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INSTALLATION FOR THE PRODUCTION OF THERMAL ENERGY WITH BIOMASS GASIFICATION

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Abstract: For most traditional energy sources, price increases are a current perspective; on the other hand, conventional fuels are considered responsible for global warming, with very negative estimated consequences. For these reasons, the use of more environmentally friendly energy sources, from the category of renewable sources, is required for the next period. The article presents a part of a system designed to obtain domestic hot water by combining 2 renewable sources: solar energy and biomass energy. For the conversion of energy from biomass, tests were performed in 2 constructive variants, in order to improve the performances.
Keywords: energy, biomass, solar, heat exchanger, domestic hot water

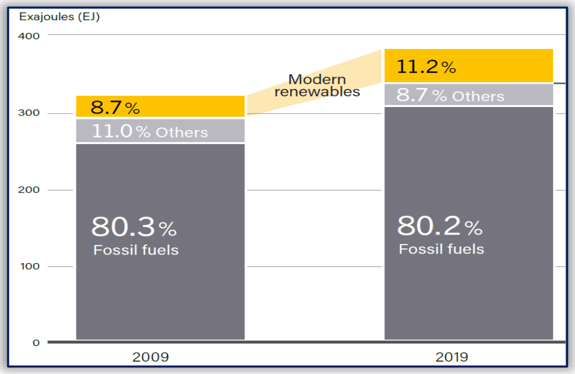
1. INTRODUCTION

Energy consumption is a characteristic of carrying out any activity, whether we are talking about the existence of life for the simplest beings or activities carried out or led by people, which seek to achieve various complex goals for the benefit of human progress. Energy consumption associated with human activity is constantly increasing, even though energy-consuming processes are considered in order to increase efficiency in most areas; in other words, the increase in energy efficiency does not keep pace with energy demand, regardless of where it comes from (from conventional or renewable sources). One of the aspects of increasing energy consumption is increasing pollution, with all the negative consequences of this phenomenon *(Rose et al., 2017)*.

At the level of 2019, Total Final Energy Consumption was approximately 381.1 EJ (or 105,900 TWh) - *(***, Renewables 2021. Global Status Report)*, increasing by 1% compared to the previous year - figure 1; of this, only 11.2% was made with modern renewables. This last category includes, according to figure 1, wind, solar, hydropower, ocean power, biomass and biofuel.

Biomass that falls into the category of Modern Renewables is the one used by modern methods, in the form of pellets or briquettes; this category excludes directly burned biomass, in the form of firewood, for heating or food preparation, in poor or developing countries *(Maican, 2015)*.

The modern conversion of energy from biomass to thermal energy is done through intermediate gasification plants, obtaining superior yields *(Shackley et al., 2014)*; however, fuel in the form of briquettes or pellets obtained from biomass has a cost that cannot be neglected, especially if the fuel in these forms is purchased on the market. In this context, reducing consumption by combining thermal energy generators that use biomass with other renewable energy conversion systems remains the most appropriate solution to reduce the final costs of useful energy produced *(Ilie et al., 2019)*.



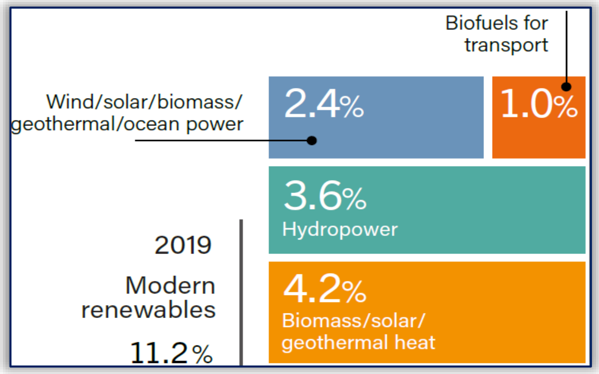


Figure 1 – The evolution of energy consumption from conventional and renewable sources in the last decade

One option is to combine a biomass-based heat generator with a system that uses solar thermal panels. In such a system, solar panels are the main source, and the generator that uses biomass comes into operation when the estimated need exceeds the amount of energy produced and accumulated, for various reasons (higher consumption, lower solar radiation, etc.).

Such a combined system was developed within INOE 2000 Subsidiary IHP Bucharest; the system uses two high-efficiency solar panels with pressurized vacuum tubes, along with a pellet-fired heat generator. The article presents the results obtained with this generator, which was used in two variants: an initial variant and an improved final variant.

2. MATERIALS AND METHODS

The schematic diagram of the combined system, in which the component using biomass and the combi boiler can be identified on the left, is shown in Figure 2.

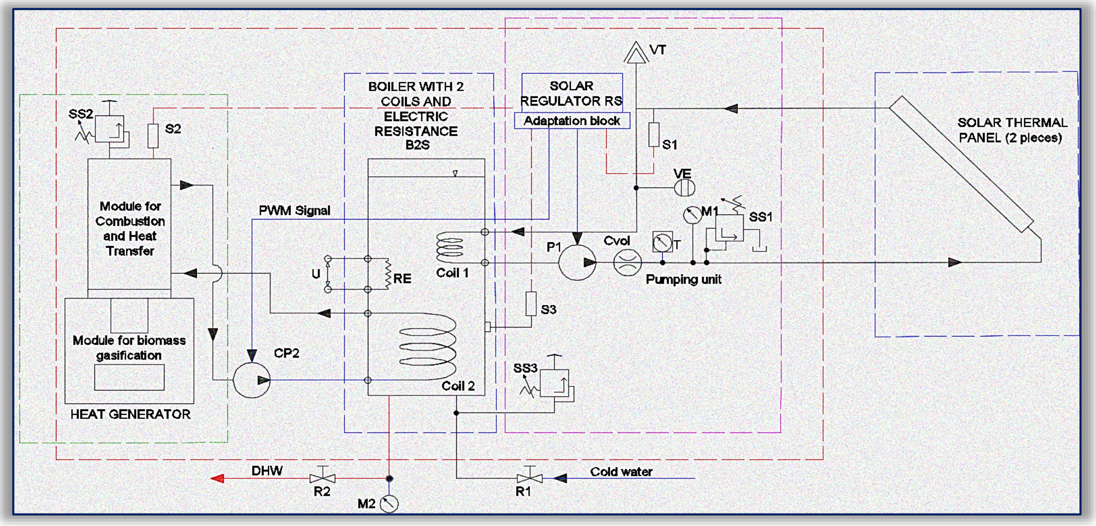


Figure 2 – Combined system schematic diagram: SS1,2 – relief valves; S1 – S3 – temperature sensors; Coil 1,2 - the inner coils of the boiler; M1,2 – manometers; R1,2 – taps; RE - electric resistance for water heating; T – thermometer; Cvol – flowmeter; VT - automatic aerator; VE- expansion vessel.

This subsystem has as a basic element a thermal energy generator composed of two modules:

≡ a gasification module
≡ a combustion and heat transfer module.

The gasification module works on the basis of the TLUD (Top-Lip UpDraft) principle, which involves the advance of the pyrolytic front from top to bottom *(Saraswati, 2018; Maican et al., 2016)*; it is a modern gasification process characterized by low-emission combustion, on the one hand, and on the other hand allows the production of biochar, a by-product of combustion that can have multiple uses in *agriculture (Latawiec et al., 2021)*.

The combustion and heat transfer module is made in the form of a water-to-air heat exchanger. Following the combustion of the gas, the thermal energy is taken up by a heat transfer fluid circulating between the heat exchanger and a combi boiler, in which the thermal energy accumulates. The fluid is transferred by means of a CP2 circulation pump specific to thermal installations, controlled by a solar regulator (SR) which allows control in various operating modes; the heated fluid circulates to the combi B2S boiler, in which it gives off heat as it passes through the Coil2 coil, to the water in the boiler, which is heated and thus transformed into domestic hot water (DHW). Another coil of the combi boiler brings heat from the solar thermal panels; in this way, the energy from the two sources is added together.

Figure 3 - The combined system developed

Figure 3 shows the physical realization of the thermal energy generator and the combi boiler, hydraulically connected by rigid pipes; the system has all the specific hydraulic elements necessary for a safe and efficient operation: pressure valves, taps, thermometers for visualizing the parameters, etc.

3. RESULTS

For this configuration of the system, experiments have been performed in order to determine the total conversion efficiency, by measuring the amount of thermal energy released in the boiler and relating it to the energy from the fuel used (pellets) *(Grîu, 2014)*. The input data of the process were:

≡ Quantity of pellets burned: M = 2.6 kg - storage container filled up under the holes for secondary air
≡ Calorific value of pellets: Qs = 18 MJ / kg (5 kWh / kg)
≡ The mass of water in the combi boiler: 120 l
≡ Circulation pump operating mode: continuous

The main values obtained from the experiment were as follows:

- Burning time: 1.5 h (90 min)
- The initial temperature of the water in the boiler: 20°C
- The final temperature of the water in the boiler: 60°C

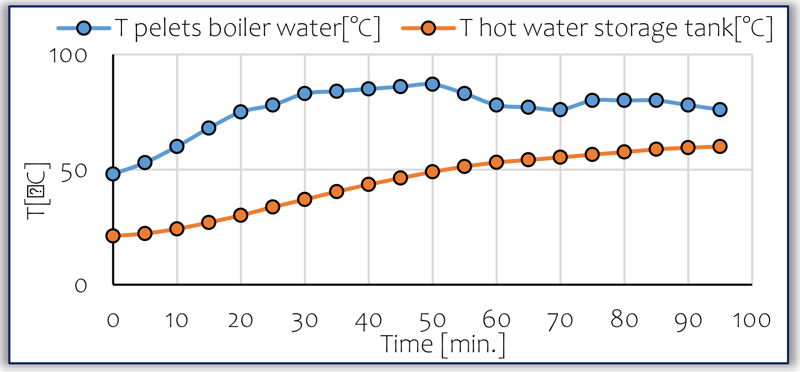


Figure 4 – The evolution of the temperature in the boiler in the initial version

The automatic recording of the data on the evolution of the water temperature in the boiler allows the graphical representation of the variation of this parameter (Figure 4).

The calculation of the primary energy (from the quantity of pellets) and respectively that of the water taken from the boiler is made with the following relations:

— For pellet energy, based on the product data sheet:

Energy stored in the mass of pellets:

$$E_{Mp} = M_p \cdot Qs_p = 2.6\ kg \cdot 18\ MJ / kg = 46.800\ MJ \tag{1}$$

where: E_{Mp} is the energy, [J]

M_p – mass of pellets used, [kg]

Qs_p – calorific value of one kg of pellets, [J/kg]

— For the energy stored in the boiler, based on the recordings during the experiment:

Energy stored in the boiler:

$$Q_{w1} = M_w \cdot C_w \cdot \Delta T_1 = 120\ kg \cdot 4182\ J / (kg \cdot °C) \cdot 40°C = 20.074\ MJ \tag{2}$$

where Q_{w1} – energy stored in the form of heat in water, [J],

M_w – mass of water in the boiler, [kg]

C_w – the specific heat of the water, [J/kg·°C]

ΔT – temperature difference, [°C]

By comparing these values, the total yield of the process is obtained:

$$\eta_1 = Q_{w1} / E_{Mp} = 20.074 / 46.800 = 0.43 \tag{3}$$

The value obtained was considered unsatisfactory, as it is much lower than the average yield of similar processes in modern installations (70… 80%); the analysis of the structure and operation led to the following changes:

- Constructive modification of the heat exchanger, by increasing the number of vertical pipes from 5 to 9; reducing the inside diameter of these pipes from 70 mm to 50 mm; height increase (figure 5). All these constructive changes have been made to improve the heat transfer of the gases resulting from combustion to the heat transferring fluid *(Dumitrescu et al., 2021)*.
- Thermal insulation of the heat exchanger, in order to reduce the heat loss outside
- Reducing the flow rate of the heat transferring fluid through the heat exchanger, by adopting a pump operating mode based on the temperature difference of 4°C between the exchanger and the boiler, instead of the manual mode (continuous operation).

Figure 5 - 9-tube heat exchanger

Following the changes, a new set of tests have been performed; the main results obtained under the new conditions are shown in Figure 6.

As one can see, the operating time has remained the same, as it depends only on the amount of fuel, given that the air flow (gasification and combustion) has been maintained at the previous values.

Under the new conditions, the amount of thermal energy stored in the combi boiler has increased, reaching a final temperature of 81°C (starting from 18°C).

Energy stored in the boiler, in this case:

$$Q_{w2} = M_w \cdot C_w \cdot \Delta T_2 = 120\ kg \cdot 4182\ J / (kg \cdot °C) \cdot 63°C = 31.616\ MJ \quad (4)$$

The efficiency of the process, in this form, will be:

$$\eta_2 = Q_{w2} / E_{Mp} = 31.616 / 46.800 = 0.68 \quad (5)$$

Under the new conditions, the yield is close to an acceptable minimum, which leads to the idea that component improvements are needed in the future for further growth.

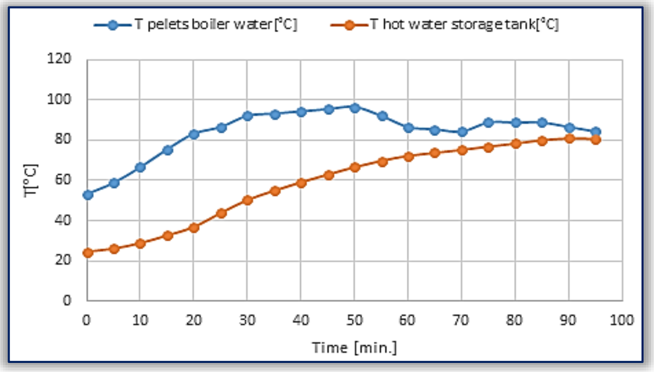


Figure 6 - The evolution of the temperature in the boiler in the final version

The main direction of study will be to improve the heat transfer process by optimizing the flow rate of hot gases from the heat exchanger; a reduction in flow rate will increase the heat transfer time.

4. CONCLUSIONS

The use of heat generators that utilize biomass in densified form (pellets or briquettes) as fuel is a current and energy efficient solution, even if such an energy source is combined with another renewable source. If the converted solar radiation using one or more solar thermal panels is used as the main source, the biomass generator is a spare source, which will be put into operation when the consumption exceeds the amount of DHW stored.

The tested system requires some improvements to increase the total efficiency, which was calculated by the ratio between the amount of heat stored in water and the amount of energy in the pellets, prior to gasification.

Since the design and implementation of the gasification module were done observing the specific parameters in the literature (air flow correlated with the volume of pellets, the ratio between primary air and secondary air, etc.), it is concluded that the main study direction for the next period will be the optimization of the hot air flow in the heat exchanger, for a better heat transfer to the heat transferring fluid. This can be done by constructive changes in the heat exchanger, but also by changes in the amount of air (mainly secondary air, combustion), so that when passing through the heat exchanger the gases give a greater amount of energy.

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