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RECOVERY OF WASTE GAS BY COMBUSTION IN AN ORIGINALLY DESIGNED PLANT

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Abstract

This work presents an original method and an automated installation to recover by combustion the waste gas obtained in the ignition process of xylites in rotary kiln. The flue gas resulting from the combustion of waste gas, with light fuel support are used in the technological processes of obtaining activated carbon, satisfying the conditions where the oxygen content does not exceed 0.3 % vol. and the temperature is above 1200°C, conditions imposed by the Project Manager of the European project LIFE 02. Our automated installation consists in a combustion chamber and a heat exchanger, which along with a rotary kiln and an activation reactor build the technological installation called "ENVACTCARB" of this project. The design of our automated installation was done by running a computer program in order to calculate the combustion parameters and based on material and energy balances. The experiments were carried out in two stages: preliminarily, to characterize the liquid fuel combustion in the pilot installation and secondary, in the technological installation. The preliminary experimental results, presented as a comparison between the variants of light fuel burning, with and without using additives, show getting a complete combustion having low emission of pollutants and the oxygen content not exceeding 0.3% volumes. The experimental results performed in the technological installation certified the use of the automated installation for waste gas recovery through combustion.

Key words: burning installation, clean technology, waste gas, xylite

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1. Introduction

In the petrochemical industries (e.g. refinery gas), in iron and steel industries (e.g. coke oven gas and blast furnace gas) as well as in the carbon black industry, pure elemental carbon can appear, in the form of colloidal particles produced by incomplete combustion or thermal decomposition of gaseous or liquid hydrocarbons under controlled conditions (Gaba and Gaba, 2012; Zinn and Bowman, 1977). If the waste gas carrying medium is a flammable gas, the waste gas can be used through direct combustion (Deublein and Steinhauser, 2011).

Sometimes, the waste gas has a small heating value, like for instance, the cupola furnace gas (LHV ≈ 1300 kJ/m^3 N). This waste gas can be used through direct combustion, but only mixed with fuel with big heating value, such as natural gas (LHV ≈ 34000 kJ/m^{3}N) (Gaba, 1983). When the waste gas has a small heating value and the pressure of the waste gas is low, the waste gas is difficult to be used. There exist several types of licensed systems and their disadvantages in comparison to our automated installation are presented below.

The components of a waste gas treatment system by combustion are as follows (BREF, 2006; Kazemi and Macoveanu, 2012; Komai et al., 2009):

- a waste gas treatment system body, including a burner part and a combustion chamber;
- a means for forming combustion flames inside the said waste gas treatment system body;
- a waste gas supply line;

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- an oxygen gas supply line;
- a fuel gas supply line;
- a mixer outside the said burner, the said mixer comprising an ejector in order to use oxygen as a driving force to suck the fuel gas into the said mixer;
- a mixed gas supply line connecting the said mixer to the said waste gas treatment system body;
- a non-combustible gas supply line;
- a purge line arranged to inject the non-combustible gas from the said non-combustible gas supply line into the said oxygen gas supply line.

The disadvantage of the combustion type waste gas treatment system whose components were briefly described above is generated by the use of oxygen, so that new systems, which do not use oxygen are necessary to be designed. The components of a waste burner assembly for burning gaseous waste mixtures using multiple ejectors, as that described by Childree (1976) are briefly described below:

- a combustor section including an outlet end adapted for installation to a furnace, an igniter, a burner for primary fuel supply, with plural high velocity fuel nozzles and for secondary fuel supply;
- a constricted section on the inlet end of the said combustor section establishing a low pressure zone extending around the periphery and inward of the said combustor section inlet end; said constricted section having means therein for introducing fuel into the said combustor section in the low pressure zone established by the said constricted section.

The disadvantage of this waste burner assembly for burning gaseous waste mixtures consists of the stabilization of the front flame by the low pressure zone in the combustion chamber.

The components of the waste gas burner "NRG" consists of the combustion chamber, central cylinder, placed in a cavity filled with air for thermal insulation, exactly as in the work of Siccama (2013). The combustion chamber has ceramic and steel walls. Nitrogen serves as the carrier gas for the toxic waste gas. The waste gas-nitrogen mixture, oxygen and methane are injected separately at the bottom of the chamber. The waste gas-nitrogen mixture is injected axially. Methane is injected through a circular crown that encloses the waste gas inlet. Oxygen enters through small holes circularly distributed around the fuel inlet and tilted toward the burner axis. In addition, the air is injected perpendicularly to the center line in a plane downstream. The ratio between the methane and oxygen mass flow rates is nearly a stoichiometric proportion (Siccama, 2013). The disadvantage of the waste gas burner-NRG is provided by the use of oxygen.

2. Material and methods

In this paper an automated installation to recover the waste gas obtained in the ignition process of xylite by combustion in rotary kiln is used, consisting of:

- light fuel oil tank (reservoir containing light fuel, LF, and fuel additives);
- water – LF emulsion tank;
- combustion chamber;
- mixing chamber;
- injector;
- ejector;
- support frame;

Fig. 1 is the schematic representation of our automated installation to recover the waste gas obtained in the ignition process of xylite by combustion in rotary kiln.

The LF tank is a daily storage tank containing maximum 1000 kg LF. The fuel contains the ENPRO 106 fuel additive. This fuel additive was designed and formulated specifically for the waste gas combustion unit by Soctech. The water-LF emulsion tank is a daily storage tank containing maximum 500 kg LF and maximum 500 kg water. The PC2 pump recycles the emulsion. The ENPRO 151 emulsifier is added in order to increase the emulsion stability. The combustion chamber is a cylinder-shaped (900 mm exterior diameter and 2000 mm length). Its interior is coated with BIP 05 thermo-insulating concrete (from Φ=900 mm to Φ=700 mm) and with BR65 refractory concrete (from Φ=700 mm to Φ=400 mm). The last part (200mm) of the interior chamber is cone shape truncated. The interior refractory insulation diameter of this zone varies between 400 mm and 300 mm. The waste gas sucked from the rotary kiln is blown in the combustion chamber trough a 110 mm-Φ pipe. This pipe is located tangentially at 775 mm relative to the combustion chamber anterior edge. The interior refractory insulation (made of BR65 concrete) is provided with a catalyst (ENPRO 137) impregnated spiral channel on the cylindrical section. The channel purpose is to improve the waste gas burning. The catalyst intensifies the burning of the waste gas with small LHV. The channel section is 60 x 110 mm. The spiral pitch is variable, between 220 and 500 mm.

A pipe (fed with compressed air by a 19 mm coupling pipe) communicates with the interior refractory insulation spiral channel through four inlets (3 mm diameter each). The mixing chamber is a cylinder-shape precinct (600 mm exterior diameter, 300 mm interior diameter and 500 mm length). Its interior is coated with refractory concrete. It is attached by flanges to the combustion chamber. Its role is to obtain homogenous burning gas, from the mixture waste gas and the LF burning. The resulting burning gas mixture should be homogenous with controlled temperature, pressure and chemical composition. The mixing chamber is provided with two 26 mm orifices. A Pt-Rhodium-Pt 13 thermocouple and a gas-drawing and pressure probe enter the mixing chamber through these orifices. The orifices are sealed. The light fuel oil injector is a Soctech type one, with a nominal fuel consumption of 20 kg/h. The minimum fuel consumption is 5 kg/h. As a part of this combustion unit, the injector will operate in the 6.0÷15.0 kg/h range.

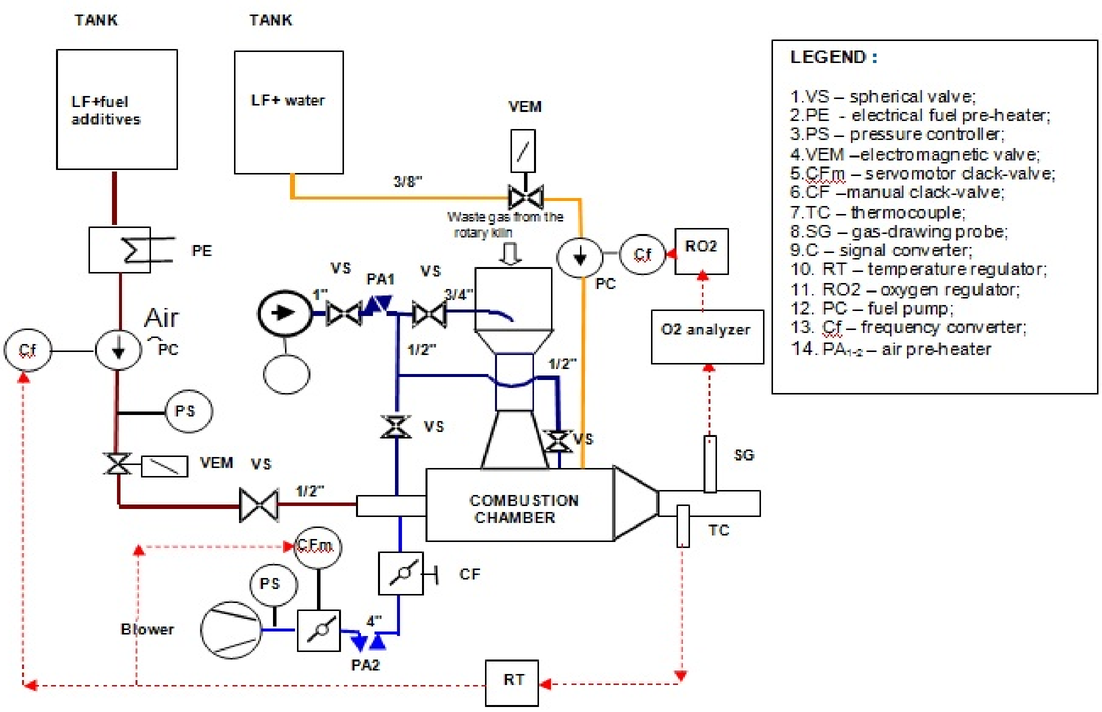

Fig. 1. Schematic representation of the automated installation for waste gas recovery through combustion

The required fuel consumption is calculated using an own computer program (Gaba, 2005). The flame generated in these circumstances is about 0.5 m long, having about 0.3 m diameter. The injector uses compressed air (4 bar) for fuel pulverization. The pulverization compressed air / combustion air ratio is about 0.1. An embrasure is foreseen in the flame propagation area. The embrasure is made of 12NiCr180 steel sheet, having an exterior diameter of 398 mm. Its interior is coated by refractory concrete (BR90). The embrasure interior is cone shape truncated on 550 mm length. It continues with a cylinder-shape part (200 mm diameter, 400 mm length). A visiting pipe (Φ = 32 x 2 mm) is foreseen at the embrasure anterior end. The pipe is piercing the refractory insulation and is oriented toward the truncated cone-shaped zone (where the flame develops). A photoelectric cell detects the flame through this pipe, supervising the burning. The embrasure enters the combustion chamber free-space on a length that will be experimentally determined. For this reason, the flange attaching the embrasure will be welded on the combustion chamber surface only after establishing their relative positions.

The ejector is attached to the 110 mm-Φ pipe entering tangentially into the combustion chamber. It is composed of a convergent part reducing its diameter from 160 mm to 31 mm and a divergent part increasing its diameter from 31 mm to 110 mm. The driving fluid is the compressed air delivered to the ejector through a 19 mm pipe. The anterior end of the pipe is fixed and it can be positioned forward or backward within a 75 mm range using a coupling. The section exhausting the furnace off-gas is Φ = 160 mm interior diameter.

The support frame bearing the combustion chamber and the mixing chamber is located at 1407 mm high relative to the construction foundation. It has support beams and six support feet, made of L 100 x 100 x10 angle steel bars. It provides safety and stability. The micro-pulverization installation, IA, contains a pump and an injector for spraying water-LF emulsion at 150 bar. To achieve and maintain over time the operating and performance parameters of the combustion installation we choose command and safety elements for operating the air-blower, the compressor, the fuel pump, the micro-pulverization installation and the two control loops for temperature and oxygen concentration. Temperature control in the gas mixing chamber is achieved using a loop temperature. Loop temperature consists of a thermocouple TC, a temperature regulator RT, whose signal commands the power-actuator of the butterfly-valve Cfm and, simultaneously, the frequency converter that controls the fuel pump PC which supplies the injector A.

The concentration of oxygen in the gas mixing chamber is maintained within 0.1 to 0.3% vol. through a loop adjustment of oxygen concentration composed of a burned gas sampling probe SG, an oxygen analyzer, whose signal is transmitted to an oxygen regulator RO2 and this, in turn, controls the frequency converter CF2 for the micro-pulverizing installation IA.

All these components are shown in the assembly picture set from Fig. 2 and Fig. 3 respectively, achieved at the complete set up of the installation on the established location (a priori to the pipes isolation and fitting of the injector and micro-pulverization installation IA).

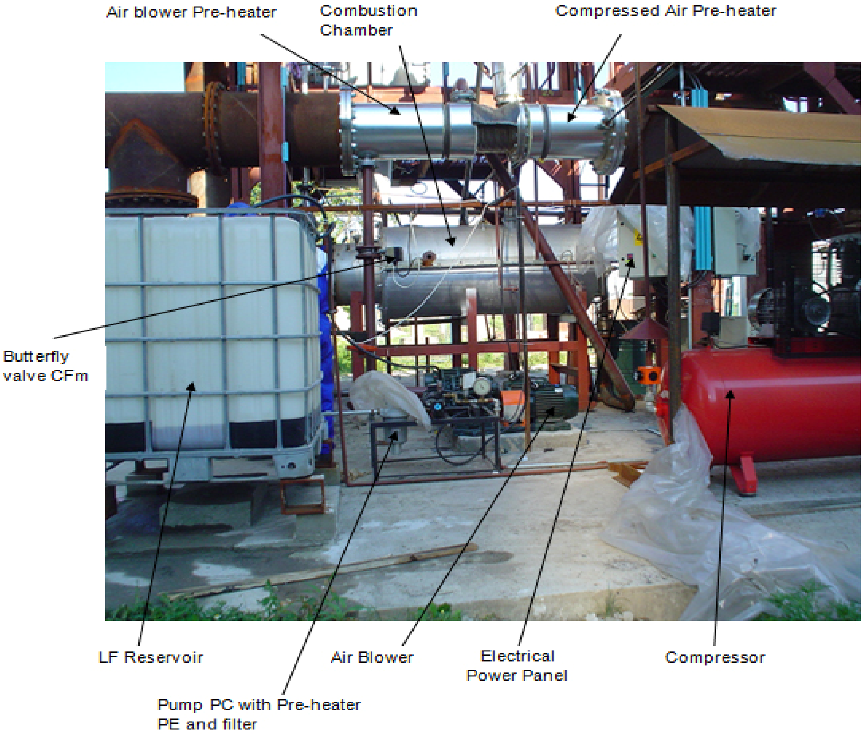

Fig. 2. Assembly view of the automated installation for waste gas recovery through combustion with the reservoir of LF as a point of view

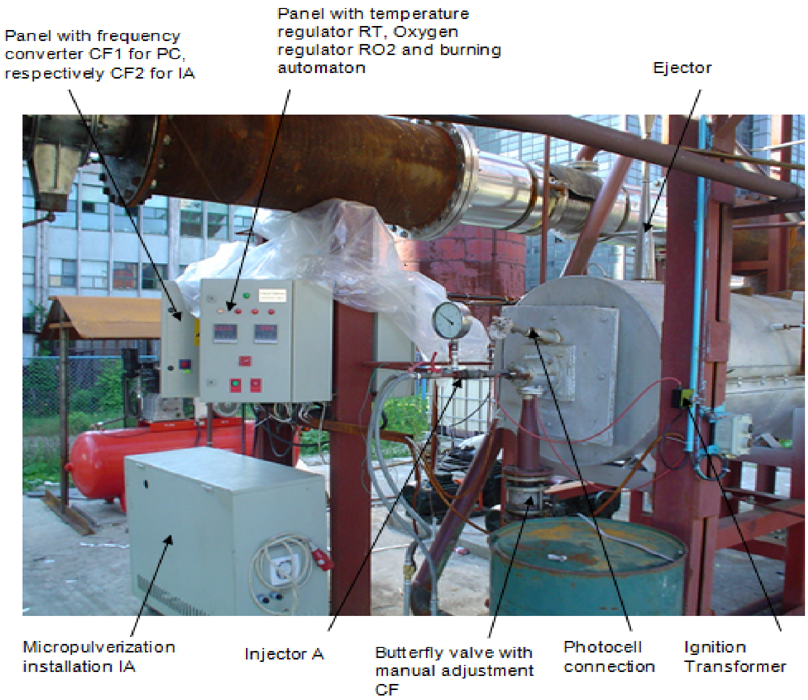

Fig. 3. Assembly view of the automated installation for waste gas recovery through combustion with the injector as a point of view

By the ignition and combustion of light liquid fuel (LF), using compressed air for spraying and combustion air supplied by blowers in order to blend the fuels – combustion air, burnt gases are produced, which are distributed in the combustion chamber. With the ejector device they are sucked from the technological installation (rotary kiln) and are distributed in the combustion chamber in order to be burned. For better controlling the oxygen content of burnt gases, compressed air is injected through four nozzles which communicate with the channel made in a refractory isolation of the combustion chamber. By the last nozzle is introduced an injector of the spraying equipment that pulverizes a water – light liquid fuel emulsion having approx. 150 bar, to correct the oxygen content of burnt gases. The chamber of homogenization is the location in which one performs the measurements of temperature, pressure and chemical composition of mixed burnt gas, which will allow the settings of the fuel flow, combustion air and LF – water emulsions. Burnt gases and mixed control parameters are discharged from the homogenization chamber and placed in the technology because of their excess.

The research methods we used were the following: on one hand to study the combustion of LF with combustion air in the pilot installation Soctech and on the other hand to study the combustion of the mixture LF-waste gases with combustion air in the technological installation "ENVACTCARB".

3. Experimental

The experiments were done in two stages. In the first stage the authors tried to obtain burned flue gas at temperatures between 1200 and 1250°C and O_2 content of less than 0.3% vol., imposed by the Project Manager of the European project LIFE 02, by the combustion of LF with combustion air. Also, one kept constant the oxygen concentration of the flue gas at levels as low as possible, in order not to exceed the limit values of the pollutants (EC Directive, 2001; M.N., 1993). Tests were made on the combustion chamber equipped with the own injector A and light liquid fuel, LF, with and without additives.

The second phase of the experiments was done on our automated installation, using the waste gas obtained in the ignition process of xylites in the rotary kiln of the technological installation "ENVACTCARB", for that we have adjusted two loops:

- the loop temperature control of the flue gas in the homogenization chamber: the signal received from thermocouple TC, installed inside this chamber, is processed by a "fuzzy" type temperature regulator RT, which acts on the converter frequency Cf1 of the light liquid fuel pump PC and on the actuator of the combustion air damper CFm;
- the loop concentration control of the oxygen present in the gas of the homogenization chamber: the signal received from the oxygen analyzer (gases are taken with the probe SG) is taken over by the oxygen regulator (RO2), which acts on the frequency converter Cf2 of the pump for water emulsion- LF from the micro-pulverization installation IA.

4. Results and discussion

The results of the first stage of the experiments are presented in Table 1 and Table 2. The main results of the experiments of the combustion of LF with combustion air, without additives, are presented in Table 1. The results of the tests performed when the additive ENPRO – 106 are presented in Table 2. Oxygen concentrations below 0.3% vol. were obtained using the additive ENPRO - 106 as can be seen in Table 2, rows 7 and 8. We emphasize the fact that we had to use the additive ENPRO-106 in order to obtain a complete combustion of the liquid fuel LF for low oxygen concentration. At the same time we did not obtain pollutants in the flue gas, maintaining a concentration of the CO below 50 mg/ Nm^3.

The results of the second stage of the experiments are presented in Table 3 and Table 4.

The main parameters of the automated installation for the recovery through combustion of the waste gas, while operating on the technological installation, are presented in Table 3.

The composition of the wet gas discharged from the automated installation while operating on the technological installation, are presented in Table 4.

The measurement results prove that the automated installation designed for waste gas recovery achieved the necessary technology meaning that:

- The temperature of the exhaust flue gases of the combustion chamber may vary within the required range: 1221 - 1249 ° C;
- The oxygen concentration of the combustion gases can be maintained below 0.3% vol.;
- The level of the pollutants in the flue gas was below the limit values (EC Directive, 2001; M.N., 1993).

It was also found that the ejector can undertake waste gas from the technological installation. Moreover, it was found that the ejector ensures in the combustion chamber the excess pressure required for the flow of fluids through the entire installation, at pressures above 4 bar for the compressed air while entering the ejector.

The automated installation for waste gas recovery through burning was designed based on data obtained upon running an own computer program for calculating the combustion parameters (Gaba, 2005). The data obtained by running the program modeling the combustion of the LF (the composition being provided by the fuel supplier) and gaseous wastes (measured in the composition of the technological installation) are presented in Table 5 for LF and for two mixtures (with a minimum LF flow and with a maximum LF flow respectively).

The composition of the two mixtures (with a minimum LF flow and with a maximum LF flow respectively) was calculated from data obtained from the technological installation (the waste gas temperature ranging between 370 and 400 °C, the heat loss through the walls of the combustion chamber varying between 376 and 457 kJ / kg fuel) and from the project of the exchanger of the combustion air (insufflated air with temperature varying between 400 and 470 °C in the combustion chamber) (Gaba, 2003; Layman Report, 2007). The min. variant (LF+WG)min. resulted by computations from maximum waste gas temperatures (400 °C) and combustion air temperature (470°C), minimum loss through the combustion chamber walls (376 kJ/kg fuel) and minimum temperature in the homogenization chamber (1200°C).

Table 1. The composition of the wet gas discharged from the combustion chamber in the tests made on the Soctech pilot installation with light liquid fuel

No.	CO_2%	O_2%	***CO*** ppm	SO_2 ppm	***NOx*** ppm	H_2O%
1	13.58	1.96	30.87	1.76	114.66	12.00
2	13.67	1.76	33.52	1.76	122.60	12.00
3	13.98	1.26	48.22	1.76	114.66	11.90
4	14.26	0.98	64.24	1.76	110.00	11.90
5	14.26	0.98	65.12	1.76	110.88	11.90
6	14.34	0.98	65.12	1.64	108.24	11.90
7	14.26	0.98	66.00	1.76	105.12	11.90
8	14.52	0.63	102.14	1.76	95.62	12.09

Table 2. The composition of wet gas discharged from the combustion chamber in the tests made in the Soctech pilot installation with light liquid fuel and additive ENPRO-106

No.	CO_2%	O_2%	***CO*** ppm	SO_2 ppm	***NOx*** ppm	H_2O%
1	14.08	1.10	2.64	1.65	98.96	12.10
2	14.17	0.95	2.96	1.64	96.68	12.08
3	14.17	0.93	2.86	1.81	96.56	12.09
4	14.08	1.09	2.73	1.76	98.16	12.09
5	14.08	1.10	2.61	1.80	97.96	12.10
6	14.17	0.97	2.84	1.78	96.48	12.10
7	14.77	0.26	10.55	1.66	92.11	12.05
8	14.98	0.12	31.47	1.58	89.85	12.00

Table 3. The main parameters of the automated installation while operating on the technological installation

No.	***LF Flow*** [kg/h]	***Temperature of waste gas entering the ejector*** [°C]	***Temperature of flue gas exiting the combustion chamber*** [°C]	***Temperature of flue gas entering the air pre-heater*** [°C]	***Temperature of flue gas exiting the air pre-heater*** [°C]	***Temperatureof the combustion hot air*** [°C]
1	8	400	1221	983	509	438
2	8	404	1238	999	514	445
3	7	408	1234	994	512	449
4	7	405	1241	1008	520	453
5	7	407	1245	1006	518	452
6	7	400	1249	1010	520	453
7	8	408	1242	1006	522	453
8	7	400	1248	1004	521	452
9	7	400	1238	996	520	451
10	7	403	1234	993	519	450
11	8	404	1231	992	518	447
12	8	404	1228	991	514	446
13	8	407	1225	988	516	445
14	7	388	1224	986	513	445
15	8	393	1230	990	515	445
16	8	400	1226	986	514	445

Table 4. The composition of the wet gas discharged from the automated installation while operating on the technological installation

No.	CO_2%	O_2%	***CO ppm***	SO_2 ***ppm***	***NOx ppm***	H_2O%
1	14.17	0.29	45.72	2.36	124	17.10
2	14.17	0.28	47.56	2.26	123	17.10
3	14.21	0.26	54.22	2.16	115	17.02
4	14.21	0.25	54.27	1.98	114	17.00
5	14.24	0.21	63.18	2.04	112	16.96
6	14.24	0.21	63.18	2.26	112	16.95
7	14.24	0.21	62.81	2.34	110	16.95
8	14.34	0.18	68.12	1.94	108	16.90
9	14.34	0.19	68.08	2.04	106	16.90

Table 5. The calculated composition and temperature of the wet flue gas obtained in the combustion of LF and mixtures: LF with waste gas respectively

Fuel type	***CO_2 %vol.***	***O_2 % vol.***	***CO ppmv***	***SO_2 ppmv***	***NOx ppmv***	***H_2O % vol.***	***Temperature °C***
LF	13.48	1.64	0.00	0.00	-	11.72	2270
$(LF+WG)_{min}$	13.99	0.27	0.00	0.00	-	17.35	1214
$(LF+WG)_{max}$	14.07	0.22	0.00	0.00	-	16.83	1235

The best alternative variant $(LF+WG)_{max}$ resulted by computations from minimum waste gas temperatures (370°C) and combustion air temperature (400°C), maximum loss through the combustion chamber walls (457 kJ/kg fuel) and maximum temperature in the homogenization chamber (1250°C). For the alternative min, the LF flow was 7.0 kg/h while for the best alternative of the LF flow was 9.8 kg/h.

The experiments performed and summarized in Tables 3 and 4 indicate an average consumption of about 7.5 kg / h LF, as we approached the minimum variant. If a comparison is made between the flue gas compositions measured in the mixing chamber and those calculated for the minimum variant, one observes the difference of maximum 3% for water vapor. For the other components the differences are lower. There were also found very small differences in terms of measured values and those computationally obtained for the others parameters, such as preheated air temperature or flue gas temperature.

5. Conclusions

The automated installation for waste gas valorization through burning was conceived and designed so that the waste gas produced in a technological installation for ignition of xylites in rotary kiln can be recovered. The flue gas resulting from the combustion of waste gas, with light fuel support, are used in the technological processes of obtaining activated carbon, satisfying the conditions where the oxygen content does not exceed 0.3% and the temperature is above 1200°C.

The experiments were done in two stages. In the first stage the authors tried to obtain burned flue gas at temperatures above 1200 °C and O_2 content of less than 0.3% vol., imposed by technology, in terms of LF over pressure combustion. Tests were made with light liquid fuel oil, with and without the additive ENPRO – 106. Experiments were performed maintaining a constant flue gas temperature at their evacuation from the combustion chamber, between 1200 - 1250 °C. Also, one kept constant the oxygen concentration of the flue gas at levels as low as possible, not exceeding the limit values of the pollutants (EC Directive, 2001; M.N., 1993). The oxygen concentration below 0.3% vol., imposed by technology, was obtained using the additive ENPRO – 106.

The second phase of the experiments was performed on the technological installation. The measurements confirmed that the automated installation for waste gas recovery through burning achieved the parameters required by technological installation. These parameters may vary within the limits covering the requirements of technological applications while respecting the pollutants limits. In other words:

- The exhaust gas temperature of the combustion chamber may vary within the required limits: 1221 - 1249 ° C
- The oxygen concentration of the flue gases can be maintained below the 0.3% vol.;
- The level of the pollutants in the flue gas was below the limit values (EC Directive, 2001; M.N., 1993).

It was also found that the ejector can undertake waste gas from the technological installation. At the same time, it was found that the ejector ensures in the combustion chamber the excess pressure required for the flow of fluids through the entire installation, at pressures above 4 bar for the compressed air while entering the ejector. The design of the automated installation of waste gas recovery through burning was based on processing the data obtained from the technological installation by using an original computer program. The computationally results have been validated by those obtained in the experiments performed on the technological installation.

If a comparison is made between gas compositions, measured in the homogenization chamber and those calculated for the minimum variant, one can notice a difference of maximum 3% for water vapor. For other components the differences are lower. One also found very small differences in terms of the experimentally measured and computationally obtained values of the other parameters, like preheated air temperature or flue gas temperature.

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