out that CO and NO_x emissions in the presented system are at extremely low levels, especially when emission levels are correlated with waste gas composition and parameters (Tab.1).

In the range of high participation of the waste gas energy in the total input energy (from 81% to 87%), differences between NO_x emissions for analogous measurements (the same participation of waste gas) carried out during an increase and a decrease in waste gas capacity can be observed. This discrepancy can be explained by the fact that the analogous measurements were done at long intervals (about 4 hours) and at that time changes of waste gas parameters probably occurred, which had influence on diversity of NO_x emission levels for the same ratio of Q_{WG}/Q_{IN}.

Relationships between boiler efficiency, exhaust gas temperature and boiler capacity are presented in Figure 10. For the nominal boiler capacity (38.0 t/h) boiler efficiency is almost 82%. Changes of boiler capacity from 20.0 t/h to 38.0 t/h have minor influence on boiler efficiency, which is in the range of 83,5% - 81,5%. It shows that the combustion process is very stable and of high quality, irrespective of natural gas and waste gas participation in the combustion process. The high efficiency results also from good design and assembly of the boiler. It follows that it is possible to burn waste gas with high capacity using the HiTAC technology and the HTB-DL-WG burners.

Exhaust gas temperature after the steam boiler rises with an increase in the boiler capacity, from 176˚C (for 20.0 t/h) to about 200˚C (for 38.0 t/h), due to an increase in exhaust gas flow. During the first period of boiler operation, after the boiler cleaning procedure exhaust gas temperature is about 200˚C for the nominal boiler capacity. Due to the dust content in flue gases (dust in waste gases) and its accumulation on the boiler walls, the exhaust gas temperature slowly rose and finally achieved the level of 240˚C for nominal boiler capacity. This temperature stabilized and has remained at the same level for a number of months of continuous boiler operation.

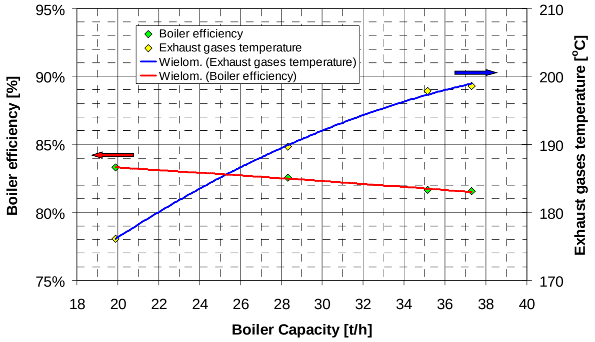

Fig. 10. Relationships between boiler efficiency, exhaust gases temperature and boiler capacity

Relationships between: the ratio of natural gas input energy to the total energy supplied (Q_{NG}/Q_{IN}), the ratio of waste gas input energy to the natural gas input energy (Q_{WG}/Q_{NG}) and the boiler capacity are presented in Figure 11.

It can be observed that if boiler capacity rises, the ratio of natural gas input energy to the total energy supplied (Q_{NG}/Q_{IN}) decreases from 26% (for 20.0 t/h) to below 15% for the nominal steam boiler capacity (38.0 t/h). At the same time, the ratio of waste gas input energy to the natural gas input energy (Q_{WG}/Q_{NG}) rises. For the nominal boiler capacity waste gas input energy is six times higher than natural gas input energy.

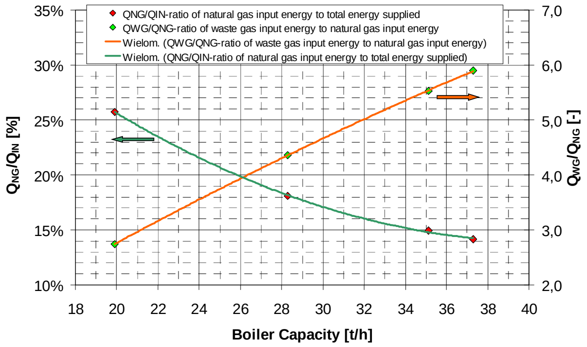

Fig. 11. Relationships between the ratio Q_{NG}/Q_{IN}, the ratio Q_{WG}/Q_{NG} and boiler capacity

In the case of operation of the utilization system with design conditions, the natural gas input energy consumption is 11,6% of the total input energy.

Conclusion

On the basis of almost one-year observation of the boiler and utilization system operation it can be claimed that in comparison to the previous system the following advantages were noticed:

- steam production maximum capacity increased from 32.0 t/h to 41.0 t/h (normally 38.0 t/h), **that is by 9.0 t/h (28% relatively).**
- steam production effectiveness increased from 64% to 82%, **that is by 18% (28% relatively).**
- utilization system capacity increased from 40,000.0 Nm^3/h to 65,000.0 Nm^3/h, **that is by 25.000,0 Nm^3/h (63% relatively).**
- substantial of the combustion process quality improvement, which has influence on utilization process quality improvement.

The system utilizes waste gas: with LHV (Low Heating Value) of 1.5 – 2.4 MJ/Nm^3, high moisture contents and solid particle contamination.

- CO and NO_x emission decreased to an extremely low level (almost zero).
- boiler control automation.
- support fuel participation decreased from 50% (coal) to 15% (natural gas) of the total energy supplied.

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 HTB-DL-WG combustion system and with the use of the same building cubature to build the installation.

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