EUROTHERM112-U-161

Innovative concentrated solar micro organic Rankine cycle plant system for residential buildings

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Abstract

Reducing the energy consumption in the building sector, as well as its associated CO_2 emissions, is one of the main environmental concerns at worldwide level. In developed countries, the building sector means 41% of the total energy consumption and 40% of the total greenhouse gases emissions. To improve the energy efficiency of residential buildings, several energy strategies were carried out in European countries to encourage the development of active energy saving systems; such as the solar thermal energy. The presented study is in the frame of the Innova MicroSolar European project, which is sponsored by the European Union's Horizon 2020 research and innovation programme. The main goal of this project is to develop an innovative concentrated solar heat and power system for residential buildings, which supplies 2-kW_{elec} and 18-kW_{th}. This technology includes a concentrated solar system, a high performance micro organic Rankine cycle (ORC) turbine, and an enhanced latent heat thermal energy storage (LHTES). The solar system is based on linear Fresnel mirrors which are considerably easier and cheaper to manufacture than their parabolic equals. Also, the mirrors are led by a sun tracking mechanism so they are always focusing the absorber tubes, heating up to 295ºC the heat transfer fluid (HTF) flow. The total area of the real scale prototype solar field is 140 square metres, which could provide from 80 to 15 kW_{th}. The micro ORC technology is equipped with a high speed permanent magnet AC alternator able to supply 2.3 kW_{el}. The ORC block has to be fed with 22 kW_{th}. Finally, the TES tank consists of two main blocks, the PCM tank and the enhanced heat sink. Both blocks are connected between them by reversible heat pipes as heat carrier. The storage is designed to supply 25 kW_{th} during four working hours. The whole system will supply 60% of the total building energy demand, reducing the energy cost up to 20%, as well as the greenhouse gases emissions when comparing against the best renewable energy technologies available on the market. This study shows the first experiments of the whole systems. The HTF (Therminol 62) is heated up to 270ºC with the solar field, then the HTF is lead to the ORC evaporator and the organic fluid (cyclopenthane) evaporates and runs the turbine. The TES tank is charged when the solar field reaches maximum power levels. Once the solar production cannot run the ORC, the solar field is bypassed and the TES tank successfully becomes the main energy supplier.

Keywords: Cogeneration, Concentrated Solar Power (CSP), Organic Rankine Cycle (ORC), Storage, Heat Pipes

1. Introduction

Building sector is one of the biggest energy consumer in the worldwide, one third of the global energy consumption; moreover, an increase of this number is expected as do the living standards [1,2]. This growing tendency is due to the growth of the worldwide population (41%), an increase of households which need service (115%), and a larger floor area per person (50%) by 2050 [2]. The residential building sector means 41% of the final energy consumption in developed countries (such as Europe), also the 40% of the total greenhouse gas (GHG) emissions [3]. Following the European Union (EU) 2030 goals of preserving the environment by means of a sustainable development and lowering the energy demand of buildings [4], there are energy actions plans which promote the active energy systems; for instance solar thermal energy technologies. The presented work is in the framework of the Innova MicroSolar European project, which is supported by the European Union's Horizon 2020 research and innovation programme. The project develops an innovative concentrated solar plant (CSP) for heat (18-kW_{th}) and power (2-kW_{elec}) supply to residential buildings. The plant includes a linear Fresnel solar system with sun tracking tool, which heats the heat transfer fluid (HTF) up to 295ºC. The power supply is produced by a micro organic Rankine cycle (ORC) turbine which heat income is 22 kW_{th}. The power plant also incorporates an enhanced latent heat thermal energy storage system (LHTES) to provide 25 kW_{th} along four additional hours when the sun is gone. The power plant covers 60% of the total building energy demand, meaning a reduction of the energy cost up to 20%. Also, a 20% reduction in the GHG when comparing this technology against the best renewable energy technologies available on the market. In this paper it is presented the first experiments of the whole power plant up to 270ºC except the TES tank.

The main goal of this project is to develop an innovative concentrated solar heat and power system for residential buildings, which supplies 2-kW_{elec} and 18-kW_{th}. This technology includes a concentrated solar system, a high performance micro organic Rankine cycle (ORC) turbine, and an enhanced latent heat thermal energy storage (LHTES). The whole system will supply 60% of the total building energy demand, reducing the energy cost up to 20%, as well as the greenhouse gases emissions when comparing against the best renewable energy technologies available on the market. This study shows the first experiments of the whole systems. The HTF (Therminol 62) is heated up to 270ºC with the solar field, then the HTF is lead to the ORC evaporator and the organic fluid (cyclopenthane) evaporates and runs the turbine. The TES tank is charged when the solar field reaches maximum power levels. Once the solar production cannot run the ORC, the solar field is bypassed and the TES tank successfully becomes the main energy supplier.

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2. Material and methods

2.1 Plant description

The experimental tests were carried out in the CSP pilot plant at the University of Lleida, the plant is placed in Almatret (Lleida, Spain). The prototype mainly consists in five blocks (Figure 1):

- Linear Fresnel concentrated solar field (Figure 2.a). which is considerably easier and cheaper to manufacture than their parabolic equals. The real scale prototype solar field area is 140 m^2 and it can provide from 15 to 80 kW_{th}, heating the HTF up to 295ºC. The Fresnel mirrors include a sun tracking device; therefore, they are always focusing the absorber tubes. The heat transfer fluid used is Therminol 62 [5].
- The micro organic Rankine cycle turbine (Figure 2.b). The ORC is equipped with a high speed permanent magnet AC alternator which supplies 2.3 kW_{el}. The ORC block thermal income is 22 kW_{th}, used to evaporate the working fluid (Novec 649 [6]), which expands the turbine. The ORC refrigeration system is used to heat the water supply for the consumer.
- The latent TES tank (Figure 3). The TES system is formed of three main components, the PCM tank, the enhanced heat sink and the latter two are connected by reversible heat pipes. The PCM chosen for this application is solar salt, this material fits the requirements of the plant and went successfully through all the characterization tests [7]. When fully charged, the storage capacity allows four additional working hours at 25 kW_{th} when the primal energy source is gone. It has to be pointed out that the TES block is out of the scope of this study and it will be added in the future.
- The balance of plant (BoP), which includes every piping item to connect and monitor the latter three blocks among them. This block consists of five pressure sensors, six thermal sensors, four electric three-way valves, the expansion vessel (totally equipped) and several manual valves; all sensors connected to the PLC for monitoring the HTF can be seen on Table 1, as well as their accuracy.
- The inertia water tank, which allows to supply hot water directly. The HTF heated by the solar field is used to produce domestic hot water without running the ORC.

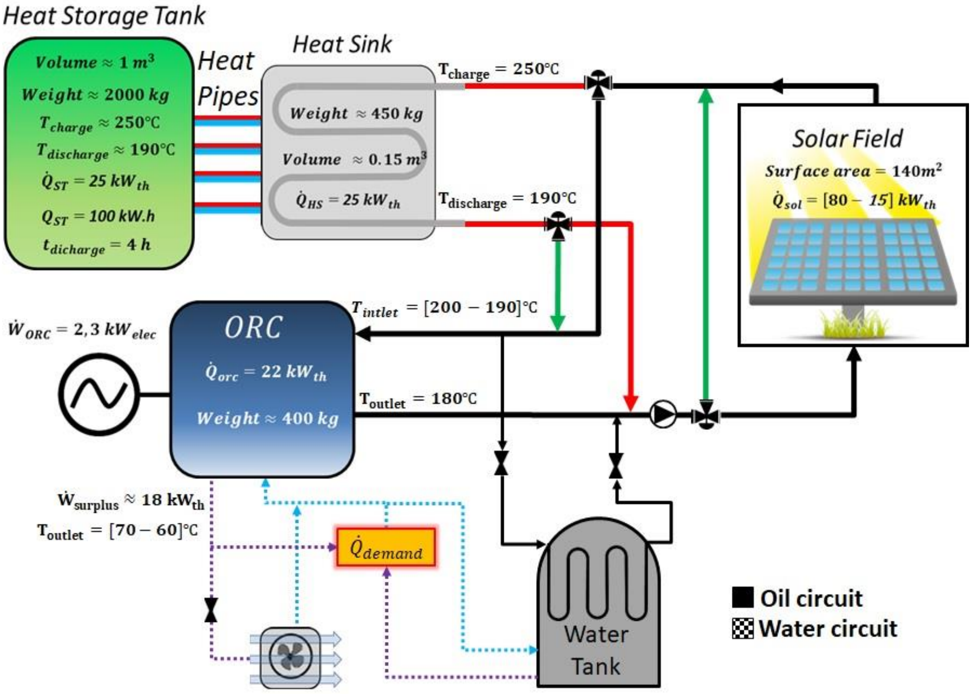

Figure 1. Pilot plant scheme.


(a) (b)

Figure 2. Linear Fresnel solar field (a), organic Rankine cycle micro turbine (b).

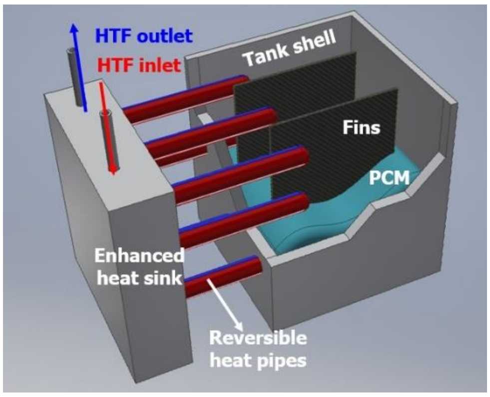

Figure 3. Thermal energy storage tank concept.

Eq.1 calculates the heat power produced by the solar field ($\dot{Q}$) as well as the heat consumed by the ORC. The HTF density (ρ_{HTF}) and specific heat (Cp_{HTF}) depend on the fluid temperature. As it can be seen on Figure 4 a linear regression adjust properly to the variation of ρ_{HTF} and Cp_{HTF} regarding the temperature; therefore, equations Eq.2 and Eq.3 are obtained.

$$\dot{Q}[\mathrm{kW}] = Cp_{HTF}\left[\frac{\mathrm{kJ}}{\mathrm{kg}\cdot \mathrm{K}}\right]\cdot \dot{V}_{HTF}\left[\frac{\mathrm{l}}{\mathrm{s}}\right]\cdot \rho_{HTF}\left[\frac{\mathrm{kg}}{\mathrm{l}}\right]\cdot (T_{outlet} - T_{inlet})[\mathrm{K}] \qquad \text{Eq.1}$$

$$\rho_{HTF}\left[\frac{\mathrm{kg}}{\mathrm{l}}\right] = -A\cdot\frac{T_{outlet} + T_{inlet}}{2}[\mathrm{K}] + B \qquad \text{Eq.2}$$

being A = -0.7226 [kg/(l*K)] and B = 969.37 [kg/l].

$$Cp_{HTF}\left[\frac{\mathrm{kJ}}{\mathrm{kg}\cdot \mathrm{K}}\right] = C\cdot\frac{T_{outlet} + T_{inlet}}{2}[\mathrm{K}] + D \qquad \text{Eq.3}$$

being C = 0.0026 [kJ/(kg*K2)] and D = 1.893 [kJ/(kg*K)].

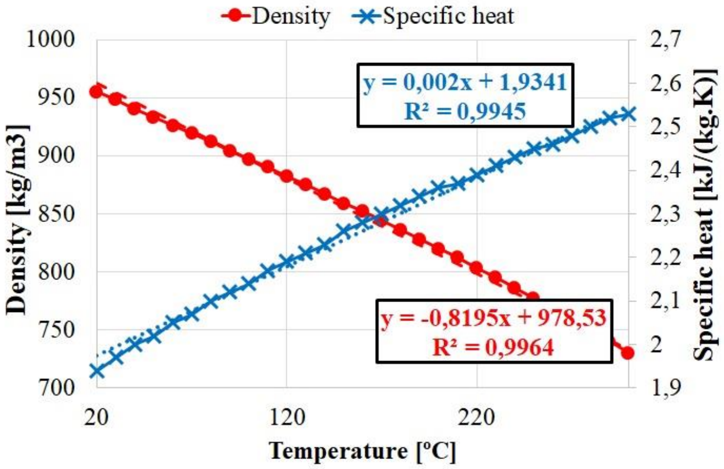

Figure 4. Therminol 62 density and specific heat regarding the fluid temperature [5].

Table 1. Model and accuracy of all pilot plant monitoring sensors.

Sensor	Model	Error	Parameters
Temperature	Endress+Hauser Omnigrad S TR88	± (0.15 + 0.002·|T|) ºC	$T_{\text{solar field outlet}}$ / $T_{\text{solar field inlet}}$ $T_{\text{ORC outlet}}$ / $T_{\text{ORC inlet}}$
Pressure	Endress+Hauser Cerabar M PMP55	± 0.67 %	$P_{\text{solar field}}$ P_{ORC} $P_{\text{pump outlet}}$ / $P_{\text{pump inlet}}$
Flowmeter	Endress+Hauser Proline Prowirl F200	< 0.75 %	$\dot{m}_{\text{solar field}}$ $\dot{m}_{\text{ORC}}$
Piranometer	Huskseflux SR20	± 0.13 x 10^{-6} V/(W/m^2)	GHI
Temperature and humidity	Electronik EE210	± (0.058 + 0.0067·|T|) ºC ± 2.3 % RH	T_{outdoor} RH

2.2 Experiments description

The experiments performed at this stage of the pilot plant consist mainly in two parts: increasing the temperature of the HTF up to 300ºC and increasing the HFT temperature up to 300ºC plus running the ORC. As the pilot plant depends on the weather conditions, several tests were carried out to ensure the repeatability of the experiments.

3. Conclusions

The experiments are currently undergoing and will be presented at the conference.

Acknowledgements

The research leading to these results has received funding from the European Union´s Horizon 2020 Research & Innovation Programme under Grant Agreement 723596 with reference name Innova MicroSolar. This work was partially funded by Spanish government (ENE2015-64117-C5-1-R (MINECO/FEDER)). José Miguel Maldonado would like to thank the Spanish Government for his research fellowship (BES-2016-076554). Alvaro de Gracia has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 712949 (TECNIOspring PLUS) and from the Agency for Business Competitiveness of the Government of Catalonia. The authors would like to thank the Catalan Government for the quality accreditation given to their research group GREiA (2017 SGR 1537). GREiA is a certified agent TECNIO in the category of technology developers from the Government of Catalonia.

References

[1] International Energy Agency. Transition to sustainable buildings: Strategies and opportunities to 2050 n.d. https://www.iea.org/etp/buildings/ (accessed February 12, 2019).

[2] Ürge-Vorsatz D, Cabeza LF, Serrano S, Barreneche C, Petrichenko K. Heating and cooling energy trends and drivers in buildings. Renew Sustain Energy Rev 2015;41:85–98. doi:10.1016/j.rser.2014.08.039.

[3] Directive 2010/31/EU of the European parliament and of the council of 19 May 2010 on the energy performance of buildings. n.d. https://www.epbd-ca.eu/ (accessed February 12, 2019).

[4] European Commission. The 2030 Energy Strategy targets for renewables and greenhouse gas reductions (2014). n.d. https://ec.europa.eu/clima/policies/strategies/2030_en (accessed February 12, 2019).

[5] Therminol 62. High-Performance Heat Transfer Fluids n.d. https://www.therminol.com/products/Therminol-62 (accessed February 14, 2019).

[6] 3M Science. Applied to life. Novec n.d. https://www.3m.com/3M/en_US/novec-us/?utm_medium=redirect&utm_source=vanity-url&utm_campaign=www.3m.com/novec (accessed February 14, 2019).

[7] Maldonado JM, Fullana-Puig M, Martín M, Solé A, Fernández ÁG, De Gracia A, et al. Phase change material selection for thermal energy storage at high temperature range between 210°C and 270°C. Energies 2018;11:1–13. doi:10.3390/en11040861.