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EXPERIMENTAL RESEARCH ON THE METHODS OF VALORIFICATION OF BIOMASS WASTE

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Abstract: *This paper presents the results obtained from testing a TLUD-type equipment, used to obtain biogas and biochar from biomass, developed and manufactured based on a patent elaborated under a research and development project by the staff of the Institute IHP. The paper presents solutions to increase the efficiency of burning boilers with gasification by recovering heat from flue gases discharged (which otherwise would be lost to the atmosphere) and reinserting it into the air circuit for gasification or combustion. The energy thus reintroduced into the combustion process can increase efficiency of gasification boilers by several percents, which means it saves large amounts of biomass and slows down global warming.*

Keywords: *Biomass, Combustion Processes, Thermal Energy, TLUD*

1. Introduction

One of the most important sources of fuel for humankind was wood. Essential for using this type of fuel is that energy can be recovered in a sustainable manner (being renewable). Worldwide there is a potential big enough for the use of wood for energy purposes. Many of Europe's forests can be used for energy purposes without compromising existing natural ecosystems. Harvesting and processing wood for energy purposes other than those involving large quantities of waste, often remain untapped. Thus, wood chips or sawdust, which can produce so-called pellets or briquettes are a valuable fuel. A big advantage of wood is that it retains the energy content in time, even in the first two to three years there is a relative increase, which is the period when drying occurs. This feature is important because if you do not have a properly degree of drying all wood humidity will be eliminated in the boilers with the price in the drop of the caloric power. Another disadvantage is the burn rate of the wet wood which decreases the temperature of the combustion, which leads to imperfect oxidation of all the combustible ingredients, the appearance of smoke, the clogging of the fumes canals and reducing the boiler life.
Gasification is the conversion of solid fuels into gaseous fuels, produced by partial oxidation using oxygen, air, water vapor or mixtures thereof in special equipment (gas-producing). The entire process takes place by partial combustion and heating of biomass with heat generated during combustion. The mixture of emerging has a high energy value which can be used, like other gaseous fuels, to produce heat or electricity.

2. Methodology

Wood boilers, gasification, with gasification, it runs on pyrolytic wood distillation process. When the air is limited, the wood turns into charcoal as it burns. At the same time appears the "wood gas", which is directed into the burner nozzle to be burned at the base of the boiler. This method of wood burning allows the effective use as fuel.

Combustion is a three-step process in every area of the boiler:

- Zone 1 - drying and gasification wood,
- Zone 2 - burning of the wood gas at the secondary preheating nozzle entrance,
- Zone 3 - lower combustion in uncooled combustion chamber.

Thus, the system for controlled combustion ensures a high efficiency - often up to 90%. Taking into account this, the boiler performance is continuously variable from 40% to 100%. Burning space typically includes the nozzles made of special refractory materials. The control of operating the boiler is made with an electronic controller, depending on the temperature.
In the gasification process there enters biomass and air and results fuel gas and ash with a neutral CO_2 balance.
The fuel gas with CO, H_2, CO_2, N_2 and tar can be used to:

- burning in a specialized burner from which results flue gases with high enthalpy containing, in very low concentrations PM and CO, hot gas that are used to:
  - processes of heating water, steam or air,
  - in internal combustion engines to produce electric energy.
- is filtered the content of tar and PM and is used in internal combustion engines to produce electric energy.

In Figure 1 is represented a block diagram of the procedure of energy recovery of biomass by thermo-chemical gasification.

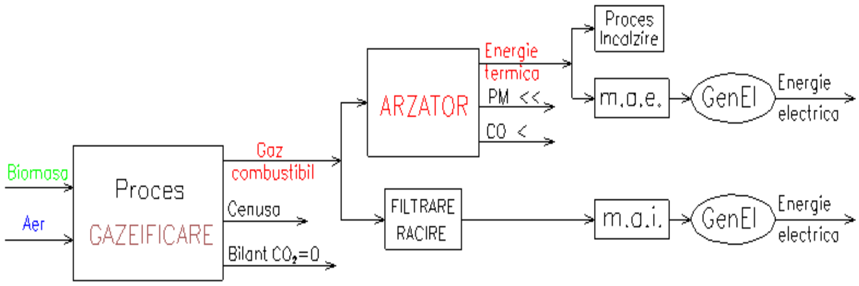

Fig. 1. Block diagram of the energy recovery from biomass via gasification

Given the high degree of automation of the gasification boilers, operation of such devices requires only minimum requirements. The content of the fuel compartment is sufficient for at least 4-10 hours of use on medium power. The boilers are designed for installation in systems with forced or gravitational circulation.
Gasification boilers can burn dry wood mass, wood waste naturally in a variety of forms, from chips to logs with lengths up to 80 cm and the a diameter of up to 30 cm, briquettes or pellets.

3. Energy module with micro-gasification process type TLUD

Functional diagram of a TLUD generator with coupled burner it is shown in Figure 2. The micro gasification process is supplied with air from a variable speed fan. In Figure 3 is represented a functional diagram of a TLUD generator at which the gasgen burner and separated from the gas producer. Gasgen is a combustible gas with low calorific power and for an efficient combustion are used specialized burners, FLOX type [1, 5, 9, 10].
Biomass is introduced into the reactor and rests on a grate through which passes, from the bottom up, the gasification air. Initialization process is made from the free top layer of biomass.
The heat is obtained by burning the hot gasgen resulted in pyrolysis phase; this is mixed with the preheated combustion air introduced into the combustion zone through orifices disposed at the top of the reactor. The mixture with high turbulence flame burns at the upper mouth of the generator with temperatures of 900-1000 ºC. To adjust the thermal capacity required the air flow rate Dag for gasification and Dard for combustion with two flaps, coupled mechanically or by varying fan speed.
The TLUD is with a fixed bed biomass process and therefore the generator operates under rechargeable batch.
The gasification process is done with a light intensity with timetables specific consumption of 80 – 150 $kg._{bm}/m^2h$ which leads to reduced specific power for the reactor 250 – 350 kW/m^2. The slow process maintains a superficial velocity of the gasgen produced at very low values $v_{sup} \leq 0,06$ m/s resulting in reduced free ash entrainment and the concentration of $PM_{2.5}$ at output from the burner

of maximum 5 mg/MJ_{bm}; value of at least five times smaller than current rules imposed for thermal generators with solid fuel. [3, 5, 7, 9, 10]
Because it provides a very good mixing of gasgen with burning air at an optimum excess of 1.4 - 1.5, in the flue gases the CO concentration is less than 2%, or 0,8 g/MJ_{bm}; value under the standards required currently. These aspects make TLUD heat generator to be less polluting compared to other systems of the heat generation using solid fuel.

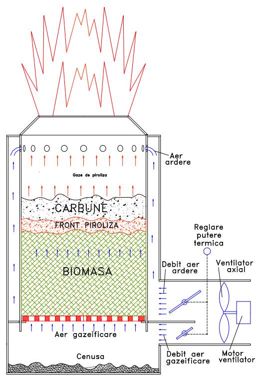

Fig. 2. Functional diagram of the TLUD generator with coupled burner

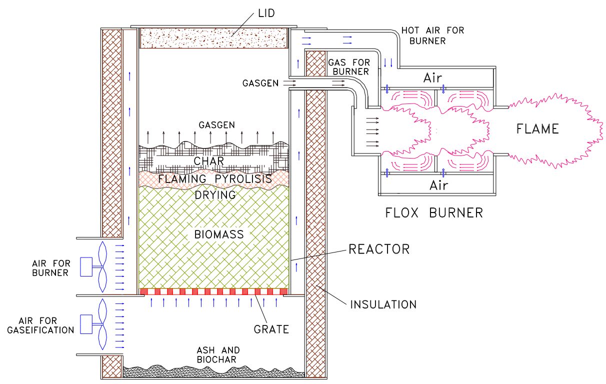

Fig. 3. Functional diagram of the TLUD generator with FLOX burner

This type of heat generator has been developed and used in stoves for preparing food in remote areas, operating very well with a wide variety of local biomass. An outstanding example is the environmental and energy performance is the portable stove produced by PHILIPS, in which the fan is powered by electricity produced by a Heat-generating semiconductor, mounted under the grill, being a typical generator thermal with energy independence.
In Figure 4 is a block diagram of a TLUD energetic module. Energetic inputs into the module are:

- biomass consumption C_{bm};
- air needed for gasification D_{ag} and for combustion D_{ard};
- the size of command u_{Pt} of thermal load.

The outputs from the energetic module are:

- biochar D_{ch} produced from pyrolysis and partly reduced;
- thermal power P_{th} of the flue gas at exit of the burner;
- concentration of C_{CO} in the combustion gases;
- concentration of solid particles PM in the combustion gases.

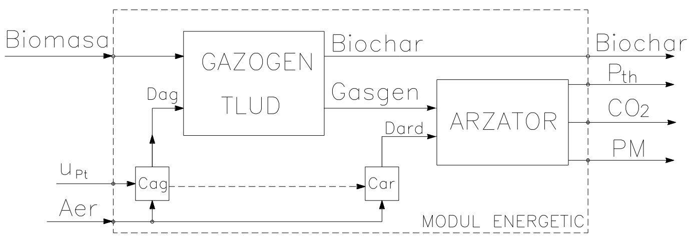

Fig. 4. Block diagram of the energetic module TLUD

In TLUD generator enters biomass gasification and combustion air and electricity. The electric energy consumption is not more than 0.3% of the thermal energy produced, aspect that recommended TLUD thermal generators in heating systems in energetic remote areas.
From the experiments carried out with modules TLUD it has been found that the conversion efficiency of the biomass entirely gasified in gasgen is in the range 92-95%. [1, 2, 4, 6, 8].

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To achieve thermal performance and functional requirements imposed by current industrial consumers of thermal energy, to the heat generator TLUD it can be attach an automatic driving device type PLC.
Energy recovery is a topic addressed by most local development strategies, national and global, this is the basis of sustainable development.
The effects of energy recovery consist in:

- lower consumption of wood to heat a space, so lower costs for maintenance,
- resource conservation,
- the natural environment is more stable,
- rescued trees bring satisfaction, wellness and relaxation to people.

In a research project there were attempted to develop alternatives of TLUD gasifiers that aim to recover energy in the chimney (which is required by 150-200º C temperature), thus avoiding condensation and the tar deposit. So the proposed solutions focus on keeping constant the temperature imposed by chimney and the heat energy recovery of this area, that can be reintroduced partial in the combustion process or can be converted into electrical energy (E.g. for charging a battery by means of Peltier modules).

4. TLUD prototype testing

The biomass is introduced into the reactor and rests on a grill through which the primary air for gasification passes from bottom to top. Rapid pyrolysis reaches a point of incandescence at the top and continues down into biomass in the reactor. Rapid pyrolysis results in gas, tar and biochar. Tars pass through the incandescent charcoal layer, are cracked and completely reduced due to the heat radiated by the pyrolysis front and the upper flame. The resulting gas is mixed with the secondary combustion air, preheated by the reactor wall, introduced into the combustion zone through the orifices disposed at the top of the reactor. The mixture with high turbulence burns with flame at temperatures of about 900 ° C. The regulation of the thermal power is done by the variation of the primary and secondary air flows. The design solution shown in Fig. 5 has been filed as Patent No. A / 00286 / 27.04.2015 [12]

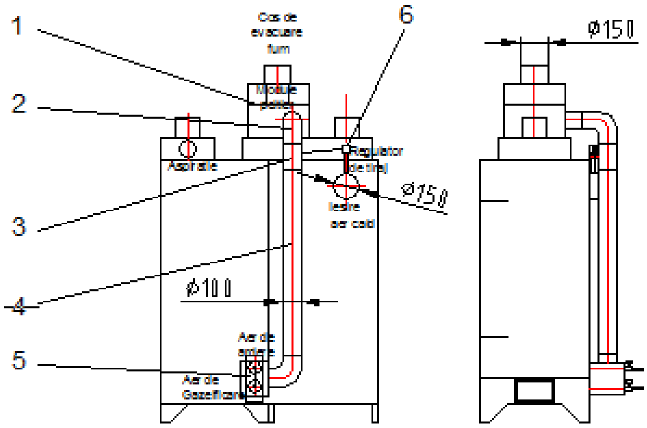

Fig. 5. Design solution of TLUD

In the tests, 15 kilograms of pellets were used as combustion material. The reactor allows the loading of two pellets.
The TLUD warm air prototype (Figure 6) was tested in the low power and maximum power mode. Tests were conducted at INOE 2000 IHP.
Recording the temperature variation at different points of the hot air generator is done with the help of Pt1000 temperature probes. They are connected to a data acquisition board via 4 ... 20 mA amplifiers, the voltage conversion for the analog input of the acquisition board is made with the help of resistors (Figure 9). An application made in LabVIEW is used to display and record the data (fig.10). The application displays numerically and graphically the temperature variation during

burning. When the recording stops, the application allows you to save the temperature values over time in a text file. These data can be processed later.

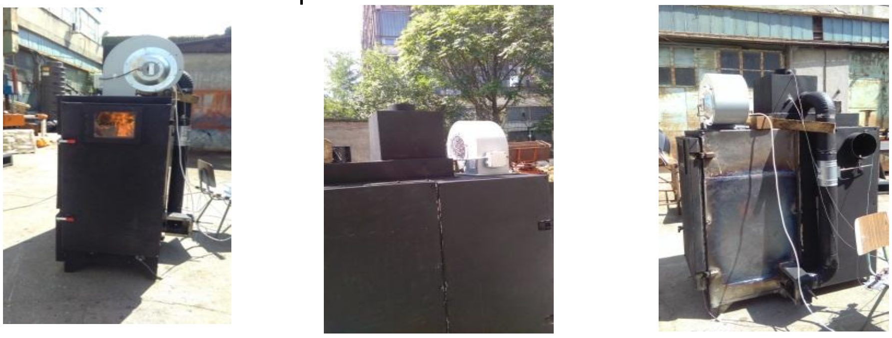

Fig. 6. The hot air generator prototype on the principle of TLU

The LabVIEW application (figure 7) contains the following function blocks: program loop with the possibility of setting the data acquisition interval, input block from the acquisition plate in which it is made and temperature scaling - output signal, numeric display, graph display, running time counter (seconds, minutes, hours), data entry in text file, graphical deletion (when starting a new sample), and a table display block.

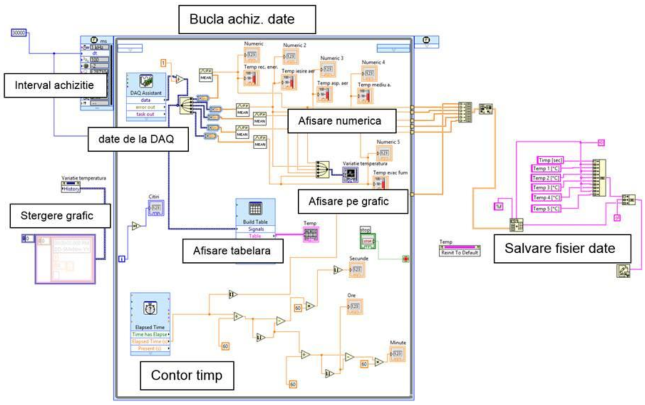

Fig. 7. LabVIEW data schematics acquisition program

4.1. Test 1 – Obtaining Gasification and biochar alternative

The contents of a pellet bag were introduced into the reactor. Initiation of the combustion process was done at the top of the material in the reactor, with commercial fire ignition lighters and from ignition to stabilized gasification entering about 12 minutes according to the data acquisition (Figure 8)

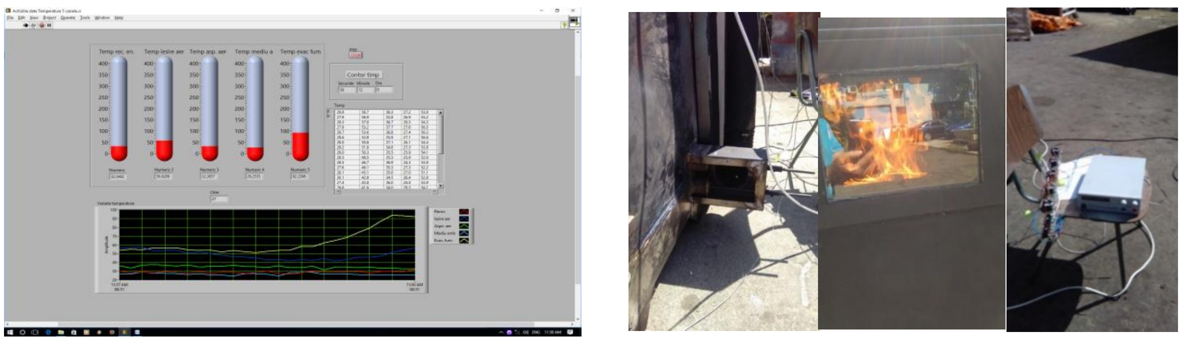

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Fig. 8.

After entering the gasification regime, the flame has moved from the combustion material in the reactor to the burner. The gas produced in the reactor was mixed with the combustion air and a flame similar to the flame from the stove was produced (Fig. 8b). Several adjustments of the gasification and combustion air intake valves (Fig.8.a) have been made and the adjustability of the hot air generator power has been found. By opening them, the flame grows almost instantaneously. Thus, the correct operation of the TLUD type gasification principle (Top-Lit UpDraft) has been demonstrated [12].
As a result of the data acquisition (Fig. 8c) for the entire duration of the operation until the flame is blue and the hot air generator (stopping the fans and opening the supply door) to get the biochar, the graph of Fig. 9.

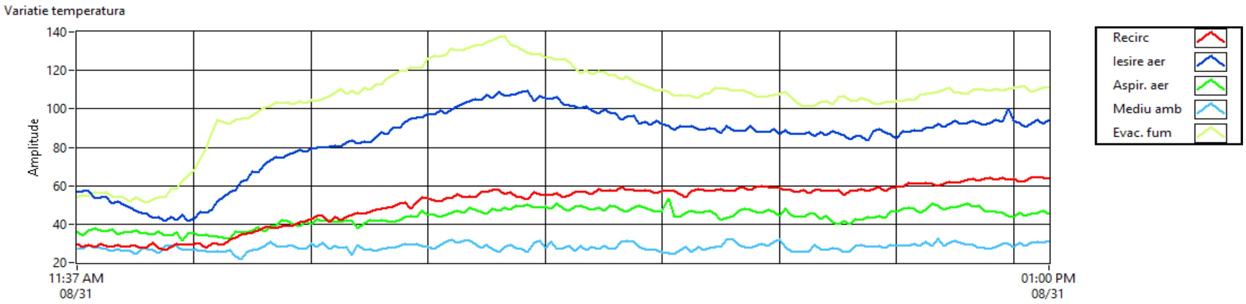

Fig. 9

The burning process lasted 83 minutes for a 15 kg pellet bag under minimal operating conditions and was interrupted when the flame was blue (signaling that the gasification of the matrix was complete and the gasification of the biochar commenced). Thus, approximately ¼ of the biochar (figure 10) was obtained from the volume of the material initially introduced for combustion.

Fig. 10. Biochar obtaining

A good adjustment of power from the hot air generator was achieved by adjusting the combustion air and gasification. The temperature of the heated air at the exit from the generator for the minimum operating condition was stabilized at about 90 ° C and the chimney temperature was about 120 ° C. The air flaps have been adjusted to approximately 1-2 mm opening.
Under these conditions it can be said that the generator cannot work below the test values, so it has a minimum operating power of 3kW

4.2. Test 2 - Gasification without making biochar with gasification of them gasification,.

Into the reactor were introduced the contents of a pellet bag. The initiation of the combustion process was done with commercial briquettes and from the ignition until the stabilized operation entered it took about 12 minutes according to the data acquisition (Figure 11).

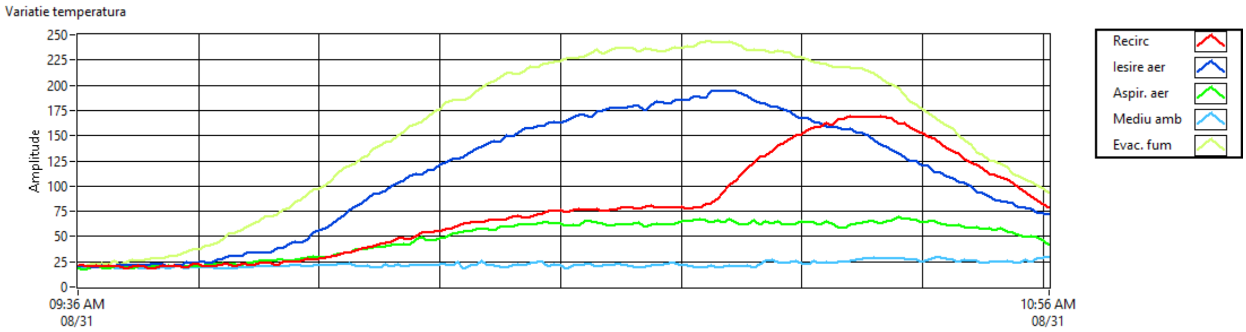

Fig. 11

Under the test conditions at maximum power with air flaps and gasification air open at more than 10 mm, an average heating air temperature of 175 ° C was obtained and the chimney temperature was approximately 230 ° C according to the graph of data acquisition.
In Test 2, the burning process was no longer interrupted to obtain the biochar (when its flame was blue) and thus a longer operating time and a higher energy amount with about ¼ of the reactor shutdown and biochar. The final result of total burning, including the batch, was a very small amount of ash of about 50 g. The generator can work very well in both ways; with the acquisition of biochar or burning it and getting energy. In both cases no emissions of smoke or fumes were found.
When the pyrolytic front reached near the bottom of the reactor and the thickness of the biochar layer decreased in the conditions of maintaining the flow of gasification and the minimum resistance created by the material, the burning process accelerated for a short time (until all combustion material including the biochar), although the burning process declined, the generator still supplied warm air for about 20 minutes due to thermal inertia.

5. Conclusions

The advantages of applying energy recovery solutions and increase efficiency on the gasification boilers are:

- superior recovery of the flue gases heat so their input temperature in the chimney is smaller, about 170...200°C compared to the 250°C of the existing boilers;
- complete combustion of gaszgen that leads to diminishing the specific loss by incomplete combustion;
- reducing the risk of carbon monoxide poisoning;
- the use of wood fuel with a moisture content greater than 20% as primary combustion air has a higher temperature;
- effectively increasing the efficiency of the boiler from 81 ... 86% to 90%;
- wood fuel saving for the same energy produced by other boilers;

The prototype tested responds to project objectives, works under different power regimes, on the TLUD principle and it can enter into an industrial design process, after which it can be manufactured and delivered to the market.
It has been found that the smoke fan is high for operating conditions less than those obtained at test 1, but for maximum power at test 2 it is well-sized. An improvement could be obtained if the electronic control panel it can provided an electronic mount for the variation of the fan speed. Thus, the hot air generator can be shown to operate from a minimum power of 3 kW up to a maximum power of 24 kW by regulating the air inlet and exhaust gas intake flaps.
If it is desired to introduce hot air into the greenhouse at a lower temperature than that provided by the generator, it is possible to adapt a mixture of hot air from the generator with fresh air from the atmosphere until the desired optimal temperature for entering the greenhouse is obtained.
Besides energy recovery of waste, it is also aimed:

- replacing fossil fuels such as fuel oil, fuel gas and coke (conservation / protection of resources);
- reducing the impact of CO_2 emissions on climate (climate protection);
- reducing the dependence of global markets of energy connected with the cost reduction;
- increase the degree of flexibility of waste management by reducing the amount of residual waste.

Arguments in support of biomass use:

- diversifying of energy supply;
- replace conventional fuels with high emissions of CO_2;
- contribute to waste recycling;
- protects and creates jobs in rural areas;
- possibility of adjusting, automation and control of the system depending on the objective requirements or heated building;
- high efficiency system.

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