Experimental study of a multistage thermoelectric heat pump using different internal heat exchangers

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***Abstract*— The current need to carry out an energy transition towards a 100 % renewable horizon places the energy storage as the key. Thermal energy storage has the potential to be an optimal technology. Nowadays electrical resistors are used to convert electrical energy to thermal energy by heating an air flux which is stored afterwards. In this work, it is proposed to use a multistage thermoelectric heat pump (MS-TEHP) to do this energy conversion. It has been experimentally analyzed and compared the performance of two MS-TEHP with different internal heat exchangers. With this preliminary research, it has been demonstrated the feasibility of this novel thermoelectric technology which aim is to improve the energy conversion process for thermal energy storage.**

Keywords—Thermoelectric heat-pump, Multistage, Heat exchanger, Thermoelectricity

I. Introduction

Nowadays, the energy storage is the only way to slow down the climate change, being able to solve the natural intermittency of renewable energies. Thermal energy storage has a great potential to keep exceeding renewable energy. Currently, electrical resistors are used to transform the exceeding electrical energy to thermal energy by heating an air flux, obtaining a coefficient of performance (COP) of one. Then this heated air flux is kept together with solid refractory material as thermal energy in a tank. Therefore, it is possible to store renewable energy when it is required.

In order to improve energy conversion, it is proposed to use thermoelectric modules (TEMs) working as heat pumps for heating the air flux. A TEM is able to transform electrical energy into thermal energy with greater coefficients of performance, COPs, than one, values that depend on working conditions. Principally they depend on reservoirs temperature. The dissipated heat to the hot reservoir is the sum of the absorbed heat from the cold reservoir and the consumed power, as it is shown in Fig. 1. Diaz de Garayo et al. [1] demonstrated the higher the difference between hot and cold reservoirs temperatures, the worse the COP of a TEM is. In this case, considering hot reservoir temperature the same as the thermal energy storage, which usually is between 373 K and 1273 K, and the cold reservoir temperature being the ambient or an industrial heat waste temperature, that is normally around 298 K and 333 K, the temperature difference between reservoirs is considerable.

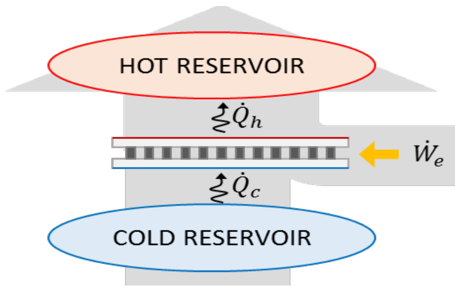

Figure 1. Thermoelectric module (TEM) working as a heat pump.

To make TEMs operate between a lower temperature difference, a novel multistage thermoelectric heat pump (MS-TEHP) is developed. This technology presents many advantages: scalability, minimum maintenance, no refrigerants, reliability, easiness of control and no moving parts.

In this research, there are designed two types of MS-TEHPs, which main difference is the internal heat exchanger (INT-HX) between stages. The first INT-HX is based on a conventional aluminium block, while the second one is a novel heat exchanger based on phase change. So as to accurately study the influence of these internal heat exchangers on the MS-TEHP performance, in this work there are studied two-stage thermoelectric heat pumps heating an air flux. The designs consist of 1 TEM in the 1st stage and 2 TEMs in the 2nd stage, thermally connected by designed INT-HXs. Finally, a finned heatsink is used in the role of heat absorber and commercial heat pipe are selected, due to the good performance studied by Aranguren et al. [2]

II. Characterization of Internal Heat Exchangers

A test bench has been built to characterize the thermal resistance (R_{th}) of the internal heat exchangers (INT-HXs), which is illustrated by Fig. 2.

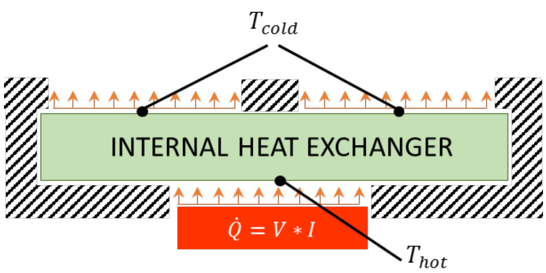

Figure 2. Internal heat exchanger characterization test bench.

The R_{th} has been calculated by (1) for different heat flux supplies on the 1st stage side, measuring the temperature drop between stages.

$$(1) \quad R_{th} = \frac{T_{hot} - T_{cold}}{\dot{Q}}$$

Fig.1 shows the calculated thermal resistance variation in function of the heat flux supply. In case of the 1st INT-HX the thermal resistance (R_{th},1) is almost constant at 0,15 K/W, presenting no heat flux dependence. Meanwhile, the 2nd INT-HX thermal resistance (R_{th},2) suffers a decrease when heat flux supply increases, reaching a value of 0,07 K/W, being this thermal resistance a 50 % lower thermal resistance.

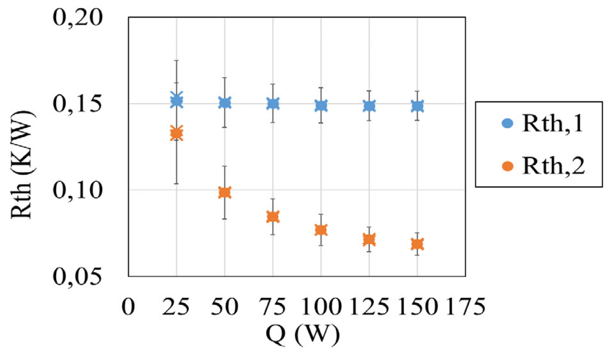

Figure 3. Thermal resistance calculated by (1) for heat exchangers based on conduction and phase change effect (Rth,1 and Rth,2) with different heat flux supply (25, 50, 75, 100, 125 and 150 W)

III. Multistage thermoelectric heat pump analysis

Once the two INT-HXs have been characterized, two MS-TEHP prototypes have been built and tested. Each prototype consists of three MS-TEHPs with different INT-HX in series for heating an air flux, as Fig. 4 presents.

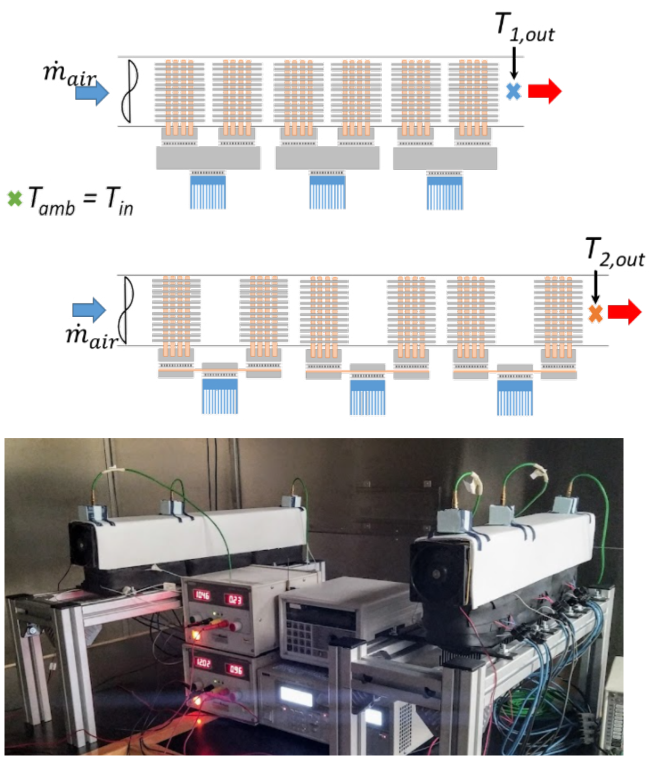

Figure 4. Multistage thermoelectric heat pump prototypes test bench.

It has been experimentally analyzed and compared the performance of two MS-TEHP with different internal heat exchangers. It has been tested both prototypes for different voltage supplies with 25 °C as ambient temperature and an air flow of 45 m³/h. All TEMs are operated at the same voltage in each tested configuration. Fig. 5 shows measured outlet temperature for both prototypes while Fig. 6 represent calculated COP using expression (2).

$$(2) \quad COP = \frac{\dot{Q}_{h,i}}{\dot{W}_{e,i}} = \frac{(\dot{m}_{air} c_p)(T_{out,i} - T_{in})}{V_i \cdot I_i}$$

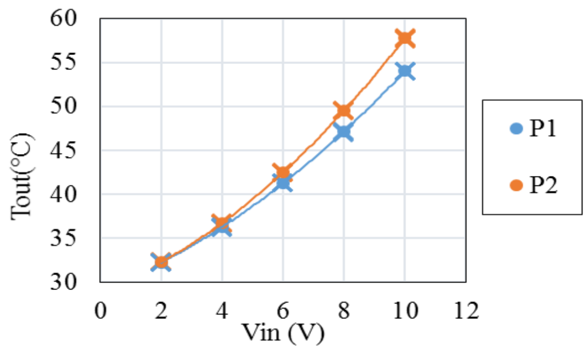

Figure 5. Outlet Temperature for different voltage supply (2, 4, 6, 8 and 10V).

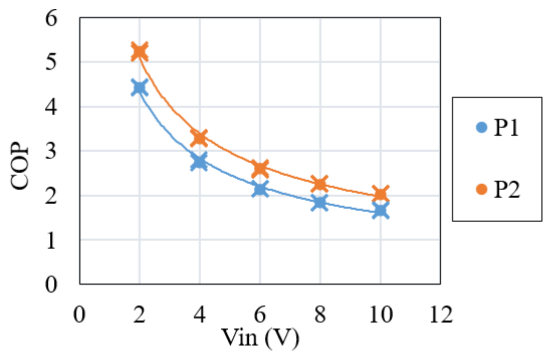

Figure 6. Calculated COP for different voltage supplies (2, 4, 6, 8 and 10V) in each prototype.

Temperature measurements demonstrate the higher the supply voltage, the higher the outlet temperature is. It has been obtained more than 30 °C temperature increase at 10 V supply. Regarding the prototypes operating performance, both prototypes achieve greater COPs than 1,5 for all voltage supplies, having a maximum value of 5. Furthermore, the prototype with phase change INT-HX always shows a 20 % increase in terms of COP.

IV. Conclusions

In this research, it has been designed, built and tested a novel multistage thermoelectric heat pump with different configurations. The possibility of using thermoelectric technology in order to improve energy conversion in thermal energy storage process has been demonstrated.

References

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