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EXPERIMENTAL MODEL OF A COMBINED SYSTEM OF THERMAL ENERGY PRODUCTION, BASED ON SOLAR AND BIOMASS ENERGY

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Abstract: *The article presents a combination of solar energy with energy obtained from biomass, quite often found in the world economy to achieve the thermal energy in the desired quantity and delivered at the right time. The solution includes as basic elements a regular solar panel, existing on the market and a gas generator made by the authors themselves. The assembly is well structured and by proper choosing of the components size, an amount of permanent and sufficient heat is obtained for a small household.*

Keywords*: Experimental model, thermal combined system, solar energy, biomass energy*

1. Introduction

The development of mankind is based on the quantity and quality of the energy used throughout history. At the level of current knowledge it is accepted as the primary source, essential of terrestrial energy is solar energy, which has been stored in fossil fuels or in plant resources, mainly forestry and which is easily accessible by humans and as such is widely used. At the level of the sun there is a permanent activity of nuclear fusion, which creates energy, which reaches the earth transmitted as electromagnetic energy. The amount of energy generated by the sun is huge, well above the level required on earth, but so far people have used very little light and heat provided by nature. Instead they used it without hesitation wood, coal, oil and natural gas, even without discernment, without restrictions and without a perspective of the future, getting in the situation that the resources of this type have diminished and the danger of the energy crisis has increased.
Moreover, all of a sudden, humanity has scientifically found, which has long been known, that the burning of these types of resources has led, and unfortunately still leads, to serious pollution of the environment [1]. The simple and handy solution of all countries was o switch to the production of energy from clean sources, renewable sources, to replace as much as possible the use of fossil fuels. One of the most important problems that should be quickly solved is the one regarding the production of hot water and heat. The first industrially applied method was the use of solar thermal panels through which hot water is produced by direct conversion of solar energy. Only in 2017 is it appreciated in the in international scientific materials that 35 GWth have been added, which provides almost 80% of the hot water and heat needs in the cold season, while in the summer almost all the hot water needs can be provided [2, 3].
The solar thermal panels are divided into two classes, some with vacuum tubes and some with flat solar panels consisting of copper plates. We must admit that solar thermal energy is not permanent 24 hours a day and therefore it should be stored during the day so it can be consumed at night. Storage is a difficult process in the current technical conditions and as a result the efficiency and the price forced the specialists to recourse to alternative solutions, the simplest and cheapest being the solution by combining the thermal panel with a gas tank. The technical and economic advantages of this combined system are obvious, they are major and especially easy to use and maintain.
Given the novelty of the solution, the realization of a combined system at the prototype level that can be introduced in manufacturing must go through an experimental model phase.
The experimental model must respect the structure of the final product, being composed of 2 sources of thermal energy, namely:
- system for converting solar energy into thermal energy using solar thermal panels with vacuum tubes;

- the biomass energy conversion system using an energy module based on a gas generator through the TLUD process and a burner.

The main categories of biomass that can be used for this purpose are wood matter, vegetable residues from agriculture and animal residues from zootechnics, as well as crops and plantations dedicated to energy recovery. The basic process is pyrolysis which consists in the thermochemical decomposition of solid biomass, a process that takes place at temperatures of 300-800 °C and in the absence of oxygen [4]. From this process results heat, which we add to that provided by solar thermal panels, as well as different gases (hydrogen, methane, carbon monoxide, etc.), bio-oil and coal. Through the thermochemical gasification process, solid biomass is transformed into gas at temperatures of 800-1300 °C. The gas obtained is called synthetic or singas gas and is a mixture.

2. The solution chosen

The scheme of the combined system, which includes the 2 conversion systems, is shown in fig.1. The main components of the system are: electric pump, thermal solar panel, thermal burner, boiler, expansion vessel.

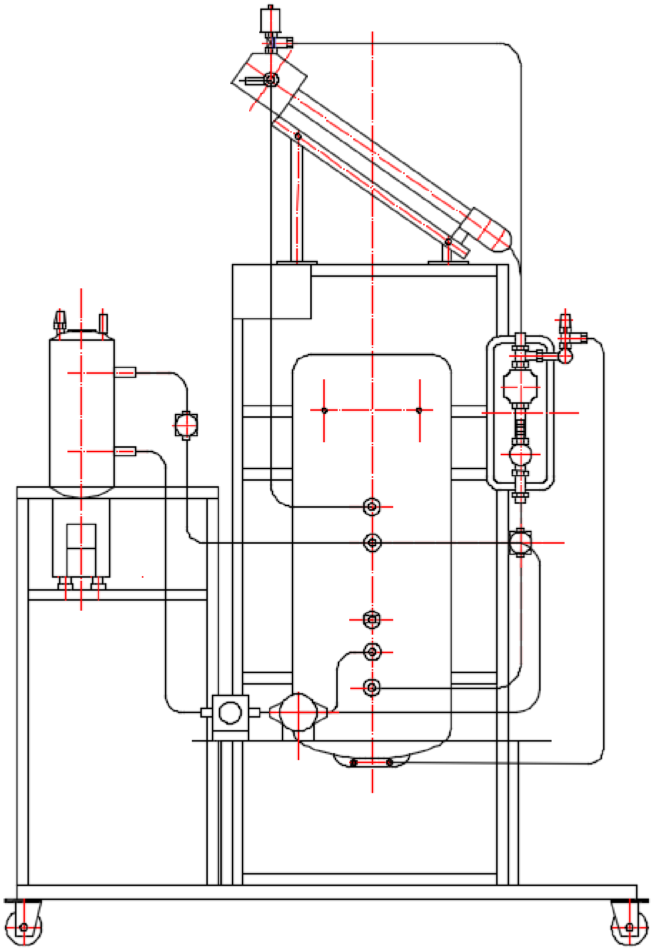

Fig. 1. Schematic of the combined system

Two systems were executed for reduced powers, their role being to validate through the experiment the possibility of cumulating the thermal energy from 2 sources.

The main components of the combined system are the solar thermal panel and the gas generator. Their main features are presented below.

For the conversion of solar energy, a medium-performance solar panel, with vacuum tubes, with the following main characteristics will be used:

Table 1: The main characteristics of the thermal solar panel

Item	Value
Number of tubes	10
Panel width	890 mm
Panel length	2030 mm
Total area	1,81 m^2
The effective surface of absorption	0,94 m^2
Material for tubes	Borosilicate glass
Material for the collector	Al / Cu / Glass / Mineral wool

2.1. Thermal panels

The panels use Heat Pipe technology; the vacuum tubes of the panel consist of 2 concentric glass tubes between which is vacuum. The inner tube is surrounded by a dark absorbent surface that transmits the heat energy to the copper pipe through which a thermal agent circulates. The vacuum between the two tubes contributes to the increase of the efficiency and the temperature, reducing the losses.

The main dimensions of the vacuum tube are the diameter D_t = 58 mm and the length L = 1812 mm. According to the technical data provided by the manufacturer, at an average solar radiation value of 1000 W /m^2, a tube heats 10 liters of water per day, from 15 to 50°C.

Therefore, the amount of heat transferred to the water will be:

$$Q_t = m \cdot c \cdot \Delta t = 10 \cdot 4180 \cdot 35 = 1.463 \cdot 10^6 J \quad (1)$$

where c = 4180 J / kg·K is the specific heat of the water.

For a panel with 10 elements, the energy produced will be:

$$Q_p = Q_t \cdot 10 = 1.463 \cdot 10^6 \cdot 10 = 14.63 \cdot 10^6 J \quad (2)$$

If the energy is expressed in kWth, then we will have:

$$Q_p = \frac{14630000}{3600000} = 4{,}06\ kWth \quad (3)$$

2.2. The TLUD generator

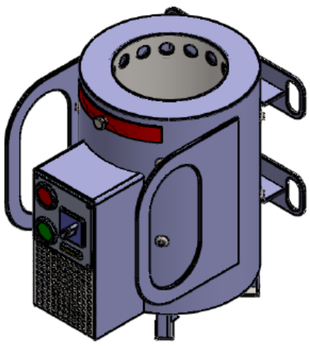

Fig. 2. TLUD type generator

The main dimensions of the generator are: Reactor diameter: $D_r = 10\ cm$
Biomass layer height (loading height): $H_{rbm} = 15\ cm$
Reactor section: $S_r = \frac{\pi \cdot D_r^2}{4} = \frac{\pi \cdot 10^2}{4} = \frac{314}{4} = 78.5\ cm^2$
Biomass volume in the reactor: $V_{rbm} = H_{rbm} \cdot S_r = 0.15 \cdot 78.5 = 1178\ cm^3$

Biomass layer density: 600 kg /m^3 (pellets).
Initial mass in the reactor: $M_{bm0} = 600 \cdot 0.1178 = 706.5\ g$.
The specific hourly consumption of gasified biomass is 85 kg / m^2·h; therefore, for the reactor surface we will have a specific consumption of:
C_{hbmg} = 85 · 0.00785 = 0,667 kg/h
The operating time will be: $T_g = \frac{600}{667} = 0.9\ h\ (\sim 54\ min.)$
Energy from gas biomass:
$E_{bmg} = M_{bmo} \cdot P_{Cibm}$ = 0.7065 · 17 = 12 MJ
The thermal power [5, 6] of the hot gases: $P_g = \frac{E_{bmg}}{T_f \cdot 3.6} \cdot \eta_{gTLUD} = \frac{12 \cdot 0.93}{0.9 \cdot 3.6} = 3.44\ kWth$ and the thermal power at the burner, which takes into account the fuel combustion efficiency (η_{ard} = 0.95) and the insulation efficiency (outward losses – η_{izol} = 0.96), will be:

$$P_{arz} = P_g \cdot \eta_{ard} \cdot \eta_{izol} = 3.44 \cdot 0.95 \cdot 0.96 = 3.13\ kWth \quad (4)$$

3. Realization of the combined system at the level of Experimental Model

The solar energy conversion system also contains a solar regulator and a pumping unit, which achieves the transfer of the heated fluid from the solar thermal panel to the tank, through one of the 2 coils. With the help of the coil, the fluid transfers thermal energy to the cold water which turns into domestic hot water. Similarly, the thermal energy generated by the combustion of the gas is transferred to a fluid in the closed circuit, which flows through the second coil of the tank.
The combined system [7, 8, 9] is designed to be based on the solar thermal panel, and the energy module, which has a limited operation in time (in this case of about 1 hour), brings additional energy supply during periods when the solar radiation is insufficient. In the experimental model phase, the energy module enters in function when the solar radiation decreases, that is indicated by a cell which measures the light radiation, and the water temperature from the tank, measured with a sensor located at the top of the tank.
The role of this experimental model is to validate the feasibility of the idea of obtaining and using thermal energy from two renewable sources; the following activities provide for the development of a calculation methodology for the quantities of thermal energy produced by each source, as well as the amount of useful energy accumulated in the bivalent boiler during a cycle carried out during a day. During the day, when there is solar radiation, the boiler will store thermal energy produced from this first source; When the solar radiation no longer has the effect of heating the water in the boiler, the energy module enters into action, which by burning an amount of biomass equal to the load capacity for a batch, produces an amount of thermal energy that is added to the initial one.
In this phase it is predicted that the energy produced from biomass will represent approx. 75% of the energy produced by the vacuum tubes (10 tubes); If it is found that the energy produced by the solar panel exceeds the estimated quantity (if the experiment takes place on a day with solar radiation above the annual average taken into account), the number of active tubes will be reduced by removing them from the hydraulic circuit.
The energy produced from the 2 sources, without taking into account at this stage the thermal losses, represents the sum of the energies produced by the 2 energy conversions:

$$Q_T = Q_P + Q_{bmg} = 14.63 + 12 = 26.63\ \text{MJ} \quad (5)$$

Considering that the boiler has a capacity of 80 l, the increase of the water temperature in the boiler will be:

$$\Delta t = 26{,}63 \times 10^6 / (80 \times 4180) = 79.6^{\circ}\text{C} \quad (6)$$

If the water temperature at the boiler inlet is considered approx. t_i = 15 °C, the final temperature of the water in the boiler will be, at the end of the day:

$$T_F = t_i + \Delta t = 15 + 79.6 = 94.6\ ^{\circ}\text{C}, \quad (7)$$

which recommends the use of a smaller number of vacuum tubes, in order not to reach the boiling temperature of the water.
In principle, the experimental model of combined thermal system groups, in one place, a solar

thermal panel and an energy module for low power biomass (3 kW), which is a TLUD-type thermal power station, to which are added the necessary components to control the operation, in good condition of the combined system, fig. 3.

Fig. 3. The experimental model of combined thermal system

The principle composition of the experimental model of combined thermal system, for solar energy and biomass, as well as the main technical characteristics, are the following:

- 1 mini solar thermal panel, type with 4 vacuum tubes of 400/500 mm, pressure of 6 bar, fig. 4;
- 1 energy module for biomass, composed mainly of a thermal power plant on biomass (TLUD type gas of 3 kW and a hot water tank), fig. 5;
- 1 hot water circulation electro-pump, with flow rate 05-06 l /min, fig. 6;
- 1 mixed boiler of 120 liters, at 10 bar, with two coils and electrical resistance, fig. 7;
- 1 electro-pump panel for water circulation with adjustment and safety elements, fig.8;
- 1 electrical control and control system with temperature sensors, flow transducers and hot water volume meter, fig. 9.

Fig. 4. Mini solar thermal panel

Fig. 6. Hot water circulation elecro-pump

Fig. 5. Energy module for biomass

Fig. 7. Boiler

Fig. 8. Electro-pump panel

Fig. 9. Electric command and control system

The experimental model of combined thermal system for the generation of thermal energy from renewable sources, solar thermal energy and thermal energy from biomass, ensures the achievement, under laboratory conditions, of the following main functions:

- the functioning in separate mode of water heating only with solar thermal panel;
- the functioning in separate water heating regime only with the thermal power plant based on the biomass burning;
- the combined operation by the simultaneous utilization of the two equipments;
- control of operating regimes;
- adaptation and maintenance of thermal parameters for safe operation.

Only after completing the experimental model and conducting the experimental research, based on the obtained results, will the design of the combined system prototype be obtained for obtaining the thermal energy from two sources: solar energy and biomass.

4. Conclusions

The proposed system at the experimental model level aims to validate the possibility of accumulating thermal energy from 2 sources: solar radiation and biomass, the conversion being made using a solar thermal panel with vacuum tubes, respectively with an energy module based on the TLUD principle. The exploitation of the two sources is managed in this experimental phase by a control and warning block, which warns about when the solar radiation can no longer increase the water temperature in the boiler, and therefore it is necessary to start the biomass-based energy module in operation. It is limited in time due to the small amount of biomass it can be loaded with. Increasing the amount of gas biomass would lead to a significant expansion of the total thermal energy quantity, competing to obtain a combined system capable of ensuring the energy autonomy of a consumer.

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