Increasing the Efficiency of Wood Biomass Gasification Boilers

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Abstract: *Increasing efficiency in combustion processes is set as a goal in all the research and innovation, energy and environment strategies. Gasification boilers work under nominal conditions while maintaining a temperature of about 200 °C along the smoke flue in order to avoid the deposition of coal tar.*
This paper presents some solutions to increase efficiency of wood gasification boilers by recovering heat from the gas exhausted at the smoke flue (which otherwise would be lost to the atmosphere) and re-introducing it in the gasification or combustion air circuit. The energy thus re-introduced into the combustion process can increase efficiency of gasification boilers by a few percentage points, which means that significant amounts of biomass are saved and the process of global warming slows down.

Keywords: *Gasification, combustion, boiler, wood biomass, pyrolysis, efficiency.*

1. Introduction

(One of the most important sources of fuel for humankind was represented by 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 the 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 causing a drop of the caloric power. Another disadvantage is that the burning time of the wet wood decreases the combustion temperature, which leads to imperfect oxidation of all the combustible ingredients, appearance of smoke, clogging of the flue gases ducts and reducing the boiler lifetime.
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-generators). The entire process takes place by partial combustion and heating of biomass with heat generated during combustion. The mixture of emerging gases has a high energy value which can be used, like other gaseous fuels, to produce heat or electricity.

2. Methodology

Wood boilers with gasification run on the process of wood distillation by pyrolysis. When the air is limited, the wood turns into charcoal as it burns. At the same time there appears the "wood gas", which is directed into the burner nozzle to be burned at the bottom of the boiler. This method of wood burning allows the effective use of wood as fuel.
Combustion is a three-step process in every region of the boiler:

- Region 1 – wood drying and gasification,
- Region 2 - wood gas burning when the secondary air enters the preheating nozzle,
- Region 3 - lower combustion in un-cooled combustion chamber.

Thus, the controlled combustion system ensures high efficiency - often up to 90%. Taking this into account, the boiler performance is continuously variable from 40% to 100%. Burning space typically includes the nozzles made of special refractory materials. The control of boiler operation is made by use of an electronic controller, depending on the working temperature.

In the gasification process the inputs are the biomass and the air, and the outputs - fuel gas and ash with a neutral CO_2 balance.
The fuel gas containing CO, H_2, CO_2, N_2 and tar can be used as follows:

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

Figure 1 presents a block diagram of the procedure of biomass energy recovery by thermochemical gasification.

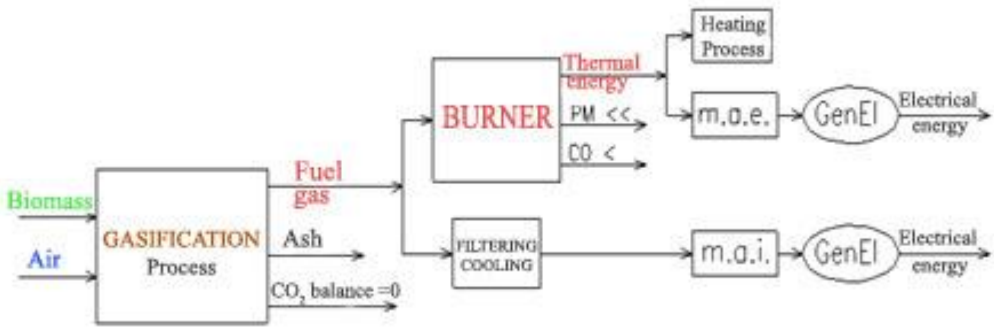

Fig. 1. Block diagram of the biomass energy recovery by gasification

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

3. Energy module with TLUD micro-gasification process

Functional diagram of a TLUD generator with coupled burner is shown in Figure 2. The micro gasification process is supplied with air from a variable speed fan. Figure 3 presents a functional diagram of a TLUD generator at which the gasgen burner is separated from the gas generator. "Gasgen" (gas generator product) is a combustible gas with low calorific power and for efficient combustion there are used specialized burners, FLOX type [1, 5, 9, 10].
Biomass is introduced into the reactor and rests on a grate through which the gasification air passes bottom-up. Process initialization is made from the free top of biomass layer.
The heat energy 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 ports arranged at the top of the reactor. The mixture with high turbulence burns with flame at the upper orifice of the generator with temperatures of 900-1000 ºC. To adjust the thermal capacity required the air flow rate for gasification D_{ag} and the one for combustion D_{ard} are varied with two flaps, coupled mechanically or by varying the fan speed. The TLUD process is with a fixed bed of biomass, and therefore the generator operates under rechargeable batch.
The gasification process is done with a light intensity with specific consumption per hour 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 entrainment of free ash and concentration of $PM_{2.5}$ at the burner output of maximum 5 mg/MJ_{bm}, value of at least five times smaller than current standards imposed for thermal generators with solid fuel. [3, 5, 7,9, 10]

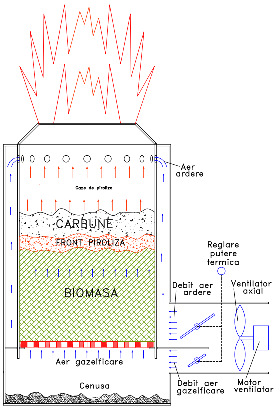

Fig. 2. Functional diagram of the TLUD generator with coupled burner

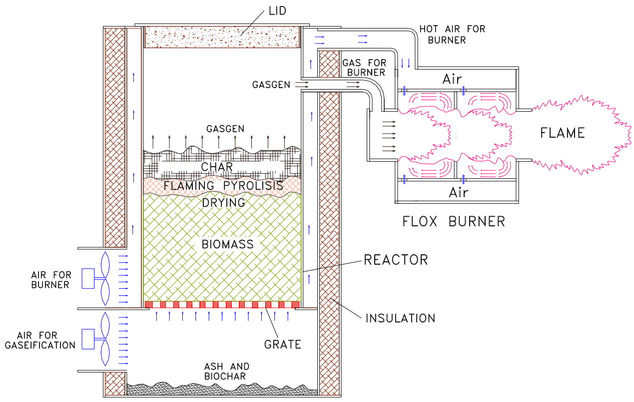

Fig. 3. Functional diagram of the TLUD generator with FLOX burner

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 below the currently required standards. These aspects make the TLUD heat generator the less polluting compared to other systems of the heat generation from solid fuel.
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 in terms of environmental and energy performance is the portable stove produced by PHILIPS, in which the fan is powered by electricity produced by a heat-generating with semiconductors, mounted under the grate, being a typical thermal generator with energy independence.
Figure 4 presents a block diagram of a TLUD energy module. The inputs of this energy module are:

- biomass consumption C_{bm};
- air needed for gasification D_{ag} and for combustion D_{ard};
- thermal load control parameter u_{Pt}.

The outputs of the energy module are:

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

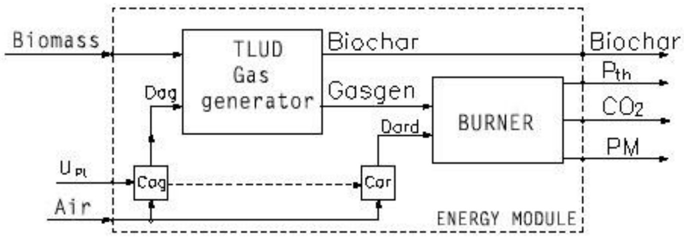

Fig. 4. Block diagram of the TLUD energy module

The inputs of the TLUD generator are biomass, gasification and combustion air and electricity. The electric energy consumption is no more than 0.3% of the thermal energy produced, which recommends the use of TLUD thermal generators in heating systems in remote areas.
From the experiments carried out with TLUD modules it has been found that the conversion efficiency of the biomass entirely gasified into gasgen is in the range 92-95%. [1, 2, 4, 6, 8].
To achieve thermal and functional performance currently required by industrial consumers of thermal energy, an automatic control device type PLC can be attached to the TLUD heat generator.
Energy recovery is a topic addressed by most of the local, national and global development strategies, and this is the basis of sustainable development.

The effects of energy recovery consist in:
- lower wood consumption for heating premises, so lower maintenance costs,
- resource preservation,
- the natural environment is more stable,
- saved trees bring satisfaction, wellness and relaxation to people.

In a research project supported by the Financial Agreement no. 67/2014 there have been developed versions of TLUD gasifiers that aim to recover energy in the chimney (150- 200º C), thus preventing condensation and tar deposition. So the proposed solutions focus on keeping constant the temperature imposed at the chimney and recovery of the heat energy in this area, which can be partly reintroduced in the combustion process or can be converted into electrical energy (e.g. for charging a battery by means of Peltier modules).

A first version is shown in Figure 5, where the energy recovery system is done using Peltier modules. This turns the heat lost at the chimney into electricity. By using this solution one can charge a battery that can provide energy independence of a hot air generator and this one can be used in locations with no other sources of energy.

Peltier modules convert the temperature difference of the outside surfaces of the module into electricity. They are mounted in the energy recovery chamber with "the warm" face towards the chimney (which has 150-200º C) at a distance of about 100 mm, and "the cold" face towards outside (to ambient temperature). From this mounting we aim to achieve a difference in temperature of the Peltier module faces of max. 68ºC, at a working temperature of max. 138ºC. From the proposed mounting according to the technical sheet there results working voltage of max. 16.2V and working current of max. 30.7A.

Power consumption of hot air generator (240W; 20A) is provided by a 12V battery which is charged by 4-6 Peltier modules which operate at nominal capacity in the described terms of installation.

Another version proposed in the project is shown in Figure 6. Recovery of energy from the exhaust gases from the chimney is based on preheating the gasification and combustion air, maintaining constant temperature of the flue gases outlet. Temperature of gases exhausted through the chimney is maintained in the range 150-200ºC to prevent condensation and deposition of tar, by use of an air flap driven by the control module. The recovery system analyzed is designed to take the heat around the chimney (that would have been lost) and introduce it in the combustion and gasification air supply circuit.

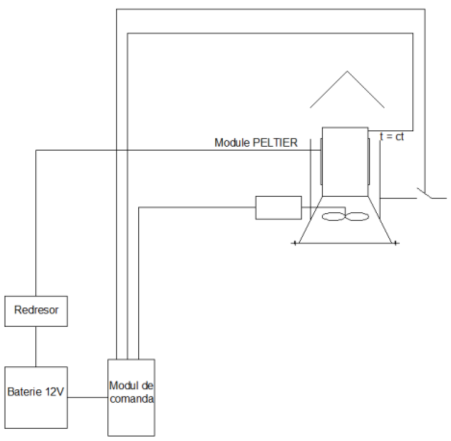

Fig. 5. Diagram of a TLUD gasifier -1st version (with Peltier module)

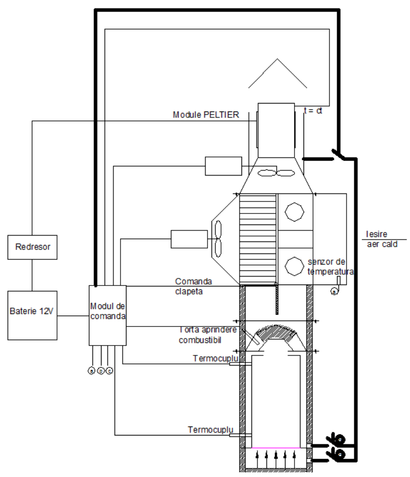

Fig. 6. Diagram of a TLUD gasifier -2nd version

Figure 7 shows a version of a system which recovers energy from the exhaust gases from the chimney by preheating the gasification and combustion air, maintaining a constant temperature at the flue gas outlet by adjusting the rotational speed of the forced draft fan.

Maintaining constant the temperature of the exhaust gases (to prevent energy losses) can be done by adjusting the forced draft fan speed, having a negative effect in reducing the power of the hot air generator.

One last version, Figure 8, shows a system for recovering energy from the exhaust gases from the chimney with a preheating of the gasification and combustion air and maintaining a constant temperature on the exhaust system by adjusting rotational speed of the warm air fan.

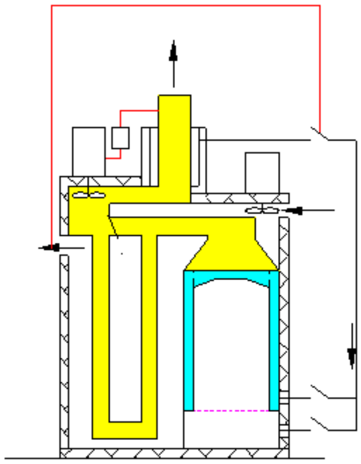

Fig. 7. Diagram of a TLUD gasifier -3rd version

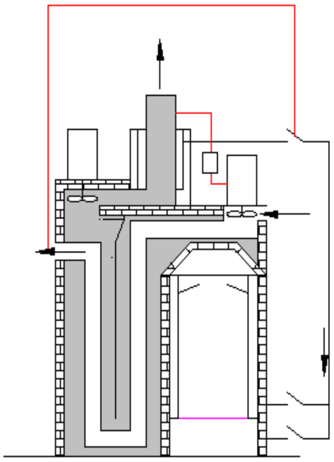

Fig. 8. Diagram of a TLUD gasifier -4th version

Maintaining constant the temperature of the exhaust gases can also be done by adjusting the rotational speed of the warm air fan and keeping the exhaust gas temperature constant in conditions of raising the hot air flow provided. A combination of both solutions of avoiding energy loss at the chimney by adjusting the forced draft fan speed or the warm air fan speed could optimize the overall efficiency of the generator.

4. Conclusions

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

Besides energy recovery of wastes, it is also aimed at:
- replacing fossil fuels such as black 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 energy markets connected with cutting costs;
- increasing the degree of flexibility of waste management by reducing the amount of residual waste.

Arguments in support of biomass use:
- it diversifies the energy supply sources;
- it replaces high CO_2 emission conventional fuels;
- it contributes to the waste recycling;
- it protects and creates jobs in rural areas;
- it gives the possibility of adjusting, automation and control of the system depending on the actual requirements or the heated premises.

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