Obtaining thermal energy from renewable sources in rural areas using a combined energy system

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Abstract. The article presents an energy system solution in which the heat energy required to get domestic hot water needed for a family home is obtained by the cumulative conversion of energy from 2 renewable sources: solar energy and biomass energy. Compared to the classic variants of thermal systems, which exploit a single source and provide only partially the energy needed, the combined use consists of energy supply from one source when the other is unavailable or insufficient. In the present case, when the domestic hot water requirement is no longer covered by the solar thermal panels (consumption during the night, days without sun or temporary consumption higher than the usual one), energy from biomass is used in the same system. It is converted to thermal energy using a generator where the gasification module uses the TLUD process. In addition to a higher yield of biomass, this process allows the use of a wide range of biomass types, existing in rural areas. The article presents the results obtained from the experimentation of the system that uses 4 solar panels and a thermal energy generator with a power of approx. 10 kW.

1 Introduction

Renewable energy covered in 2018 a percentage of 18.1% of the total final energy consumed. On the other hand, the renewable energy sector provides jobs for approx. 11 million employees worldwide.

Despite progress in implementing renewable energy systems, increasing energy efficiency and access to conversion systems, the world is not on track to meet the goals of the Paris Agreement or the Sustainable Development Goal 7. Global carbon emissions (CO2) related to energy production increased by about 1.7% in 2018 due to increased consumption of fossil fuels. Global subsidies for fossil fuel consumption have increased by 11% since 2017, and companies selling fossil fuels have continued to spend hundreds of

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millions of dollars lobbying for delaying, controlling or blocking climate change policies and advertising to influence public opinion [1].

It is therefore clear that the solution cannot come only from national or global policies, and that in addition to these, at the micro level there is a large room for maneuver for the population to use renewable energy to help reduce the negative impact of fossil fuel use, on the one hand, and on the other hand to reduce the final energy bill [2]. The use of one or more types of renewable energy, as far as possible in a unitary system, is a solution to this problem. The article presents some aspects related to the development of an energy system that exploits 2 types of renewable energy, in order to produce heat for a small final consumer, such as a home for a family of 3 ... 4 persons. The system covers the need for domestic hot water (DHW) consumption, in conditions of medium comfort.

2 Presentation of the principle underlying the proposed system

The proposed system is based on modern, high-efficiency solar thermal panels, to which is added, for completion, an energy module in which biomass in the form of pellets or briquettes is gasified and burned, when the energy requirement exceeds the amount provided by the panels. The main component is represented by thermal solar panels because solar energy in Romania is in large quantities, superior to other countries, due to its geographical location. The combination of solar energy and biomass energy is also recommended by the large amount of biomass of various types, available at national level (agricultural, forestry, fruit growing, wood processing, etc.) [3, 4].
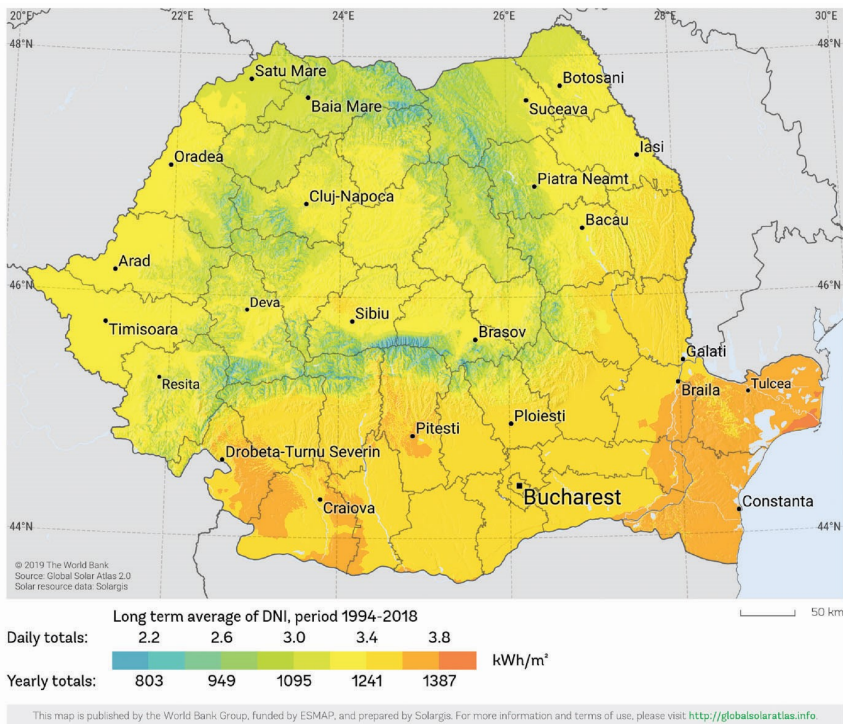

Fig. 1. Map of normal solar radiation in Romania - © 2019 The World Bank, Source: Global Solar Atlas 2.0, Solar resource data: Solargis.
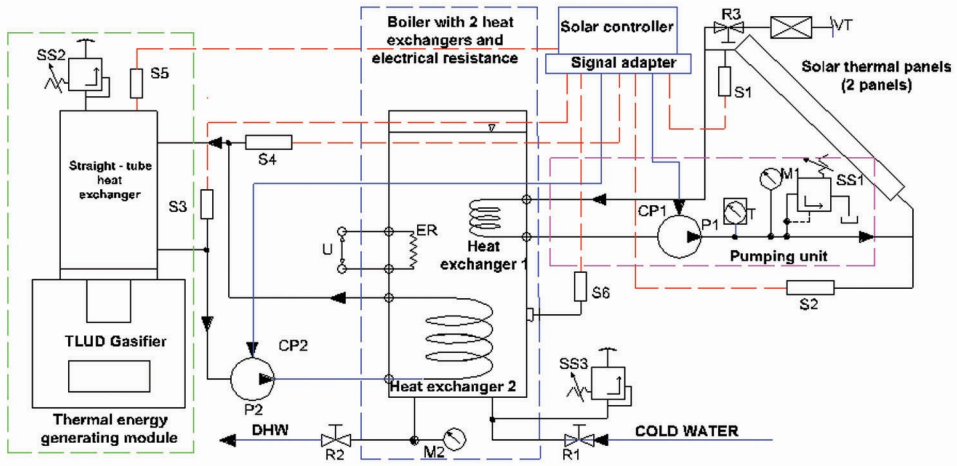
Fig. 2. Schematic diagram of the combined system.

In the figure above one can see the entire structure of the combined system. In addition to the main components, others appear in the diagram: ● SS 1,2,3 – Relief valves; ● S 1,2,3,4,5,6 – Temperature sensors; ● ER – Electrical resistor; ● CP 1,2 – Circulation pumps; ● VT – Air-vent valve; ● M 1,2 – Manometers; ● T – Termometer; ● DHW – Domestic hot water. Besides the solar thermal panels, the system comprises an energy module that converts energy from biomass into thermal energy. This energy, together with that produced by the solar panels, is stored in a bivalent tank (boiler with 2 coils). The system is managed by a solar regulator, which controls the operation of the circulation pumps that transfer energy from the production areas (solar panels and the energy module, respectively) to the storage area.

3 System description and sizing of main components

The pressurized thermal solar panels (2 pieces) will each have 12 vacuum tubes. Current solar panels with vacuum tubes are "heat pipe"- type solar panels. The vacuum tubes consist of two concentric glass tubes between which a vacuum is formed. The inner tube is covered by an absorbent surface and inside of it there is a copper tube through which a thermal agent circulates. The vacuum between the two tubes minimizes heat loss through convection and conduction, allowing superior performance (higher efficiency and temperatures). Such a solar thermal panel produces from 569 to 780 $kWh/m^2/year$, if the solar radiation is 1000 $kWh/m^2/year$ [5]. Considering that in Romania there are higher values, of 1000...1450 $kWh/m^2/$ year, it was considered reasonable to choose a calculation value of 1200 $kWh/m^2/year$, a value that covers most of the regions of the country where the system can be installed.

If we intend the purchasing of medium performance solar panels, a conversion value of at least 600 $kWh/m^2/year$ can be taken into account.

Given that a 12-tube panel has a minimum surface area of 2 m^2, the amount of energy that the panel can produce annually under the above conditions results as calculated:

$$E_p = 2m^2 \cdot 600 \cdot \frac{kWh}{m^2 \cdot year} \cdot 1\,year = 1200 \;\; kWh \tag{1}$$

For 2 panels we will have:

$$E_{2p} = 2 \cdot 1200\,kWh = 2400\,kWh \tag{2}$$

If we consider an overall heat transfer factor of 0.9, it results that the useful energy transferred to the water to be heated will be:

$$E_u = 0.9 \cdot \; 2400\,kWh = 2160\,kWh \tag{3}$$

On the other hand, the need for hot water to be produced was calculated at the level of an average family with 3 members, each using approx. 35 liters of DHW per day, according to current standards used in this field. Therefore, the combined system will have to produce a minimum of 105 liters / day, at a temperature of max. 60°C.

To convert cold water to DHW, heating with 45°C is required (e.g. from 15 to 60°C); therefore, the energy required for annual consumption will be:

$$Q_a = 365 \cdot m_d \cdot C \cdot \Delta T \tag{4}$$

where $m_d = 105$ kg, C = 4.181 J / kg • K and $\Delta T = 45$°C, hence it results:

$$Q_a = 365 \cdot 105 \cdot 4181 \frac{J}{kg \cdot K} \cdot 45\,K = 365 \cdot 105 \cdot 4.181 \cdot 45 = 7.21 \cdot 10^9\,J \tag{5}$$

or Qa = 2003 kWh, taking into account the relation:

$$1\,kWh = 3.6\;MJ \tag{6}$$

If we compare this value with the value of 2160 kWh, we find that the energy produced by the solar panels and transferred is higher than the one required only for use as DHW.

For systems where another energy source is used, whether renewable or conventional, the coverage of the primary source demand is calculated at 80% [6].

The DHW production capacity of the 2 panels was correlated with that of the bivalent boiler, which will have a capacity of at least 120 l. This capacity is considered sufficient to cover the DHW requirement of a family with 3 members, given that the system has 2 sources of thermal energy; thus, during periods when solar radiation, which is the main source of energy, is absent or insufficient, the energy module is put into operation, which also transfers heat energy to the boiler, raising the water temperature. The boiler will also have an electrical resistance.

The energy module is the second source of thermal energy in the combined system. It was designed to produce energy from biomass that is found in various forms, in nature or processed [7].

The energy module consists of 2 main parts, which can be identified in the Figure 3 below:

1. Gasifier made using the TLUD (Top-Lit Up-Draft) principle
2. Heat exchanger

The main characteristics of the gas generator, as it results from the calculation algorithm for a gas generator on the TLUD principle of 10 kWth and operating time of 3.5 h, are the following:

If the specific power of the reactor is approx. 300 kWth / m², then for the power of 10 kWth, proposed in the project, results the reactor section of 10/300 = 0.033 m². This section led to a reactor diameter of 0.2 m.

The input data for the calculation algorithm for the 10 kWth gas generator will be: Reactor diameter: D_r = 0.2 m; biomass layer height (loading height): H_{rbm} = 0.5 m.
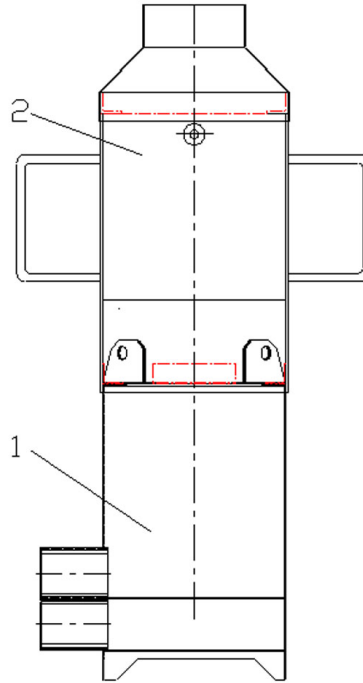

Fig. 3. Thermal energy generating module - part of the combined energy system.

Knowing the diameter of the reactor we obtain the area of its section:

$$S_r = \frac{\pi \cdot D_r^2}{4} = \frac{\pi \cdot 0.2^2}{4} = \frac{0.19625}{4} = 0.0314 \, m^2 \tag{7}$$

Volume of biomass in the reactor:

$$V_{rbm} = H_{rbm} \cdot S_r = 0.5 \cdot 0.0314 = 0.0157 \, m^3 \tag{8}$$

Since in this phase we intend to use pellets with density ρ_{pel} = 600 kg / m³, the initial mass in the reactor will be:

$$M_{bm0} = \rho_{pel} \cdot V_{rbm} = 600 \frac{kg}{m^3} \cdot 0.0157 \, m^3 = 600 \cdot 0.0157 = 9.42 \, kg \tag{9}$$

For the designed gas generator with the main geometric parameters above, the amount of biomass consumed during a cycle was calculated:

The specific hourly consumption of gasified biomass is $C_{hs} = 85 \frac{kg}{m^2} \cdot h$; therefore, for the surface of the reactor we will have an hourly consumption of:

$$C_{hgbm} = C_{hs} \cdot S_r = \frac{85\,kg}{m^2 \cdot h} \cdot 0.0314\,m^2 = 2.669 \frac{\text{kg}}{\text{h}} \tag{10}$$

The functioning time will be:

$$T_f = \frac{M_{bm0}}{C_{hgbm}} = \frac{9.42\,kg}{2.669\frac{\text{kg}}{\text{h}}} = 3.53\,h \tag{11}$$

Energy from gasified biomass:

$$E_{gbm} = M_{bm0} \cdot P_{Cibm} = 9.42 \cdot 17 = 160.14 \text{ MJ} \tag{12}$$

where the pellet biomass was considered to have a calorific value of 17 MJ / kg [8].

Thermal power of hot gases, expressed in kWth:

$$P_g = \frac{E_{gbm}}{T_f \cdot 3.6} \cdot \eta_{gTLUD} = \frac{160.14 \cdot 0.93}{3.53 \cdot 3.6} = 11.719\,kWth \tag{13}$$

The thermal power at the burner, which takes into account the combustion gas combustion efficiency (η_{burn} = 0.95) and the insulation efficiency (external losses η_{insul}= 0.96), will be:

$$P_{burn} = P_g \cdot \eta_{\text{burn}} \cdot \eta_{insul} = 11.719 \cdot 0.95 \cdot 0.96 = 10.68\ kWth \tag{14}$$

The heat exchanger takes the heat resulting from the combustion of the combustible gas at the top of the gas generator and transfers it to the fluid circulating between the exchanger and the bivalent boiler. It is a tubular construction, with 5 tubes with a diameter of 60 mm, which is mounted above the gas generator, so that the flame produced in the upper part of the gas generator heats the fluid in the exchanger.

4 Conclusions

The combined system, in the proposed structure, covers the domestic hot water needs of a family of 3 ... 4 persons, even in periods when solar energy, which is normally the most important source of energy, is diminished or absent. The system allows easy scaling to increase the amount of DHW. Depending on the area where the system is located and the availability of sources, the share of the 2 primary energy sources (and therefore the size of the 2 subsystems) may vary. At the same time, the system can be used to reduce the consumption of the home heating system, performing a preheating of the heating medium.

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