EXPERIMENTAL MODEL OF A COMBINED THERMAL SYSTEM FOR EFFICIENT USE OF RENEWABLE ENERGIES
/
MODEL EXPERIMENTAL DE SISTEM TERMIC COMBINAT PENTRU UTILIZAREA EFICIENTĂ A ENERGIILOR REGENERABILE

Dumitrescu C.[1)], Rădoi R.*[1)], Cristescu C.[1)], Dumitrescu L.[1)] [1]
[1)] Hydraulics and Pneumatics Research Institute INOE 2000-IHP / Romania;
Tel: 0721253787; E-mail: radoi.ihp@fluidas.ro
DOI: *https://doi.org/10.35633/inmateh-60-32*

Keywords: *renewable energy; efficiency; solar; biomass; thermal system*

ABSTRACT

The article presents an experimental model of a modular structure system for the production of thermal energy and the results of conducting specific tests. The experimental model uses two renewable energy sources - solar energy and energy generated by burning biomass - to provide thermal energy for an increased duration, regardless of the atmospheric factors. Properly sized, the system can be designed as a series product, in a variety of powers, to be used by heat suppliers, and also by individuals, especially the ones from remote areas, who want to ensure their thermal energy independence by using renewable energy.

REZUMAT

Articolul prezintă un model experimental de sistem destinat producerii de energie termică, în construcție modulară, precum și rezultatele obținute în urma realizării experimentărilor specifice. Modelul experimental utilizează două surse regenerabile de energie, energia solară și energia generată prin arderea biomasei, în scopul furnizării de energie termică pentru o durată crescută, indiferent de factorii atmosferici. Printr-o dimensionare adecvată, sistemul poate fi conceput la nivel de produs de serie, într-o gamă variată de puteri, pentru utilizarea de către furnizorii de energie termică, precum și de către persoane private, mai ales din zonele izolate, care vor să-și asigure independența energetică termică prin utilizarea energiilor regenerabile.

INTRODUCTION

Currently, the functioning of the world economy is largely based on energy from non-renewable resources (coal, oil, natural gas). A number of negative aspects, such as greenhouse gas emissions, which favour global warming, pollution, acid rain, are due to the use of these conventional resources, which, moreover, are close to depletion. This has triggered a significant investment process globally to make the most of renewable energy resources, which come from natural resources that are constantly renewed in relatively short intervals or are inexhaustible in the medium or long term. According to the latest reports, they contributed more than 22% to the production of electricity and accounted for 19% of total energy consumption globally *(Maican E., 2015)*.

Compared to the trend of continuous growth of the capacity of renewable energy conversion systems, and so of the energy production from these sources, a current but also future problem is on the one hand, increasing the efficiency of clean energy production systems, and on the other hand, optimizing associated consumption *(***, 2018)*. What is important for the consumer is the amount of energy delivered, the form of useful energy needed, how high the energy losses are, and how much he/she has to pay for the delivered energy *(Bostan et al, 2017)*. For energy-efficient generation and use of renewable energy, one of the modern trends is to develop hybrid or combined systems, which use two or more renewable energy sources *(Guo et al, 2018)*. Nowadays, a lot of technologies and equipment for the capture, storage and use of renewable energy have been developed *(Cristescu et al, 2016)*.

As to the thermal energy - used to obtain domestic hot water and to heat the house - one of the modern solutions is combining solar energy with energy from burning of plant biomass *(Anvari et al, 2019; Dumitrescu et al, 2018)*. Significant quantities of thermal energy can be produced by high efficiency biomass recovery processes, such as gasification followed by combustion *(Kozlov et al, 2019; Srinivas and Reddy, 2014)*.

---
[1] *Dumitrescu C., Ph.D. Eng.; Rădoi R., Ph.D. Eng.; Cristescu C., Ph.D. Eng.; Dumitrescu L., Ph.D. Stud. Eng.*

Such a combined thermal system that uses solar thermal energy and the thermal energy generated by the burning of plant biomass has been designed and developed in the Institute INOE 2000-IHP. This combined thermal system was developed as an experimental model and was subjected to experimental tests, according to a special methodology, to maximize results. In the following, the experimental model of combined thermal system is presented, as well as several experimental results obtained from testing it.

MATERIALS AND METHODS

Presentation / description of the combined thermal model

The development of the experimental model of combined thermal system was imposed by the need to test the constructive solutions adopted, the feasibility of the idea of obtaining and using thermal energy from two renewable sources, and also the way to control the related processes, in order to experimentally validate them. For the physical development of the experimental model of the combined thermal system, an execution project was first developed, based on which the main components were acquired and the main subassemblies were executed. Considering the target group addressed throughout this research project, that is individual consumers, usually from remote areas, several minimum requirements were put at the base of the project, namely:

- The two types of combined renewable energy sources are: solar energy and biomass energy (pellets), since both are accessible to isolated consumers;
- The experimental model will have a modular design, with minimal costs;
- the main components of the system must have a performance / price balance that will be the basis of marketing them; thus, the solar panels will be of evacuated tube type, and the energy module will be based on a TLUD (top-lit-up-draft) type gasifier *(Mukunda et al, 2010)*.

On the whole, according to figure 1, the experimental model of the combined thermal system consists of several main parts, presented in the lines below.

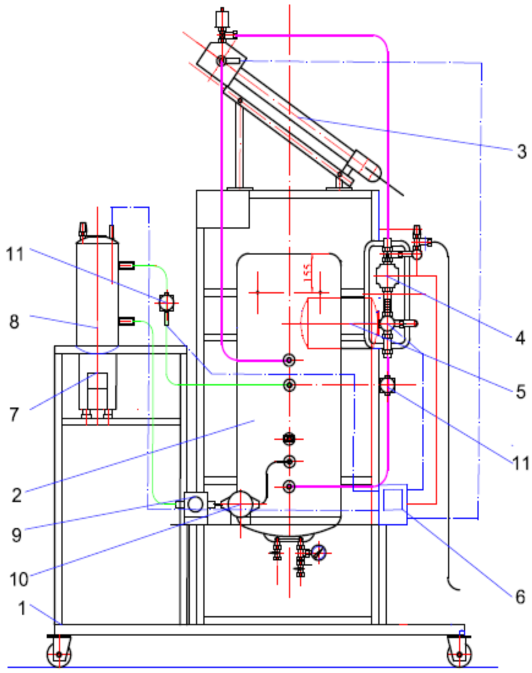

Fig. 1 - Draft of the combined thermal system

Fig. 2 - Physical development of the combined thermal system experimental model

On a frame (1), welded from laminated profiles, the main parts of the system are installed, namely: a boiler with two serpentines and electrical resistor (2), provided with pressure valve, pressure gauge and taps required for connection to the cold water source and to the consumer, respectively; a solar thermal panel (3), equipped with pressure valve and temperature sensor; a pumping group (4) for the solar thermal panel, which includes the recirculation pump, visual flow meter, visual thermometer, pressure gauge and safety valve, to which an expansion vessel is connected (5); a solar controller (6), which ensures automatic control of pump operation depending on the temperature in the boiler and the solar panel; an energy module with TLUD type gasifier, based on the burning of biomass (pellets) that heats the water which is in a well-insulated thermally tank (8), equipped with safety valve and temperature sensor; a recirculation pump (9) of hot water to the boiler and return, controlled by the solar controller depending on the temperature of the boiler and the water tank; a water volume meter (10) with electrical signal; two volumetric flow meters (11), located on the circuits of the hot water recirculation pumps.

The tests were performed on the basis of a methodology elaborated previously, which includes the description of the main operations, in chronological order necessary for the testing, referring to the (physical) means of testing and testing schemes, the nomenclature of tests and specific responsibilities.

Before carrying out the tests, it was necessary to carry out preparatory, preliminary activities, to achieve the appropriate conditions in order to maximize the results obtained experimentally. First, an operational testing scheme - presented below - has been developed.

Testing scheme of the combined thermal model

The operational testing scheme developed is shown in Figure 3 below. It includes the mechanical-hydraulic assembly of the combined thermal system, as well as the sensors and transducers necessary for the appropriate operation, and also the computer-based system for acquisition and recording of the experimental data regarding the evolution of the thermal parameters of interest.

The functional scheme of the combined thermal system has as its central element a bivalent boiler (1) with 2 serpentines (SERP1 and SERP2) and an electrical resistor (RE), equipped with the necessary elements for pressure control (safety valve SS2, pressure gauge M2). The boiler performs heating of domestic water from two renewable energy sources (solar thermal energy and thermal energy obtained from burning of plant biomass), and, for safety reasons, from electrical energy.

Solar thermal energy is captured using a solar thermal mini-panel (2) (PST), equipped with a solar station (3) (ST), which provides the fluid for taking over and conveying heat through a circulation pump (P1), supervised by a safety valve (SS1) and a pressure gauge (M1), which sends the hot fluid into a serpentine (SERP1) of the bivalent boiler (B2S) to dispose the captured solar heat; the temperature is measured visually with a dial thermometer (T), and the fluid flow is measured with a volumetric flow meter (4) (DV1). Fluid temperatures at the solar thermal panel (PST) outlet and at the panel inlet are measured and taken via thermal sensors (S1 and S5).

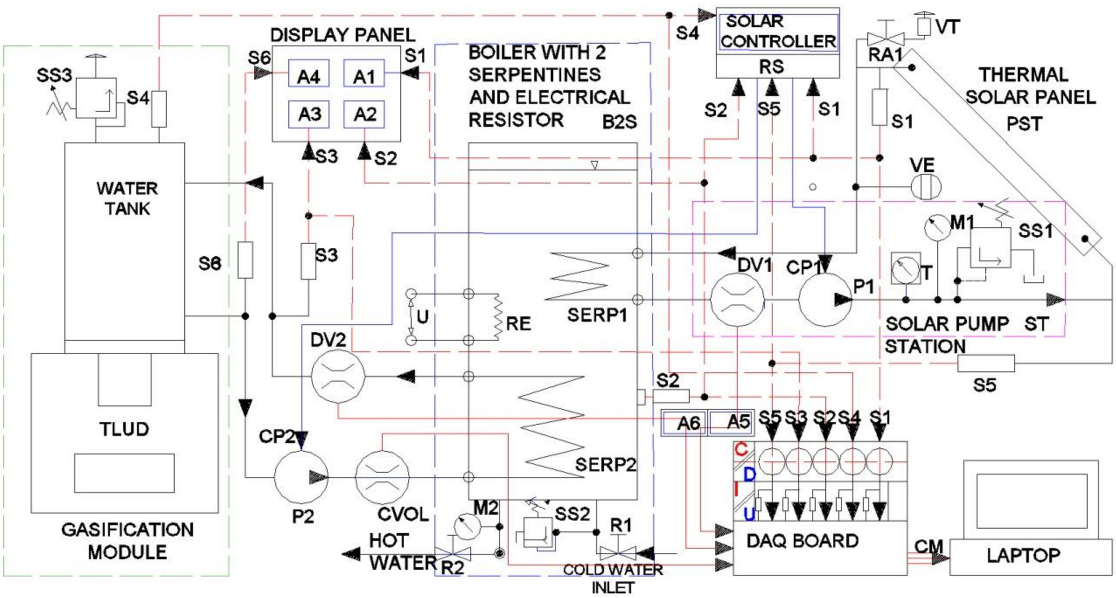

Fig. 3 - Test diagram of the combined thermal model

Thermal energy from biomass is captured by combustion, using a gasifier (TLUD) type oven (5) where combustion and gasification of pellets of vegetal nature take place; the heat is taken up by a water tank (REZ) (6), which can operate under pressure, assisted by a safety valve (SS3), the temperature of the fluid in the tank being measured by a thermal detector (S4). The captured heat is taken up by a fluid (water) conveyed by a circulation pump (P2), through a serpentine (SERP2), the flow being measured with a volumetric flow meter (DV2) (7), and the volume of fluid being evaluated with a volumetric meter (CVOL). Fluid temperatures at the tank inlet and outlet are measured by means of temperature detectors (S3 and S6).

Equipping the combined thermal system with sensors and transducers

To perform the experimental testing on the combined thermal system, in order to assess its thermal efficiency, the acquisition of the evolution of the process parameters (temperatures, flows, volumes of fluid, etc.) was considered. To capture these parameters, the system was equipped with a series of thermal sensors, flow meters, pressure gauges, thermometers, fluid volume meter. The correct location / installation of the thermal sensors on the indicated circuits, including the flow meters, was carefully taken care of, and on the other hand the installation of elements to adapt their signals, usually continuous, by converting these signals into digital signals, compatible with the acquisition board on the processing computer. The installation of the main sensors can be seen in figures 4 ... 11 below.

Fig.4 - Solar thermal panel with thermal sensor (S1)

Fig. 5 - Installation of thermal detector to the boiler inlet (S2)

Fig. 6 - Installation of thermal detector to the boiler outlet (S3)

Fig. 7 - Installation of thermal detector to the tank (S4)

Fig. 8 – Installation of volumetric flow meter to the panel (DV1)

Fig. 9 - Installation of volumetric flow meter to the gasifier (DV2)

Fig. 10 - Measuring water consumption at the TLUD gasifier

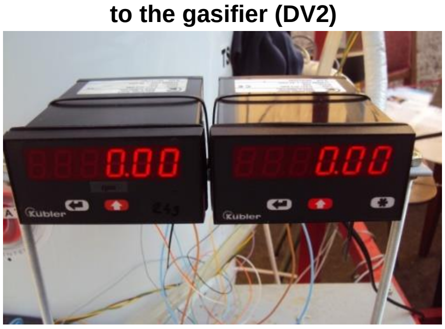

Fig. 11 - Circulation pumps flow display

Computer system for data acquisition and functioning control

For acquisition of the experimental data regarding the evolution of the parameters of interest, a data acquisition system has been designed which consists mainly of hardware components**:** electrical and electronic circuits, acquisition board, continuous to digital (C/D) signal converters, (I/U) elements transforming current (I) units to voltage (U) units, including elements displaying parameters of interest (A1, A2, A3, A4, A5 and A6), and also original software components, installed on a laptop computer, through which recording and processing of experimental data describing the evolution of the parameters is done.

Consideration was given to the correct implementation of the electrical circuits in order to acquire signals, adapt and process information, and also register the files of interest.

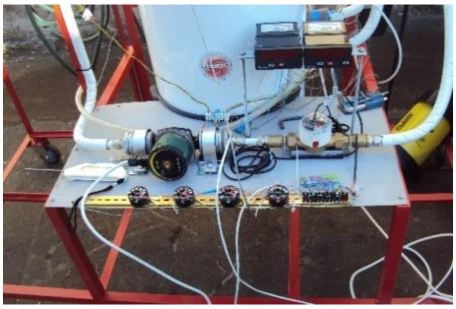

Fig. 12 - Bench with signal adaptation circuits

Fig. 13 - Power supply

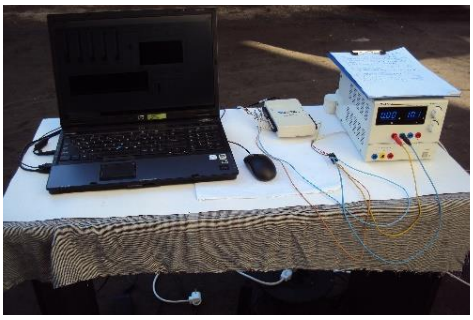

Fig. 14 - Data acquisition subsystem

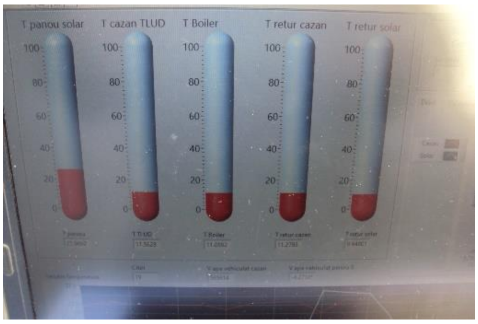

Fig. 15 - Computer display

The main thermal parameters measured for the evolution of the combined system are as follows:

- hot water temperature at the solar thermal panel outlet (S1), as displayed on the panel;
- hot water temperature inside the boiler (S2), as displayed on the panel;
- water temperature at the boiler outlet and gasifier inlet (S3), as displayed on the panel;
- water temperature inside the solid fuel / pellet gasifier (S4/S6), as displayed on the panel.

The secondary thermal parameters measured, of functional interest, are as follows:

- water temperature at the solar panel let (S5);
- water temperature at the solid fuel gasifier outlet (S6);
- ambient temperature (Tmed).

The main quantitative parameters measured are as follows:

- flow pumped by the pump P1 into the solar thermal panel PST (Q1);
- flow pumped by the pump P2, from the solid fuel gasifier REZ (Q2);
- volume flow pumped by the pump P2, during operation, CVOL.

In the end, the operation of the main components of the combined thermal system - the circulation pump of hot fluid generated by the gas module, the circulation pump within the solar thermal panel circuit, the fluid volume meter - was verified; the correct wiring of electrical circuits and signals of the sensors was also verified, including testing of the acquisition and calibrating the signals on the computer.

RESULTS

The functional behaviour of the combined thermal system experimental model was monitored, by simultaneous use of the two renewable energy sources: biomass energy and solar thermal energy.

Consideration was given to creating the conditions for the two subsystems to work at normal parameters, and the measurement instrumentation and data acquisition subsystem to produce significant data records.

The experiments have been conducted in the open air, in the yard of the Institute INOE 2000-IHP, (figure 16). Ambient temperature was measured by using a HANNA type digital thermometer.

Fig. 16 - The combined thermal model experimental test bench

Fig. 17 - Exposing the solar thermal panel to the sun

Following the conducting of experimental tests, according to the test methodology, a number of numerical results and also graphs regarding the evolution of the parameters of interest were obtained. The experimental results regarding the parameters of interest were visually tracked and monitored by means of the computer. Two types of records resulted, namely:

Written visual records of experimental data

The main parameters of interest are the temperatures which influence the thermal process, namely: ambient temperature, water temperature in the gasifier, water temperature in the solar panel and water temperature in the boiler.

The following table records the parameters mentioned above, depending on the time at which they were read visually, using the available equipment / instrumentation.

Table 1

Recorded values of the main parameters

Time of recording	Symbol	11:20	11:30	11:50	12:05	12:15	12:30
Ambient temperature (^{0}C)	T_{med}	7.3	7.5	7.9	8.1	8.2	8.6
Temperature in the TLUD gasifier (^{0}C)	T_{TLUD}	15	14	22	38	50	40
Temperature in the solar panel (^{0}C)	T_{PST}	25	23	25	35	40	50
Temperature in the boiler (^{0}C)	T_{boiler}	10	11	12	12	14	18
Pressure in the boiler (bar)	P_{boiler}	1.2 … 1.3					

From the analysis of the tabular numerical data regarding the system temperatures, one can notice a higher increase of water temperature in the boiler, due to the contribution of both thermal subsystems.

Computer records of experimental data

During the experiments, computer data recordings were made, mostly in graphical form, but also as numerical data. In the following, some examples of graphs are given, which are completely in line with the numerical data presented above. The computer screen shows the increase of the temperatures of interest, through the variable vertical bars for: temperature in the solar thermal panel T_{PST}, temperature in the TLUD gasifier T_{TLUD}, temperature in the boiler T_{boiler}, and also the return temperatures of gasifier and solar panel.

The computer screen is shown in figure 18 below, and the variation graph of the flow rates of the circulation pumps for gasifier (red) and solar panel (blue) is shown, in detail, in figure 19.

For the acquisition, registration and processing of experimental data, a Virtual Instrument application was created in the LabVIEW platform, 2014 version.

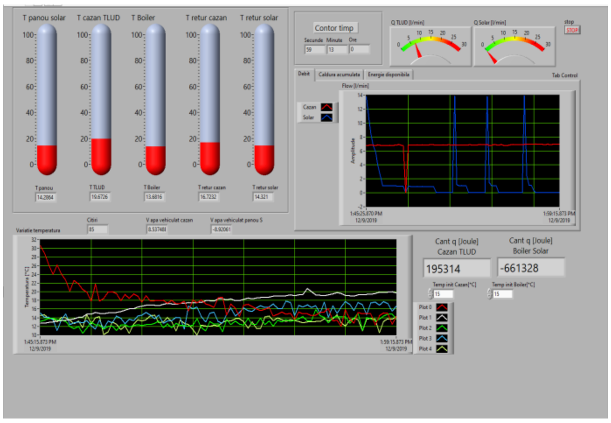

Fig. 18 - Computer screen capture

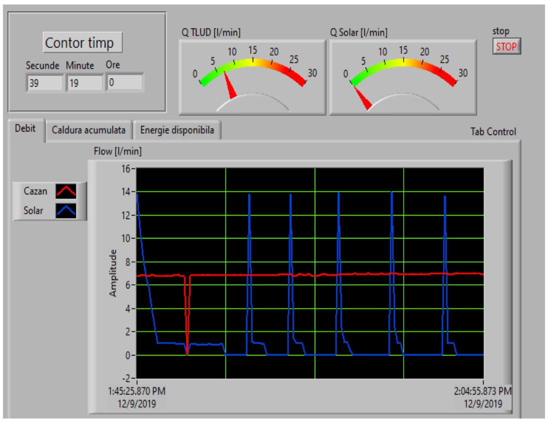

Fig. 19 - Graph of variation of flow rates of circulation pumps

Figure 19 shows, in addition to the flow variation at the circulation pump of the TLUD gasifier, which can be read both on the graph (red colour) and on the clock above the graph (6.6 l/min), frequent discharging taking place in the solar thermal panel, a fact illustrated by the blue graph. To reduce the frequency of hot water discharge in the solar thermal panel one should add more panels or increase their dimensions.

From the analysis of the complex graph in figure 20, below, one can notice the red graph (Plot 0) indicating discharge of hot water in the solar panel, while the TLUD gasifier is still accumulating heat, even above 20^{0}C, which can be seen on the white graph (Plot 1), then it begins to descend due to the action of the circulation pump, which leads to the increase in temperature in the boiler, from about 11-12^{0}C, to about 16-17^{0}C, as shown in the green graph (Plot 2), somewhat in line with the data read visually, presented in the table above.

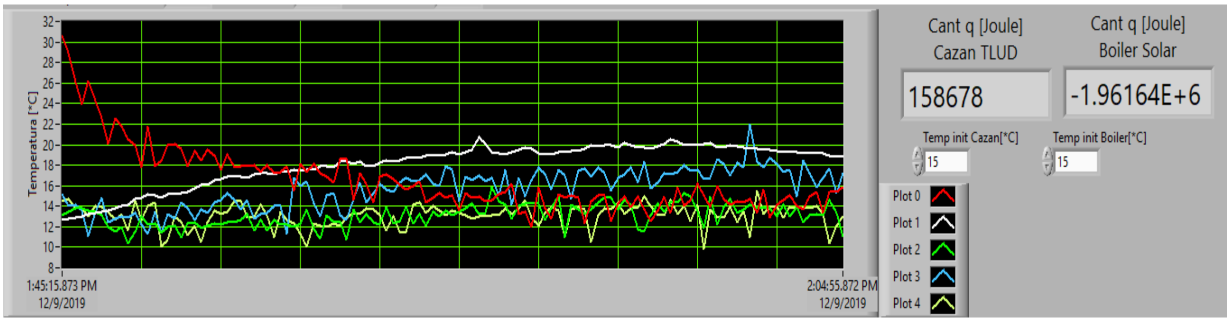

Fig.20 - The complex graph of temperature variation in the combined thermal system

The blue graph (Plot 3) shows the evolution of the water temperature upon return to the gasifier, showing that the circulation speed is too high; there is not enough time for the heat exchange in the gasifier to occur, that is, the water returns to the gasifier at a fairly high temperature. As an immediate measure it is necessary to reduce the circulation pump flow for the water in the gasifier, which is achievable if the pump speed were variable. The orange graph (Plot 4) shows that the discharge of hot water from the solar panel is done at high flow rates, almost double compared to the ones in the gasifier, but also at high frequency, which keeps the water on return to a relatively low temperature.

CONCLUSIONS

Testing of the experimental model of the combined thermal system revealed some important conclusions regarding the functional behaviour, as follows:

- The experimental model of combined thermal system functionally corresponds to the requirements of the technical documentation, achieving the purpose for which it was designed;

- The ratio of the heat sources (the biomass-based thermal generator and the solar thermal panel) size and the boiler size must be optimized, in the sense of increasing the power of the former. In other words, the capacity of the boiler is too high compared to the heat sources;
- This disproportionate situation is due to the impossibility of purchasing a smaller boiler with two serpentines, its volume of water (about 120 l) being too large, situation that we have accepted since an experimental model was in discussion;
- The biomass / pellet based thermal generator, although functionally appropriate, turned out to be too small, so for a prototype one has to think something bigger, i.e. for a power of about 10-12 kW;
- In conclusion, to develop a prototype, it is necessary to increase the powers of both thermal subsystems, to make a greater contribution to the increase in water temperature inside the boiler, on a larger range, in a much smaller time. In this way, an optimal consumption of hot water can be provided and guaranteed to the beneficiary.

ACKNOWLEDGEMENT

This paper has been funded under Programme I – Development of national R&D system, Subprogramme 1.2 – Institutional performance – Projects financing excellence in RD&I, Financial Agreement no. 19PFE/17.10.2018, while the scientific results have been obtained in the framework of a project co-financed by the European Union through the European Regional Development Fund, under Competitiveness Operational Programme 2014-2020, Priority Axis 1: Research, technological development and innovation (RD&I) to support economic competitiveness and business development, Action 1.1.4 - Attracting high-level personnel from abroad in order to enhance the RD capacity, project title: *Establishing a high level proficiency nucleus in the field of increasing renewable energy conversion efficiency and energy independence by using combined resources*, project acronym: CONVENER, Financial Agreement no. 37/02.09.2016.

REFERENCES

[1] Anvari S., Khalilarya S., Zare V., (2019), Power generation enhancement in a biomass-based combined cycle using solar energy: Thermodynamic and environmental analysis, *Applied Thermal Engineering*, Vol.153, pp.128-141, Ed. Elsevier, London/U.K.;

[2] Bostan I., Dulgheru V., Sobor I., Bostan V., Sochireanu A., (2017), *Renewable energy conversion systems. Wind, Solar, Hydraulic Energy (Sisteme de conversie a energiilor regenerabile. Eoliană, Solară, Hidraulică)*. Tehnica-Info Publishing House, Chişinău/Republic of Moldova;

[3] Cristescu C., Dumitrescu C., Drumea P., Dulgheru V., Kedzia K., (2016), Technologies of capture and storage of energy from renewable sources, *Proceedings of 22nd International Conference on Hydraulics and Pneumatics HERVEX 2016*, ISSN 1454 – 8003, pp.368-382, Baile Govora/Romania;

[4] Dumitrescu L., Cristescu C., Barbu V., Mateescu M., (2018), Combined system for the production of thermal energy using solar and biomass energy, *Proceedings of International Symposium ISB-INMA TEH' 2018*, ISSN-L 2344 - 4118, pp. 965-970, Bucharest/Romania;

[5] Guo S., Liu Q., Sun J., Jin H., (2018), A review on the utilization of hybrid renewable energy, *Renewable and Sustainable Energy Reviews*, Vol.91, pp.1121-1147, Ed. Elsevier, London/U.K;

[6] Kozlov A., Marchenko O., Solomin S., (2019), The modern state of wood biomass gasification technologies and their economic efficiency, *Energy Procedia*, Vol.158, pp.1004-1008, Ed. Elsevier, London/U.K;

[7] Maican E., (2015), *Renewable energy systems (Sisteme de energii regenerabile)*. Printech Publishing House, Bucharest/Romania;

[8] Mukunda H.S., Dasappa S., Paul P.J., Rajan N.K.S., Yagnaraman M., Kumar D.R., Deogaonkar M., (2010), Gasifier stoves—Science, technology and field outreach, *Current Science*, Vol.98, Issue 5, pp.627–638, Bengaluru/India;

[9] Srinivas T., Reddy B.V., (2014), Hybrid solar–biomass power plant without energy storage, *Case Studies in Thermal Engineering*, Vol. 2, pp.75–81;

[10] ***(2018), *Renewables 2018. Global Status Report*, ISBN 978-3-9818911-3-3, https://www.ren21.net/wp-content/uploads/2019/05/GSR2018_Full-Report_English.pdf.