EMISSIONS ANALYSIS OF HIGH TEMPERATURE AIR COMBUSTION OF WOOD PELLETS

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Scopul acestei lucrări îl reprezinta urmărirea comportamentului emisiilor rezultate în urma combustiei biomasei, utilizând oxidant de înaltă temperatură. Procesul de combustie a fost studiat pe cale experimentală si constă în arderea de pelete din lemn într-o instalaţie pilot ce funcţionează cu oxidant (aer) la înaltă temperatură. Instalaţia experimentală a fost construită la Royal Institute of Technology din Stockholm (Suedia). Au fost analizaţi următorii parametrii: concentraţia de CO si CO_2 în gazele de ardere si nivelul emisiilor de NO_x. Toţi acesti parametrii au fost analizaţi în funcţie de două temperaturi ale agentului de oxidare (800 °C si 1000 °C) şi pentru o concentraţie a oxigenului ce variază între 5% si 100% în aerul de combustie. Durata unui experiment a variat între 30 de secunde si 5 minute, pentru fiecare caz în care concentratia oxigenului si temperature acestuia au fost variate.

The purpose of this paper is to present the pollutant emissions behaviour during biomass combustion using high temperature air combustion. The process was studied experimentally by burning wood pellets into the High Temperature Air Combustion (HTAC) furnace (technology developed at the Royal Institute of Technology – Stockholm, Sweden). The following were examined: CO_2 and CO flue gases concentration and NO_x emission level, with respect to two oxidizer temperatures (800 °C and 1000 °C) and oxygen concentration (between 5% to 100%). The experimentation time varied from 30 seconds to 5 minutes for each oxygen concentration and oxidant temperature.

Keywords: biomass, high temperature air combustion, rich / diluted air

1. Introduction

The concern about biomass utilization for energy production as an alternative to the fossil fuels is increasing permanently in the last years. This interest is due to both continuous depletion of fossil fuels and biomass benefits. Biomass is the main renewable resource with high potential on medium and long

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terms; the carbon dioxide resulting from biomass combustion has a neutral character; the lower emissions of SO_x; all this issues and others constitutes the benefits of biomass energy utilization.

There are different ways to convert biomass into energy due to its versatile character. One of the oldest conversion methods is the combustion. In order to survive to the latest conversion techniques, the combustion technology requires constant improvements. One of the most promising technologies for biomass combustion is High Temperature Air Combustion (HTAC). The major advantages of this technology are already known. The HTAC furnaces have the following advantages: significant energy savings (reduced fuel consumption), low environmental impact, NO_x emission reduction, efficient and stable combustion, enhanced heat transfer and reduced combustion noise [1- 9]. Many researches were conducted in the field of gaseous fuel combustion using HTAC facilities, but less attention was focused on the behaviour of biomass combustion in HTAC conditions. There is still a lack of information with respect to biomass, combustion in high temperature and oxygen diluted/enriched conditions.

2. Experimental facility and procedure

2.1. Scheme of the facility

The experimental facility developed at Kungliga Tekniska Högskolan (KTH) is shown in Fig.1. It is a cylinder-type batch furnace of about 1000 mm length with a horizontal combustion chamber having an inner diameter of about 100 mm.

The schematic representation of the facility is presented in Fig.2.

3. Experimental procedure

The first step of the experimental procedure is heating up the combustion chamber. Hence, a flow of methane (1) and air (2) are feed up into the burner (5). During combustion process of the methane, which takes place in the first part of the combustion chamber (6), the ceramic honeycomb (7) is heated up until the required temperature is reached. Then, the flue gas resulted is passed through the second part of the combustion chamber (8) and is evacuated through the facility outlet (16). When the desired temperature of the honeycomb was attained, the burner was shut down.

The next process step starts with the admission of the oxygen (3) and nitrogen (4) flows into the combustion chamber. This gaseous mixture (oxygen and nitrogen) is heated up by passing through the already hot honeycomb and its purpose is to oxidize the biomass sample. At the same time, the biomass sample is inserted into the cooling chamber (9) through the special flange (11) where it is

constantly cooled by a nitrogen flow (10) in order not to react with the oxygen existing in the combustion chamber. The flows of oxygen and nitrogen were measured by three BRONKHORST flow meters.

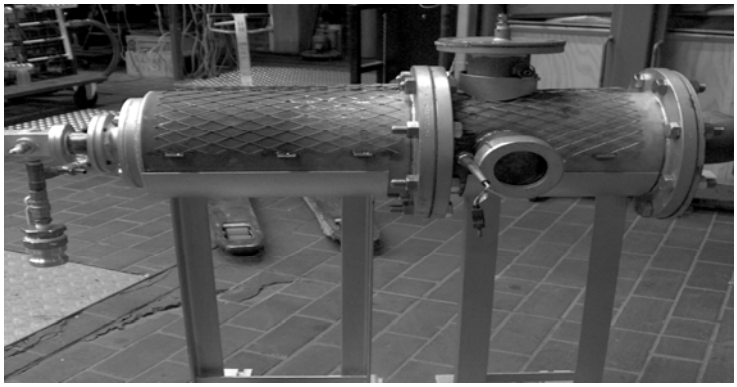

Fig. 1. KTH High Combustion Air Facility

After a short time, when the conditions inside the combustion chamber are stable, the biomass sample is inserted into the reaction zone and kept for a specified duration of time. A glass window (12) was mounted on one side of the furnace in order to observe the combustion process. A digital camera was recording the experiments.

During the experiments, the temperature of oxidizer, the temperature of the flue gases and the temperature of the pellet centre were measured by means of three S-type thermocouples (13, 14, and 15). A sample from the evacuated flue gases is analysed in order to determine the concentration of CO, CO_2 and NO_x (17). The CO and CO_2 concentrations were analysed by a MAYHAK - MULTOR 610 analyser. A CLD 700 EL ht (chemiluminescence NO/NO_x) analyser from TECAN analysed the NO_x level.

After the reaction required time is completed, the pellet sample is taken out from the combustion chamber and held about five minutes in nitrogen cooling atmosphere within the cooling chamber and then, the sample is taken out from the cooling chamber and the process can be restarted with another biomass sample.

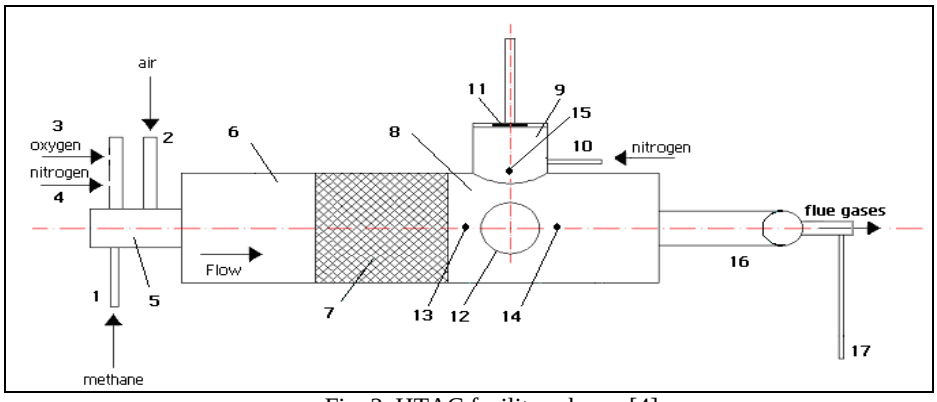

Fig. 2. HTAC facility scheme [4]

Legend:

1- methane inlet;
2- oxidation air inlet;
3- oxygen inlet;
4- nitrogen inlet;
5- burner;
6- 1rst part of the combustion chamber;
7- ceramic honeycomb;
8- 2nd part of the combustion chamber;
9- cooling chamber;
10- cooling nitrogen inlet;
11- pellet inlet flange;
12- glass window;
13- thermocouple (T_1);
14- thermocouple (T_2);
15- thermocouple (T_3);
16- facility outlet;
17- flue gas analysis probe.

Before and after the experiment, the samples were weighted with an electronic balance. The time was counted with an electronic timer. The data acquisition system is a KEITHLEY Multimeter type 2700 and the software is EXCELINX.

The flue gas analysers were calibrated using a gas calibrator to make sure the gas system was working in perfect condition.

4. Feedstock material and investigation range

The feedstock material investigated during the experiments was a woody biomass pellet. The material is very homogenous. Its physical properties, proximate and ultimate analysis are presented in Table 1. The experiments were carried out under two different temperatures of the oxidizing agent (800 and 1000 ºC) and under different concentrations of the oxygen in the oxidizer, which ranged between 5% and 100%. The combustion time was varied between 30 seconds and

5 minutes for each case. Table 2 shows the experimental investigation range. There were carried out 50 experiments.

Table 1

Biomass feedstock characteristics

Physical properties:		
Pellet length	mm	13.00 - 15.00
Diameter of the pellet	mm	8.00-9.00
Average pellet weight	g	5.00
Proximate analysis (wet basis):		
Ash content (550 ºC)	%	11.10
Volatiles content	%	19.41
Fixed carbon	%	62.79
HHV	MJ/kg	28.95
LHV	MJ/kg	27.99
Ultimate analysis (wet basis):		
Moisture content (105 ºC)	%	6.7
Carbon (C)	%	70.91
Hydrogen (H)	%	3.73
Oxygen (O)	%	5.78
Nitrogen (N)	%	1.40
Sulphur (S)	%	0.32
Chlorine (Cl)	%	0.01

Table 2

Experiments range

Temperature / Oxidizer	800 (ºC)					1000 (ºC)				
5 %	-	30s	60s	180s	300s	-	30s	60s	180s	300s
10 %	-	30s	60s	180s	300s	-	30s	60s	180s	300s
21 %	-	30s	60s	180s	300s	-	30s	60s	180s	300s
30 %	-	30s	60s	180s	300s	-	30s	60s	180s	300s
70 %	-	30s	60s	180s	300s	-	30s	60s	180s	300s
100 %	15s	30s	60s	180s	300s	15s	30s	60s	180s	300s

5. Results and Discussions

In this section several aspects of combustion behaviour will be presented with respect to the CO_2 and CO concentrations and NO_x pollution level.

During biomass combustion, two major pollutants groups can be distinguished as follows:

- Pollutants resulted from complete oxidation as NO_x and CO_2;

- Pollutants resulted from biomass incomplete oxidation as CO.

These pollutants significantly depend on combustion conditions.

5.1 NO_X emission level

During combustion, the nitric oxides are formed in three different reactions as follows:

- Thermal NO_x: formed by the oxidation of nitrogen contained in the air; the reaction takes place at high temperature;
- Prompt NO_x: formed during combustion in reaction of atmospheric nitrogen with CH radicals;
- Fuel NO_x: during the combustion process a part of the nitrogen contained in the fuel is oxidized to nitrogen oxides.

The comportment of NO_x during the combustion process is showed in Figs. 5 and 6 for different temperatures of oxidizing agent (1000°C and 800°C) and for different oxygen concentrations. It can be observed that the NO_x level is proportional with the concentration of oxygen and temperature. At high temperature, the NO_x level increases rapidly with oxygen due to the predominant formation of thermal NO_x (see Fig. 3 (a, b)). This phenomenon was not so evident for lower temperature (800°C) excluding the case of 70% oxygen (see Fig. 4 (a., b)). The maximum level of NO_x was obtained for oxygen concentration around 70%. In this case, the larger amount of NO_x is resulted from combination between the nitrogen bounded within the fuel matrix and the oxygen in excess and from combination between oxygen and nitrogen from air.

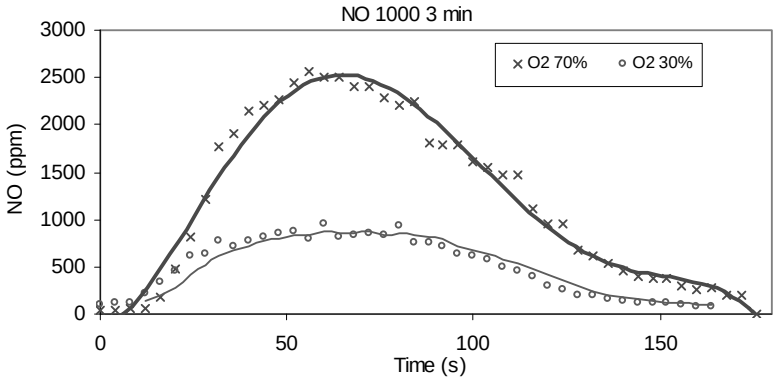

Fig.3a. Variation of NO_x emissions with time for different concentrations of O_2 (1000 °C for 180s)

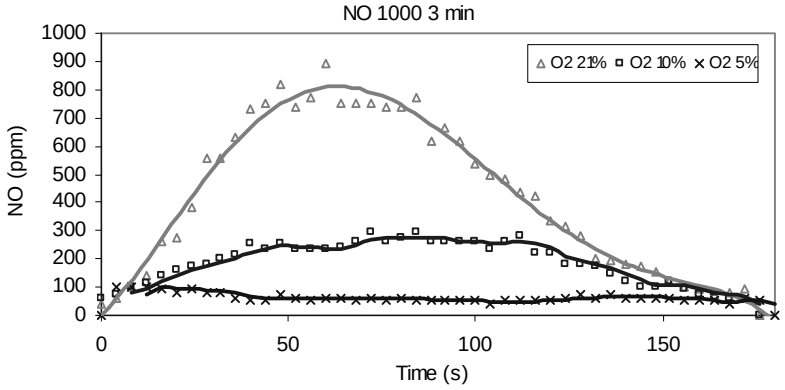

Fig.3a. Variation of NO_x emissions with time for different concentrations of O_2 (1000 °C for 180s)

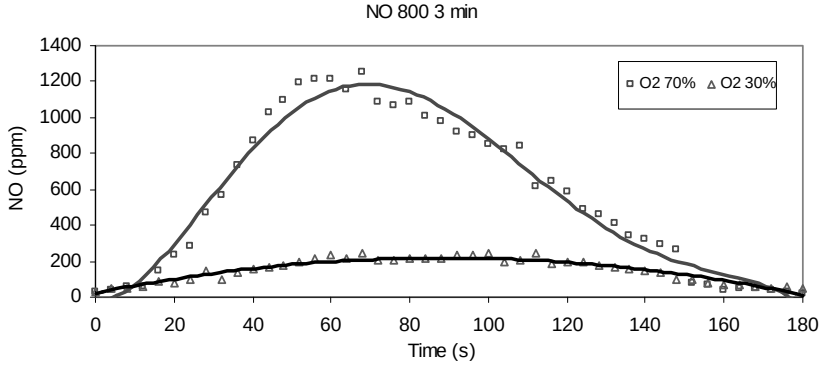

Fig. 4a. Variation of NOx emissions with time different concentrations of O2 (800 °C for 180s)

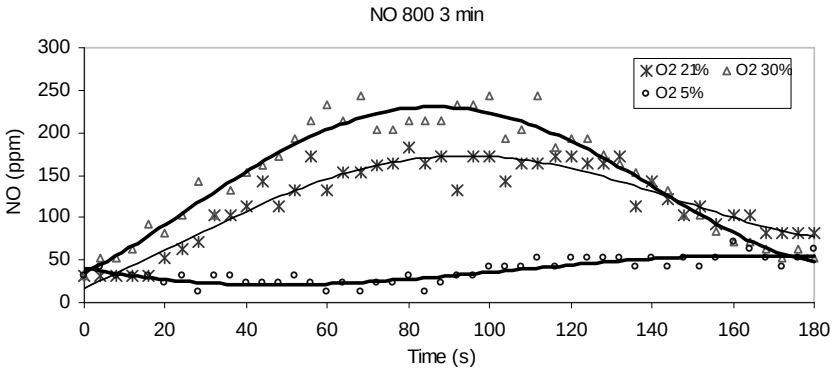

Fig. 4b. Variation of NOx emissions with time different concentrations of O2 (800 °C for 180s)

Analysing the diagrams, it can be seen that the HTAC technology has good results when high temperature oxidant and low oxygen content is utilized and the emission of NO_x are kept at a very low level. This is one of the main benefits when using HTAC.

5.2 CO_2 and CO concentration level

Carbon dioxide and carbon monoxide are also important air pollutants. Fig. 7 (a, b) and show the CO2 and Fig. 8 (a, b) shows the CO emissions profiles for different temperatures and concentrations of oxidant. As it was expected, the levels of CO_2 and CO are strongly influenced by oxygen concentration.

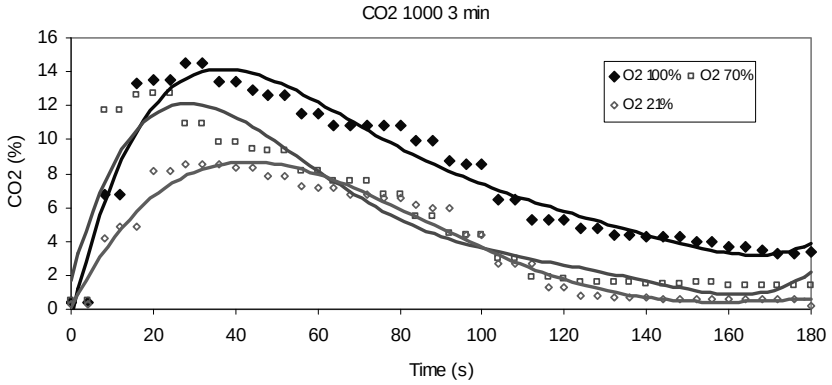

Fig. 7a. CO_2 variation in time for different concentrations of O_2 (1000 °C for 180s)

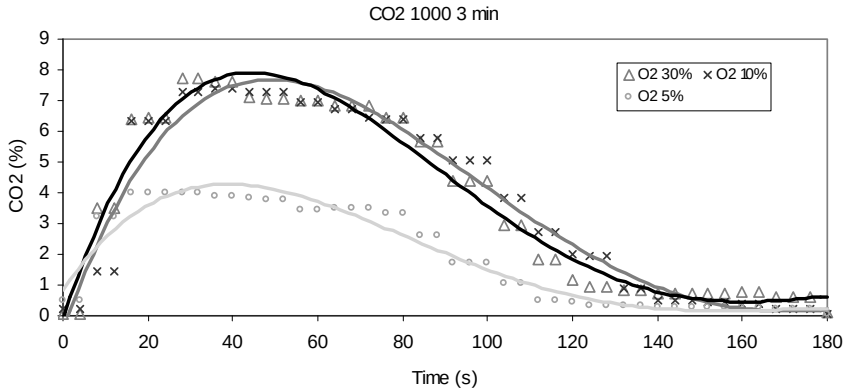

Fig. 7b. CO_2 variation in time for different concentrations of O_2 (1000 °C for 180s)

When oxygen concentration increases, the emissions of CO_2 also increase. This phenomenon is dependent on oxygen availability - more oxygen is available to combine with the fuel carbon - so, the maximum level is reached at 100% O_2. On the contrary, for identical conditions, the CO level is decreasing while oxygen concentration increases.

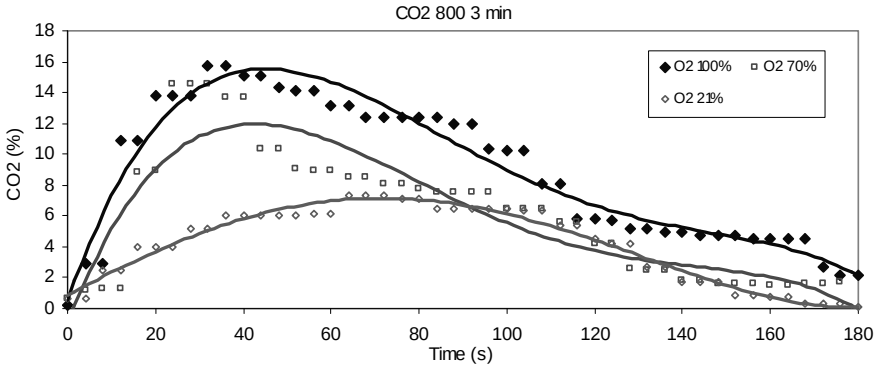

Fig. 8a. CO_2 variation in time for different concentrations of O_2 (800 °C for 180s)

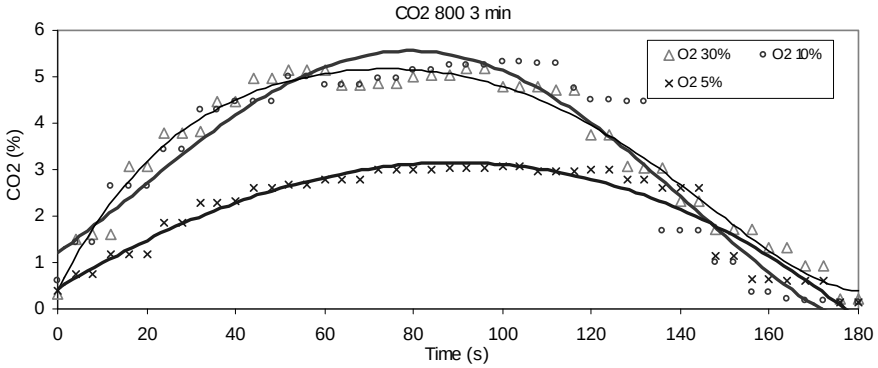

Fig. 8a. CO_2 variation in time for different concentrations of O_2 (800 °C for 180s)

The maximum of CO is reached when low oxygen concentrations are used (5 % and 10%). Hence, CO is produced by the incomplete combustion of pyrolysis products of biomass, char or as an intermediate combustion product [10]. It can be also seen that the CO_2 production is important at lower temperatures while, CO production is favourable at higher temperatures due to CO_2 dissociation reactions.

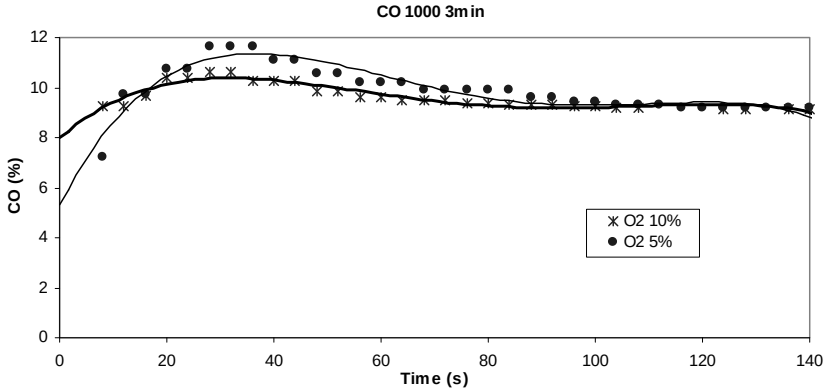

Fig. 8.a: CO variation in time for different concentrations of O_2 (1000 °C for 140s)

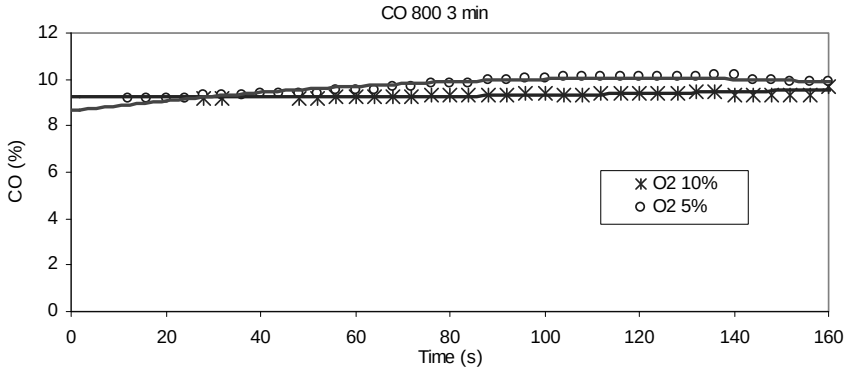

Fig. 8.b: CO variation in time for different concentrations of O_2 (800 °C for 140s)

The last part of the curves (between 120-140s and 180s) plotted in the Figs. 7.a; 7.b; 8.a and 8.b correspond to char oxidation stage. During this period, for high oxygen concentrations (over 70%) and residence time of the sample inside the combustor over 180s, the char is completely consumed.

No presence of CO was recorded within the analysed flue gas sample but the CO_2 level was quite constant until char oxidation was completed.

6. Conclusions

In this study, the combustion characteristics of woody biomass pellets were investigated experimentally. The pollutants emissions level and behaviour was the subject of this work. Some conclusions can be drawn after the data analysis.

1. The level of NO_x is proportional with the oxygen concentration and oxidant temperature. At higher temperatures (1000 ºC), the NO_x level increases rapidly with oxygen.
2. The increment of NO_x was not so important when oxidant temperature was 800 ºC, excepting the situation when the percentage of oxygen was 70%, explained by the reaction between the nitrogen bounded within the fuel matrix and the oxygen in excess and from combination between oxygen and nitrogen from air.
3. For high temperature air combustion and low oxygen concentration (10% and 5%), the NO_x level was low (around 200 ppm for 10 % oxygen and below 200 ppm for 5% oxygen).
4. The levels of CO_2 and CO are also dependent on oxygen concentration and temperature.
5. CO_2 formation was important at higher oxygen concentrations and lower temperatures, while CO formation was favourable at lower oxygen concentrations and higher temperatures.
6. Compared to a common combustions system, the HTAC technology reaches a low level of CO_2 and CO emissions.

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