Laboratory Equipment for "Hot Air Generator with Forced Draft Fan Based on the TLUD Principle"

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Abstract: *The issues related to the optimization of energy consumption in heating equipment have emerged in recent years, when research has been intensified for a more ecological, more modern and more efficient combustion achievable, for example, by addressing new combustion solutions or technologies, such as the use of the Top-Lit Updraft (TLUD) principle for heating equipment. The article presents a laboratory equipment piece for a "Hot air generator with forced draft fan based on the TLUD principle" that operates in the loop to maintain the temperature at 180°C at the chimney outlet, which is recommended for boilers with biomass gasification, to avoid tar deposition. Also, the equipment can control the temperature of the hot air produced, by controlling the gasification air flow rate and adjusting the working power. The combustion quality can be optimized by controlling the* CO_2 *emissions or other unburned gases and suspended particulate matter (SPM) at the chimney outlet.*

Keywords: *Gasification, Top-Lit Updraft (TLUD), biomass, biochar, greenhouse gases, stoichiometric combustion*

1. Introduction

Energy consumption in developing countries for cooking and heating is mainly based on biomass fuels. An estimated 40% of the global population relies on burning solid biomass fuel to meet some or all of their household energy needs [1] which is very inefficient and produces harmful emissions through incomplete combustion.

A growing number of publications suggest that incomplete combustion by-products and noxious emissions from traditional biomass burning have contributed significantly to climate change [2, 3].

Combustion technologies are fairly well-defined for equipment that burns biomass cleaner and more efficiently [4]. However, it has been noted that not all solutions are supported by research and market demands [5]. For this reason, it is important that equipment is tested before being released to the market to ensure that new models offer significant improvements given the cooking or residential heating practices prevalent in a particular area with a particular type of biomass [5].

The reduced fuel consumption of modernized combustion equipment is linked to increased efficiency, therefore, assessing their thermal performance is essential for the development of more efficient technologies [6,7]. The energy performance of various combustion equipment has been achieved by some researchers by using biomass fuel as a renewable energy resource, CO_2 neutral and a viable alternative to fossil fuel [8-11].

The practice of using renewable biomass resources to generate bioenergy has increased significantly recently [12,13]. Among the various technological options, biomass gasification is a relatively simple solution in process/reactor design and implementation [14]. After gasification, two components result: synthesis gas and biochar. Biochar is known for its carbon-rich nature that provides valuable benefits to the environment [15].

Top-lit updraft (TLUD) gasification has the potential to simultaneously produce biochar and syngas from biomass. It was found that some models of TLUD gasifiers have relatively high yields in the production of biochar and synthesis gas [16,17].

Gasification is a process by which solid fossil fuels are converted into a synthetic fuel gas called syngas (mainly a mixture of carbon monoxide and hydrogen); is a thermochemical degradation process that takes place at high temperatures (800-1000°C) in an environment where the amount of oxygen is lower than that required for complete combustion. In order for the biomass gasification

combustion process to be complete, it is necessary that the air required for complete combustion and the resulting gas (syngas) be mixed in a certain ratio under appropriate conditions of turbulence and temperature. If the combustion is incomplete, either due to a lack of oxygen, or if the excess oxygen cools the vapors below the optimal point at which they will burn, unwanted pollutant emissions and energy waste result [18].
Forced draft gas cookstoves have been shown in laboratory studies [19-21] to reduce CO and PM emissions by 90% compared to free combustion (as one can see in Figure 1).

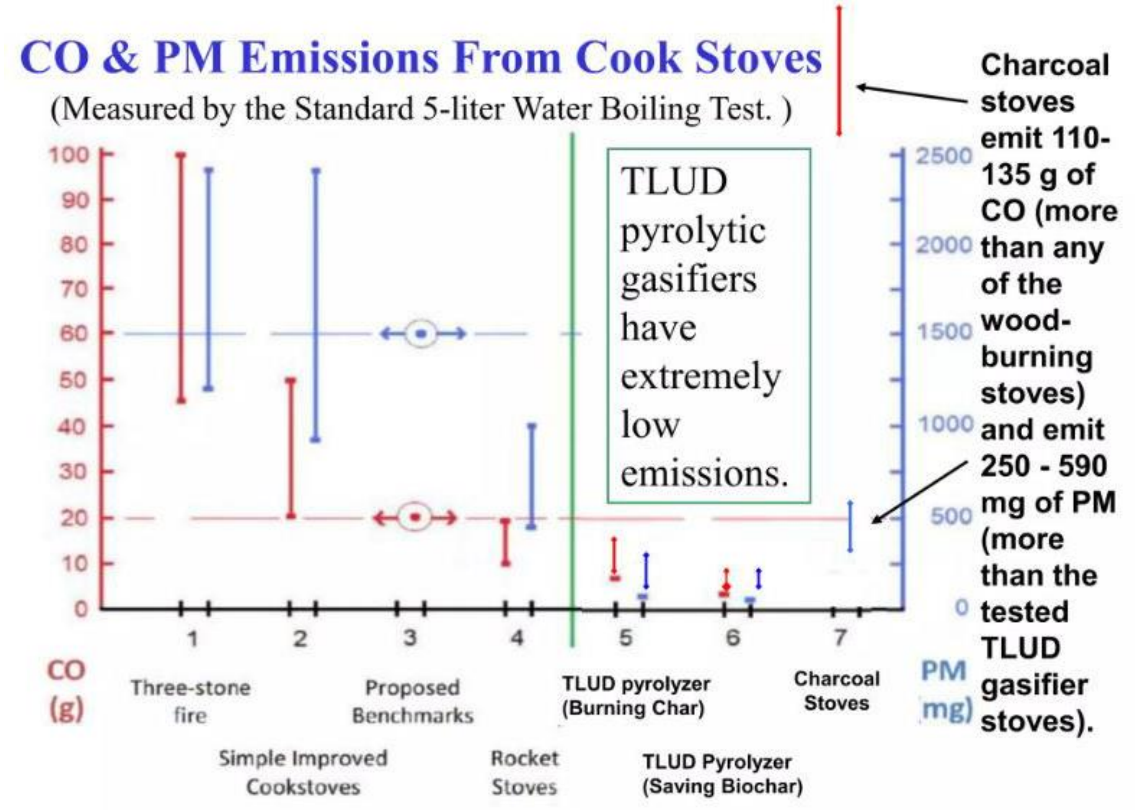

Fig. 1. Comparison of CO and PM emissions from various combustion technologies and systems [22]

Materials considered waste (bark, residues from forest wood cutting, residues from secondary agricultural production, etc.) can be used effectively to produce thermal energy and store carbon in biochar. Virtually any chopped and dried or densified wood material can be fuel for TLUD installations.

2. Presentation of the "TLUD hot air generator" laboratory equipment

2.1 General characteristics of the TLUD principle

The TLUD process implies a fixed layer of biomass (the pyrolytic front advances in the biomass layer) and as a result the gasifier works in a batch mode with recharging. The gasification process is done with a reduced intensity with specific hourly consumption of 80 – 150 kg.bm/m²h; this fact results in reduced specific reactor powers of 250–350 kW/m². Due to the slow gasification process, the surface velocity of the produced gas has very low rates, namely below 0.06 m/s, which ensures a reduction in the rate of entrainment of free ash at concentrations below PM 2.5 at the burner outlet, to a maximum of 5 mg/MJbm. This value is at least five times lower than the current norms imposed for solid fuel thermal generators.
Limiting the air speed in the reactor to ≤ 0.06 m/s has to be observed so that any entrained particulates do not advance through the chimney towards the atmosphere. In our case, the reactor has a diameter of Ø100 and the primary air flow rate is 25 l/min.

$$D_{react} = \phi 100 \tag{1}$$

$$Q_{primary\ air} = 25 l/min \tag{2}$$

It results that the air speed in the reactor is:

$$V = \frac{Q}{A} = \frac{25 l/min}{\frac{0.1^2 \cdot 3.14}{4} m^2} = \frac{0.025/60 \cancel{m^3}/s}{0.00785 \cancel{m^2}} = 0.053\, m/s < 0.06\, m/s \tag{3}$$

The research endeavours at the level of the INOE 2000-IHP Institute to study this combustion process have taken the shape of a laboratory equipment. A series of tests will be carried out on it that could transform the classic cooking equipment into a forced draft hot air generator, with pollutant emissions below the norms proposed by 2030, with a conversion efficiency of up to 85%, which also produces – in an amount of about 10...20% of the initial amount of biomass - residual charcoal, not converted into gas, known as biochar.

2.2 Presentation of the laboratory equipment

The laboratory equipment (Figure 2) consists of frame <1>, electronic scale <2>, gas generator <3>, combustion chamber <4>, heat exchanger <5>, draft regulator <6>, forced draft subassembly <7>, chimney temperature sensor <8>, grip for noxious emissions sensor <9>, grip for particulate matter sensor <10>, hot air temperature sensor <11>, combustion air manual control throttle <12>, secondary air servo valve <13>, secondary air flow meter <14>, primary air flow meter <15>, primary air throttle <16>, primary air servo valve <17>, pressure sensor <18>, laptop <19>, acquisition board <20>, temperature controller <21> and PLC <22>.
The equipment works in a loop to maintain a temperature of 180°C at the chimney outlet, which is recommended for boilers with biomass gasification, to avoid the deposition of tar. The equipment can also control the temperature of the hot air produced, by controlling the gasification air flow rate and adjusting the working power. The combustion quality can be optimized by controlling the CO_2 emissions or other unburned gases and suspended particulate matter (SPM) at the chimney outlet.

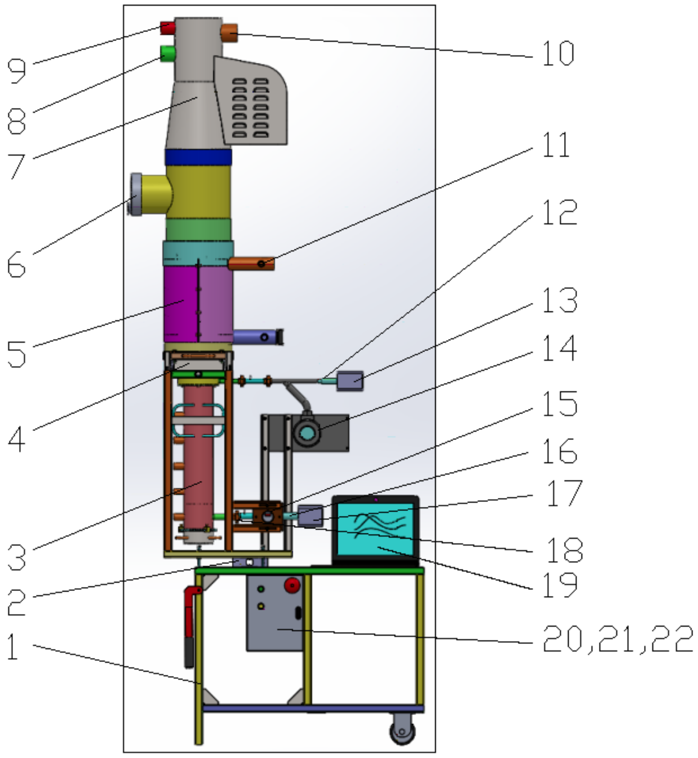

Fig. 2. "TLUD hot air generator" laboratory equipment – 3-D design

2.3 The principle of operation

As one can notice in Figure 3, the equipment is provided with a computer (2) and a data acquisition program developed in LabView, with a friendly graphic interface, which displays and records all acquired parameters and their graphs in real time, a controller (3) for monitoring the temperature on the chimney and a PLC for controlling the pneumatic servo valves (11). The temperature sensors (5) monitor the temperature in various points of the reactor (6) during the gasification and combustion process.
To initiate combustion, the heat exchanger (13) is disconnected from the reactor (6). After ignition, the forced draft fan (15) is switched on again; in this way a depression is created and the required amounts of gasification and combustion air are provided. This air flow can be adjusted by varying the fan speed and by means of the draft regulator (14). These flow rates are monitored by using the flow transducers (9), and the depression value at the gas generator inlet is monitored by using the transducer (8). Right after ignition, the gasification and combustion air flow rates will have maximum values so that the temperature on the chimney reaches the value of 180°C read by the sensor (18) as quickly as possible. When the value is reached, the sensor sends a control signal, through the controller and the PLC, for the proportional closing of the servo valves (11), thereby reducing the air flow rate. The hot air temperature at the outlet of the exchanger is monitored by using the temperature sensor (12). The quality of the combustion is monitored by means of a gas analyzer (17) and a SPM analyzer (16) at the chimney outlet. Biomass consumption is monitored in real time by using the electronic scale (7).
As the laboratory equipment is fitted out in a complex manner, it allows the monitoring of the TLUD combustion process and its quality, and thus the optimal operating parameters and control loops for this type of equipment can be determined.
The main purpose of this paperwork is to present a hot air generator solution based on the TLUD principle, with forced draft fan, and a solution for optimizing combustion by maintaining the chimney temperature at 180°C to avoid the formation and deposition of tar, by setting the maximum speed of the main (gasification) air flow rate so as to avoid PM emissions in the atmosphere and by dosing the secondary (combustion) air flow rate so as to reduce the noxious emissions.

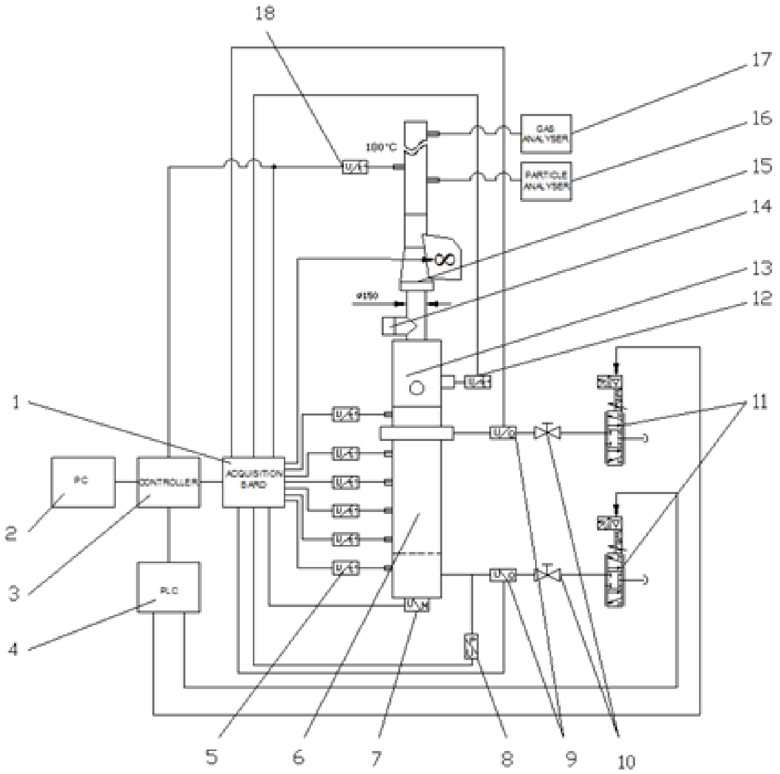

Fig. 3. Operating diagram of the laboratory equipment "hot air generator based on the TLUD principle"

The amount of hot air required is monitored by the temperature sensor (12), and through the acquisition board of the controller and the PLC (or the dedicated PC software) the primary and secondary air flow rates can also be adjusted in order to control the power of the gas generator and implicitly the amount of hot air required.

3. Conclusions

The most important benefit that the gas generator working on the TLUD principle offers is that it provides clean energy compared to any of the other combustion methods; it offers environmental protection solutions by storing carbon in biochar and by PM and CO_2 emissions at the chimney below the values imposed by European legislation, thus contributing to the reduction of greenhouse gas emissions, to the effective protection of the environment and to ensuring a sustainable energy development.
By continuing research with the TLUD hot air generator laboratory equipment, it is possible to deepen the study of the combustion quality and control at the TLUD equipment, which can move these devices from the category of food preparation equipment to the category of automated heating equipment similar to gasification boilers, and this can be a solution for replacing heating equipment operating on outdated, less cost-effective and less environmentally friendly combustion systems.

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