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TLUD hot air generator with forced draft

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***Abstract*— Energy consumption for heating and hot water in commercial and residential buildings holds a leading place in the top of the major consumer in Europe, but also in the top of the responsible for greenhouse gas emissions resulting in the atmosphere. The application of a gasification combustion technology with carbon storage in the biochar, based on the TLUD principle on environmentally friendly residential heating equipment can replace other heating systems with less environmentally friendly and less energy efficient minced biomass. The TLUD principle is recognized as the most environmentally friendly combustion process that extracts from biomass, by gasification, all volatiles (producer gas) and unconverted carbon (biochar) remains, which can be used to improve the quality of degraded soils, responding to the requirements of environmental strategies for storing carbon in the soil and reducing greenhouse gas emissions to achieve sustainable development. The article presents a hot air generator solution based on the TLUD principle and laboratory testing of the forced draft subassembly with which low speeds of the producer gas generated in the reactor (below 0.06 m/s) were obtained in order to reduce the free ash drive under the current rules imposed for solid fuel thermal generators.**

Keywords*— gasification; Top-Lit Updraft (TLUD); biomass; biochar; greenhouse gases; stoichiometric combustion

I. Introduction

Increasing renewable energy production is essential to reduce both fossil fuel dependence and greenhouse gas emissions, thus contributing to energy security and sustainable development, especially in rural areas. The free combustion of agricultural biomass from waste production produces a large amount of pollutant emissions as well as a massive waste of thermal energy. Using this resource to heat residential spaces would solve many of the users' daily problems. The problems of burning optimizing at heating equipment has appeared lately, when the research activities for greening, modernization and efficiency of combustion has been intensified, or by addressing new solutions or technologies such as the use of the TLUD principle (Top lit up draft) in heating equipment. The incomplete combustion of biomass has the effect of polluting the environment by releasing CO_2 and PM into the atmosphere causing the global temperature to rise and climate change [1]. Most of the projects for the modernization of combustion equipment aim to reduce pollution in order to achieve sustainable development and conservation of forest resources. There are many developing countries in the world where open fire is still used for cooking or heating, which has less than 10% energy efficiency. Increasing energy efficiency can be achieved by using improved combustion systems, which have the effect of reducing pollution, reducing the consumption of firewood and combating deforestation [2]. The negative effects of using biomass for energy production primarily result from the incomplete combustion of biomass and the release of CO2 and PM into the atmosphere, resulting in an increase in global temperature and an increase in climate change [1]. Climate change mitigation and forest resource conservation have been two main motivations for most improved combustion system projects. In many developing countries, the cooking technique used is still traditional open fire, which has less than 10% energy efficiency. The percentage can be greatly increased with the use of improved combustion systems, thus reducing the consumption of firewood and helping to combat deforestation [2].

II. The Current Situation

Currently, the TLUD gasification process is experienced on cooking equipment. This equipment is of low power and a small part of it is produced in saleable variants, most of the one presented on the Internet being improvisations or experiments made by various people. These equipment generate a flame at the top, which comes from the burning of gas from the gasification of wood materials and is used in the preparation of food.

Some materials considered waste (bark, wood cuttings, agricultural secondary production debris, etc.) can be used efficiently for heat energy production and carbon storage in the biochar. In principle, the fuel for TLUD installations can be any chopped, dry or densified wood material [3]. High tolerance to the chemical composition of biomass and granulomere distribution makes it possible to use a wide variety of locally harvested biomass, chopped at 10…50 mm and naturally dry or forced to a humidity below 20%, which leads to lower biomass usage costs, thus producing cheap, clean energy with a negative carbon balance.

The gas generator on the TLUD principle (fig. 1) is composed of a gasifier with upper gasification air circulation coupled to a burner.

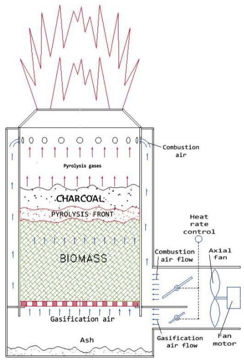

Fig.1. The functional diagram of the gasifier working on the TLUD principle [4]

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Biomass in the reactor is supported by a sieve through which the primary air passes for gasification. Ignition and initiation of the pyrolytic front is done at the top of the gas, and the front advances into the biomass bed.

Pyrolysis results in gas, tar and char. The gas from the gasification is mixed with the secondary combustion air, which comes preheated by the reactor wall and is inserted through the holes arranged at the top of the reactor. The tar passes through the hot pyrolytic front, and through the flame arranged in the upper part where they are cracked and totally reduced. The high turbulence mixture burns with flame at temperatures of about 600-900ºC, depending on the calorific value of biomass [4].

The TLUD process works as a batch with recharging, as the pyrolytic front advances into the fixed biomass layer and continuous feeding is difficult to achieve. The gasification process is done slowly, with specific hourly consumption of 80 – 150 kg.bm/m²h resulting in reduced specific power for the reactor of 250–350 kW/m². The slow process also requires a superficial speed of the produced gas at very low values below 0.06 m/s and thus avoids training free ash at concentrations below PM 2.5 at the outlet of the burner of maximum 5 mg/MJbm; these values are much lower than the norms imposed for solid fuel thermal generators [5],[6],[7].

The concerns of INOE 2000 IHP to study this process have materialized in a laboratory equipment on which a series of tests are carried out that could optimize burning on the TLUD principle. The final objective of the research is to create a hot air generator, with forced circulation, with pollutant emissions below the proposed rules for 2030, which uses chopped and dried biomass or pellets, with conversion efficiency of up to 85% and also producing about 10%...20% waste coal, not converted into gas, called biochar current. This is a good amendment for agricultural soils and reduces the concentration of CO_2 in the environment by sequestration of carbon in the soil over long periods.

The most important benefit of the TLUD gas is that a clean energy is obtained compared to any of the other combustion modes (fig.2), and also a green energy with PM and CO_2 emissions to the chimney below the values required by European legislation, and in addition, carbon storage in the biochar results in a negative CO_2 balance, helping to achieve efficient environmental protection and ensure sustainable energy development.

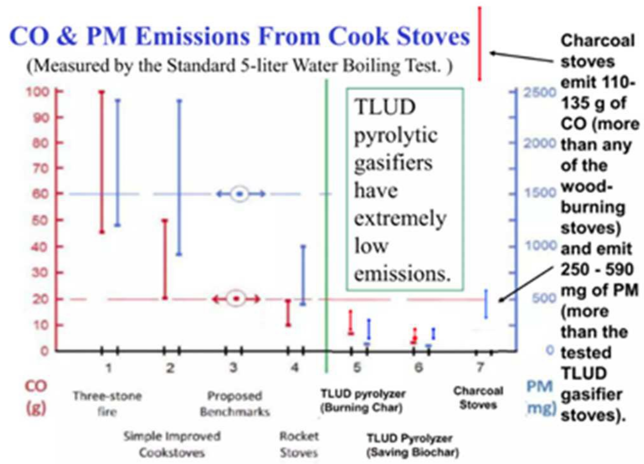

Fig. 2. Comparison of CO and PM emissions from various combustion technologies and systems [8].

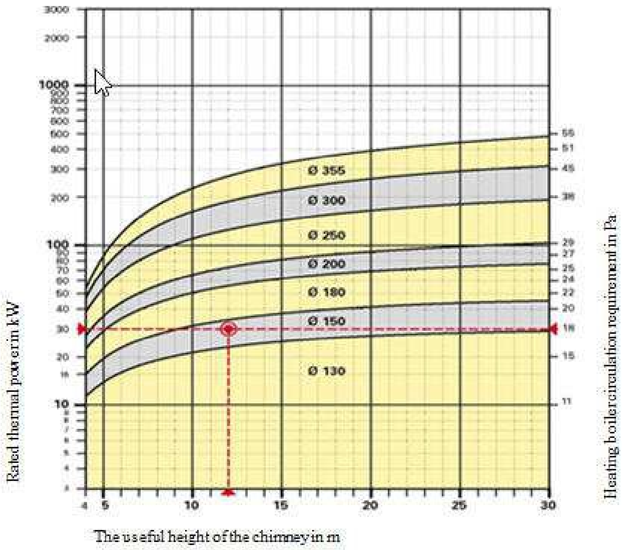

Fig.3. Boilers' draft requirement [9]

The need for flue gas circulation can be estimated from the literature (fig. 3).

In the example in the picture, for a wood boiler with a rated thermal power of 30 kW and a useful height of the chimney of 12 m, a diameter required for the chimney of Ø 150 mm results.

In our case, for the power of 3 kW it takes 4 m of chimney Ø 130 mm, or 1 Pa vacuum for forced circulation.

III. Materials and Methods

Laboratory equipment (fig. 4) consists of a frame 1, an electronic scale 2, gas generator 3, combustion chamber 4, heat exchanger 5, forced draft subassembly 6, primary air throttle 7, primary air flowmeter 8, secondary air flowmeter 9, secondary air throttle 10 and chimney 11.

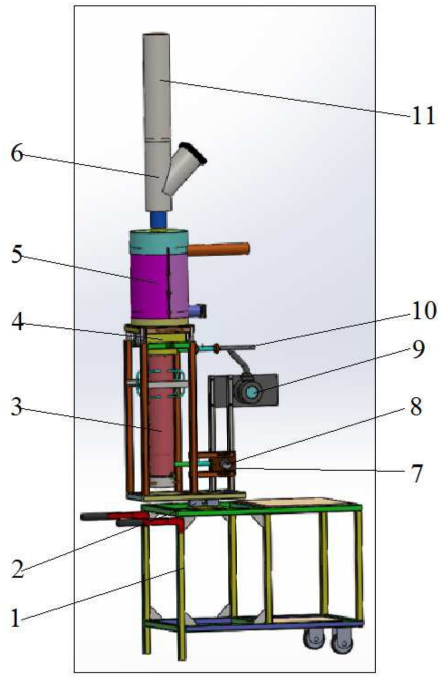

Fig.4. TLUD hot air generator from INOE 2000 IHP laboratory

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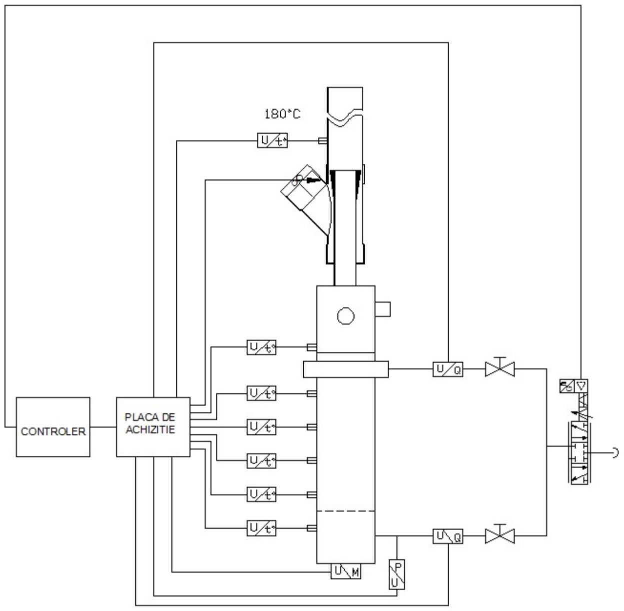

Fig .5. Functional diagram of the TLUD hot air generator

The functional diagram of the hot air generator is shown in Fig. 5. For the correct ecological operation of the generator, the outlet temperature on the chimney must be maintained around 180°C. The nominal opening from which the forced draft subassembly absorbs air is adjustable by a servo valve that controls the flow of the combustion air necessary to maintain the condition of 180°C at the outlet. Another adjustment of the generator power can be made by decreasing the rotative speed of the forced draft fan. The ratio of secondary air to primary air is maintained constant with the two throttles.

The forced draft control system tracks the best air-to-fuel ratio. The optimum ratio (gasification air / combustion air) recommended in the literature is 1/3, which means that from the total air necessary to to be burned of 75 l /min, a ratio of 25/50 l/min is adjusted by means of throttles 7 and 10 (fig.4). The mixture can be completely burned, leading to less toxic gas emissions and heat loss, which is of great importance in energy conservation and emissions reduction.

The forced draft solution was tested on a subassembly (fig. 6) consisting of a chimney 1, which can be replaced when checking the fan flow with cover 2, fan 3, branching 4, cover 5, cover 6, anemometer 7, tube 8 and the air concentrator 9.

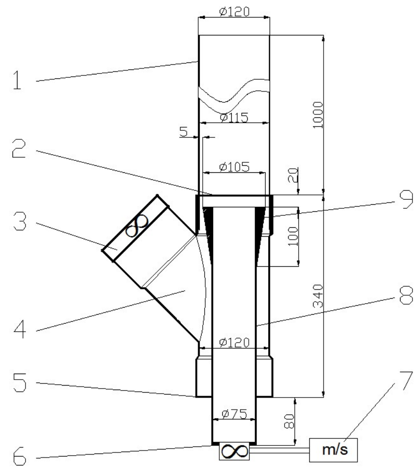

Fig. 6. Forced draft sub-assembly

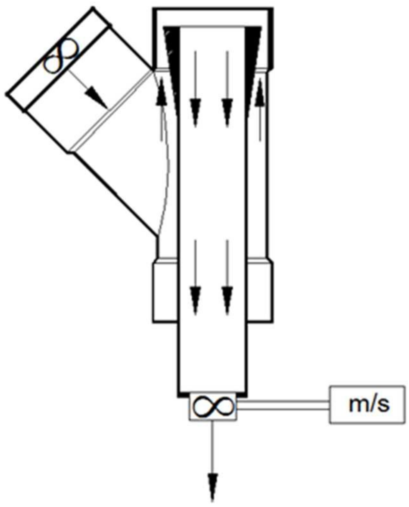

Fig.7. Mounting for fan air flow measurement

To check the flow rate (fig. 7) supplied by the fan (for this installation), it was fitted instead of chimney 1, cover 2.

Thus, the flow provided by the fan is constrained to pass through anemometer 7 in fig. 6. The air speed was 2.8 m/s. The air flow section through the anemometer is Ø 30 mm in diameter.

It follows that the air flow provided by the fan is:

$$Q = A \cdot v \tag{1}$$

$$v = 2.78 \ m/s \tag{2}$$

$$A_{\phi 30} = (\pi \cdot d^2)/4 = (3.14 \cdot 0.03^2)/4 = 7 \cdot 10^{-4} m^2 \tag{3}$$

$$Q = 7 \cdot 10^{-4} \cdot 2.78 = 2 \cdot 10^{-3} m^3/s \tag{4}$$

$$Q = 2 \cdot 10^{-3} m^3/s = 2 \cdot 60 = 120 \ l/min \tag{5}$$

The cover 2 has been replaced by the stove pipe 1, and from the installation created (fig. 8) a circulation of an upstream forced draft with a speed read on the anemometer of 1.8 m/sec. was obtained by means of the fan flow.

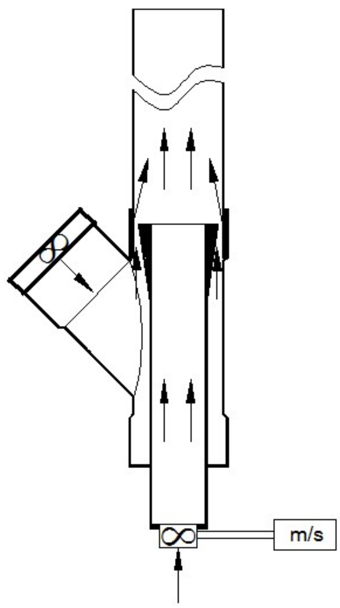

Fig.8. Determining the air flow rate and speed on the forced draft chimney

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The fan blows air through the 5 mm circular slot (fig. 6) accelerating the circulation of forced circulation on the smoke column. The anemometer measures the speed and calculates the air flow that flows through the gasifier.

It follows that the air flow of the forced draft is

$$Q = A \cdot v \quad (6)$$

$$v = 1.8\ m/s \quad (7)$$

$$A_{\phi 30} = (\pi \cdot d^2)/4 = (3.14 \cdot 0.03^2)/4 = 7 \cdot 10^{-4} m^2 \quad (8)$$

$$Q = 7 \cdot 10^{-4} \cdot 1.8 = 1.26 \cdot 10^{-3} m^3/s \quad (9)$$

$$Q = 1.26 \cdot 10^{-3} m^3/s = 1.26 \cdot 60 = 75.6\ l/min \quad (10)$$

The diameter of the existing reactor on stand is Ø100.

It follows that the transit speed of syngas in the reactor for Ø100 is:

$$v = Q / A \quad (11)$$

$$A_{\phi 100} = (\pi \cdot d^2)/4 = (3.14 \cdot 0.1^2)/4 = 7.85 \cdot 10^{-3} m^2 \quad (12)$$

$$Q = 25\ l / min = 0.025 m^3/min \quad (13)$$

$$Q = 0.025 / 60\ [m^3/s] = 0.416 \cdot 10^{-3}\ m^3/s \quad (14)$$

$$v = Q / A = (0.416 \cdot 10^{-3} m^3/s) / (7.85 \cdot 10^{-3} m^2) = 0.053 m/s \quad (15)$$

IV. Conclusions

Most sustainable development strategies conclude that new energy systems and carbon capture methods are needed. Lately, numerous studies and scientific articles highlight ecological solutions for the production of bioenergy with optimized biomass combustion equipment, resulting in biochar (carbon) that is stored in the soil for long periods of time, and which contributes to the increase of soil quality, with long-term effects of climate change mitigation.

It seems that pyrolysis is the promising solution for the use of biomass in the production of green energy and biochar. The quality and quantity of biochar obtained depends on the temperature in the pyrolytic front, the amount of gasification air, the type and quality of the biomass, granulation and last but not least, the construction of the reactor. The use of biochar in agriculture and the sequestration of carbon in the soil for long periods of time contribute to the reduction of global warming, and to the improvement of soil health and fertility, which leads to the increase of agricultural productivity.

The automatic control of the optimized combustion operation in the hot air generator on the TLUD principle can be done with the diagram shown using a programmable automatic that controls the loop between the exhaust gas outlet temperature and the nominal opening of a pneumatic servo valve.

The required air flow for burning one kg of biomass is 75 l/min; the condition is met by forced circulation, and the recommended speed of syngas must be less than 0.06 m/s, condition also met in our case is 0.053 m/s.

The forced circulation subassembly meets the conditions regarding the air flow parameters and the flow rate to ensure the optimal ecological burn, with minimal losses when leaving the chimney and with emissions and PM below the limits imposed by the legislation for boilers with solid fuels.

The forced circulation subassembly can be mounted on the hot air generator and tested in the loop (fig. 4) to maintain the temperature of 180°C when leaving the chimney (a condition recommended by the boilers, to avoid the tar deposits) and to reduce the training free ashes at concentrations below PM 2.5 at the exit on the chimney, or of maximum 5 mg/MJbm.

By continuing the research with the combustion test equipment in the gas producer of TLUD type of little power, presented as a physical achievement, the study and control of the burning equipment can be deepened at gas producer type TLUD, that can pass simple food preparation equipment to environmentally friendly, automated heating equipment that responds to the requirements of current pollution rules. which can pass simple food preparation equipment, to environmentally friendly, automated heating equipment that responds to the requirements of current pollution rules.

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