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Realization of a Based Concrete Thermal Storage Module used with a Medium Temperature Parabolic Trough Solar Collector

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Abstract

Thermal solar energy has been considered for years as one of the most promising candidate for the substitution of the conventional systems providing a clean and sustainable energy solution. However, the intermittent aspect of the solar irradiation received by the earth surface presented a major obstacle for the exploitation and the integration of such technology in various applications. In order to avoid this barrier a thermal storage system for solar energy became a necessity especially for the concentrated solar power technologies. This paper shows the work carried out to determine the thermal behavior of a concrete storage unit for medium temperature applications. The experimental thermal storage module using concrete was realized and tested in order to be integrated in an advanced setup to a solar cooling installation powered by a parabolic trough solar collector. The thermal characteristic of the used concrete matrix was determined. The thermal storage module was tested under the same thermal conditions provided by the solar collectors. The temperature variations of the module during the charging and the heat loss during the night time were investigated. The test results showed some interesting thermal inertia of the concrete based storage module. The integration of the proposed storage module to the solar loop of the cooling installation will lead to extend the operation time after sunset and to decrease time lasted by the solar parabolic trough collector to reach the required operational temperature in the morning.

Keywords: *Concrete, Parabolic Trough, heat exchanger, thermal storage, CSP.*

1. Introduction

The development of solar thermal energy technology has been growing since the beginning of 1990s [1]. Due to the unlimited and clean aspect of the solar energy, concentrating solar power (CSP) became one of the most promising candidates for substitution of conventional technologies [2, 3]. Meanwhile, the intermittent and the diurnal nature of the solar energy source affected negatively the efficiency of such technology and presented a barrier toward its applications. Hybridisation and heat storage are considered as a significant and effective solution toward a more stable and reliable power source [3]. Generally there are three categories of heat storage including latent heat storage, chemical heat storage and sensible heat storage. Among the three methods sensible heat storage is the mostly applied in CSP systems [4, 5]. Multiple parameters determines the choice of the sensible heat storage material including , but not limited to, the operational temperature range, the life cycle of the material in terms of physical properties degradation and the size of the energy source. As a solid state heat storage material concrete is generally the preferred choice for solar thermal systems and this is by reason of its low cost, good thermal conductivity and thermal inertia [6]. The present work consists of the design and the construction of a heat storage module using concrete as a solid medium, for a 16 kW solar cooling system using a medium temperature parabolic trough solar collector. The solar cooling system is installed to provide the air conditioning for an administrative building. During the morning hours and because of the low temperature of the heat transfer fluid the system start-up was delayed approximately two hours till the solar irradiation reached a certain level capable of starting the

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system, also at the end of the day the system was unable to reach the set-temperature. Meanwhile, during the day the input thermal energy exceeded the cooling demand. The aims of this paper are to observe and to analyze the thermal behaviour of the concrete module during the charging phase “heating" and during the night time "storage" in order to enhance the cooling system capability and extend its operational time.

2. System Description

Figure 1 represent a 16 kW air conditioning installation powered by a 39 m2 aperture area parabolic trough solar collector. In the test configuration the parabolic collector was replaced by a heated oil tank to provide the same inlet condition for the storage module in a closed loop. The thermal storage module is composed of a thermal isolated cylindrical tank filled with concrete and in which four tubular heat exchangers were introduced Figure.2. The same thermal fluid (Thermal oil type Seriola 1510) used for the solar collector is used for the test. The measurement and data acquisition system consist of multiple thermocouple probes (type K) introduced inside the concrete storage module in two levels of elevation.

Figure 1: Solar cooling installation

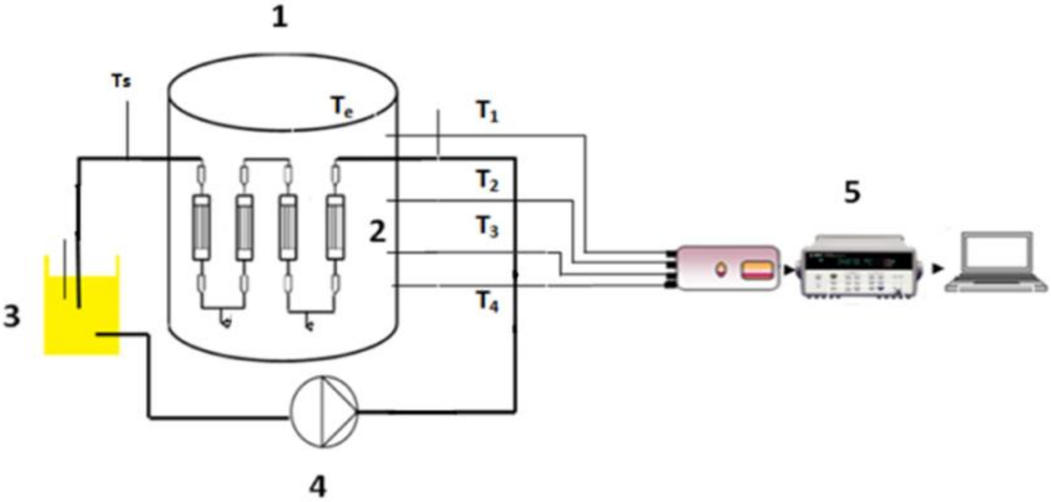

Figure 2: Configuration of the thermal storage module equipped with the temperature measurement system

The test configuration consists mainly of a:

(1) Concrete storage volume (0.97 m^3)

(2) Four tubular stainless steel heat exchangers

(3) Heating tank for the thermal oil

(4) Pump

(5) Data acquisition system

2.1. Heat storage module

As shown in Figure3 a cylindrical container "mold" was thermally isolated (interior side) using glass wool insulation then a steel structure integrated inside the mold to be the metallic frame for the concrete module. The used concrete was prepared basing on the local construction norms (1 volume of cement equal to 250 Kg, 0.5 volume of water, 2.5 volume of sand and 3.5 volume of gravel). A sample of the prepared concrete was characterized to determine its thermal conductivity 2.049 W/m.K.

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2.2. Heat exchanger

The selection of the heat exchanger size, material, dimension and type was based on the available type of material, the mechanical strength of the material facing the weight applied by the volume of concrete and the thermal fluid operating temperature.

In order to deliver the heat to the concrete module four tubular heat exchangers were made from stainless material Figure.4. The total volume occupied by the heat exchanger is equal to 0.037 m3.

The four elements were connected to the loop in a parallel configuration so that the entering thermal fluid passes through all the heat exchangers Figure.5. In addition, the heat exchangers were installed in manner to be distributed on the majority of the concrete matrix. After the determination of the heat exchanger dimensions we calculated its surface compactness which was equal to 170, 27 m2/m3.

Figure 3: Preparation of the heat storage module

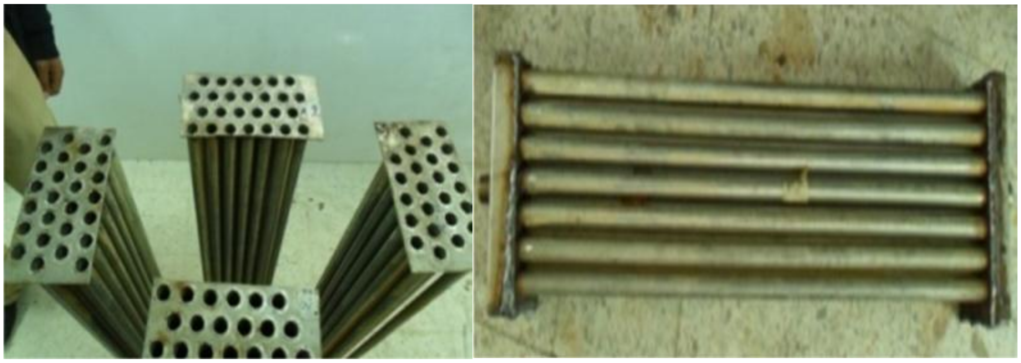

Figure 4: The stainless steel heat exchangers

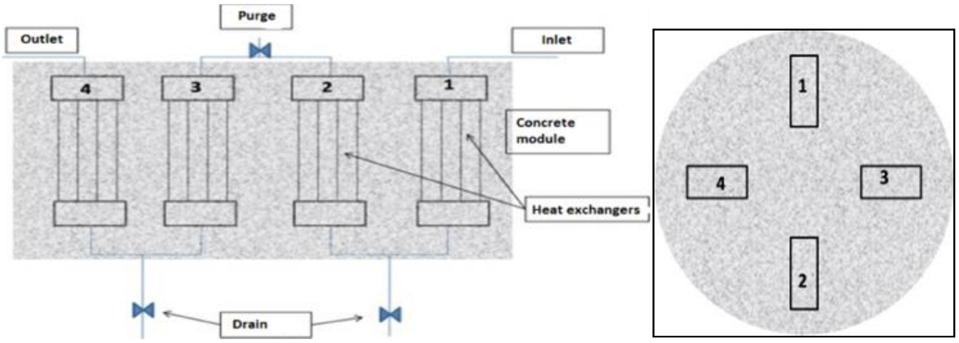

Figure 5: Configuration of the heat exchangers inside the concrete volume

3. Results and discussion

3.1. Thermal behavior during the heating phase

N The figure.6 represent the measured thermal oil temperatures during the charging phase of the input of the storage module (Ti) and the in the output (To) with an average ambient temperature of 27°C. During the 5 hours of the heating phase an average of 8 °C difference between the input and the output temperature was recorded which represent a significant amount of thermal energy being absorber threw the heat exchangers to the concrete mass.

The figure.7 represents the concrete inside temperature in two different levels (T2-1) bottom half and (T1-2) upper half. If we observe the temperature difference between the two levels we notice that there is a periodic behavior of thermal stratification. Compared to the relatively steady increasing temperature of the input thermal oil the pattern temperature of the two concrete probes were quiet unstable. The temperature increasing inside the concrete module was relatively slow. The temperature of the upper part (T1-2) changed took 5 hours to go from 32°C to 81°C in an unsteady thermal behavior. Meanwhile, the downer part temperature (T2-1) attained 60°C practically with a similar thermal behavior.

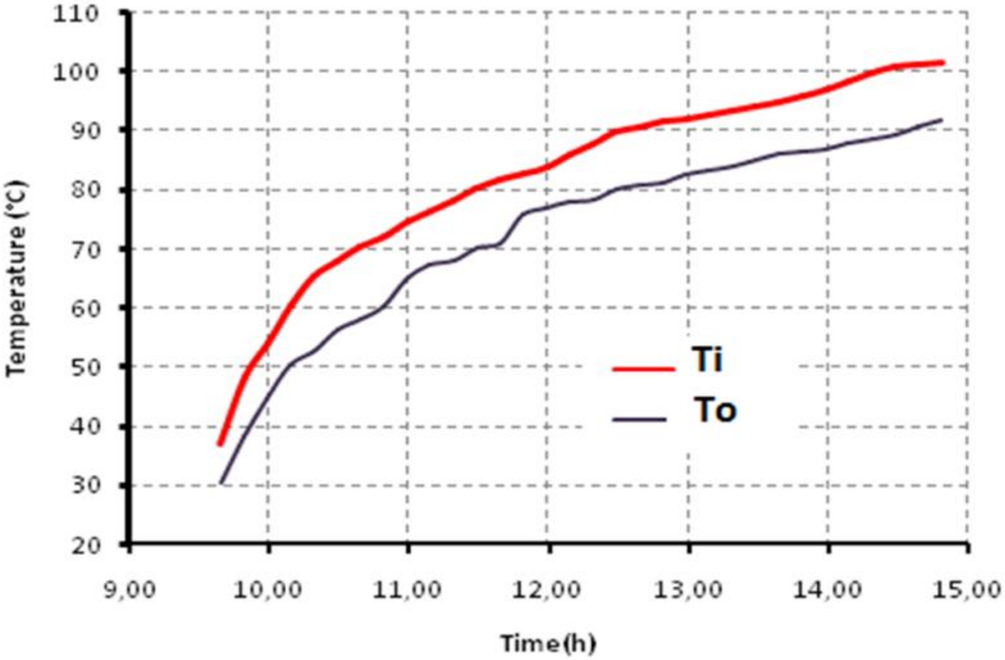

Figure 6: Input and output oil temperature during the heating phase.

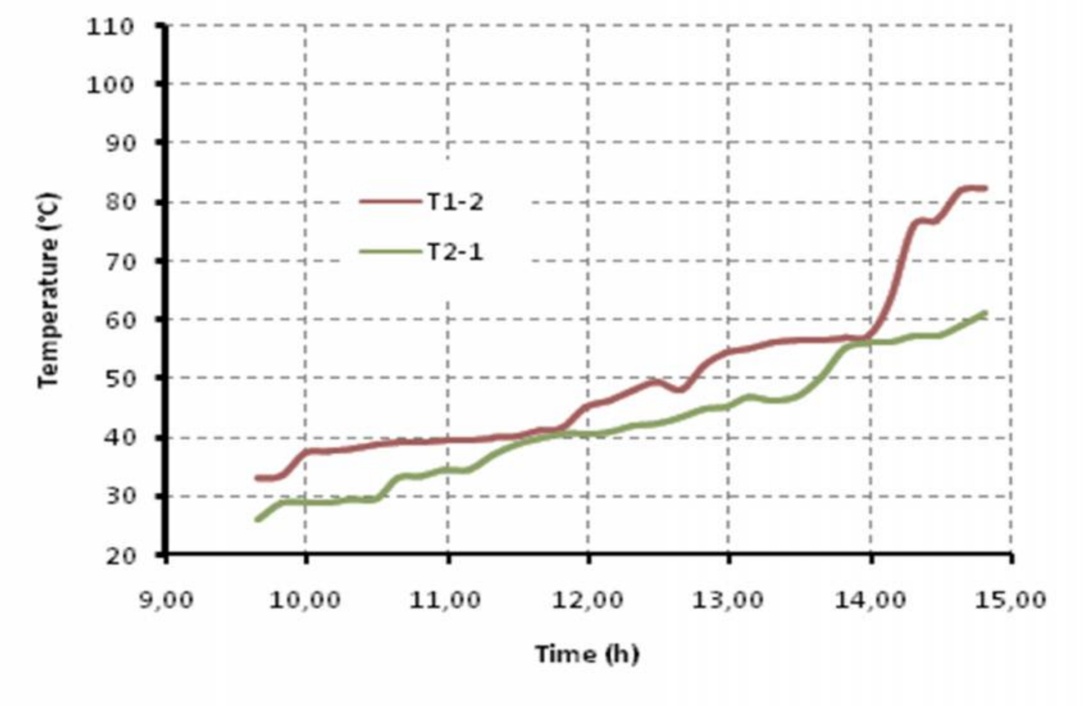

Figure 7: The two levels concrete temperature during the heating phase

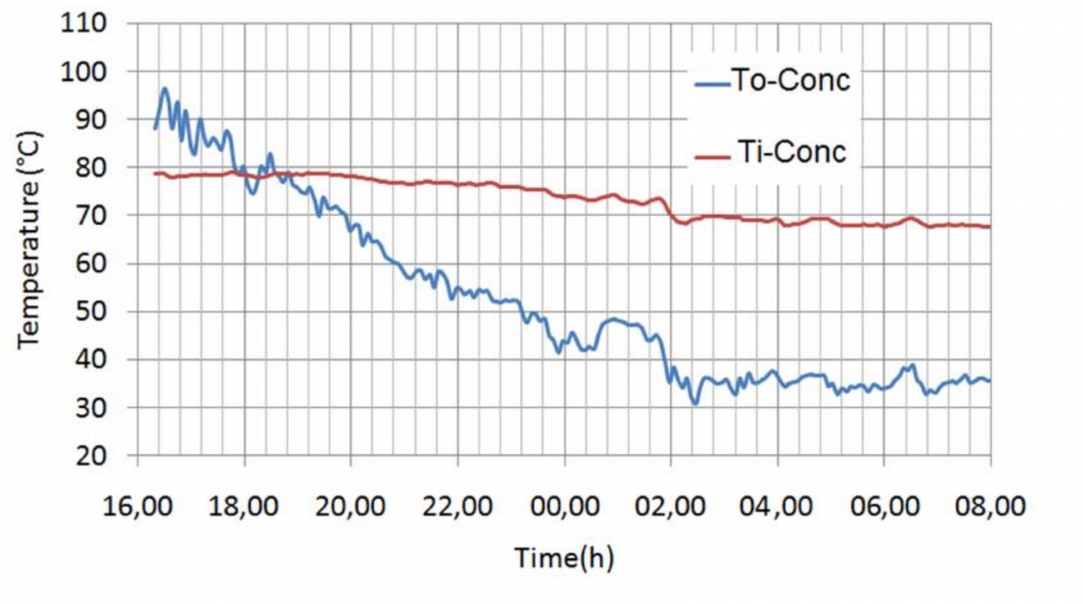

Figure 8: Thermal behavior of the storage module

3.2. Thermal nocturnal behavior of the storage module

During the storage phase in the night the heating and the pumping system were turned off, the thermal storage module was left during all the night till the next morning. In the figure.8 two temperatures were measured exterior temperature of the concrete module upper face (To-Conc) and the average internal temperature of the concrete volume (Ti-Conc). As we may notice in the first two hours that the exterior temperature of the concrete volume was superior than the average interior temperature, which is due to the exposition to the sun light.

In the sunset time around 18:00h, the external temperature dropped down rapidly compared to the interior one.

During 10 hours the external temperature of the concrete volume, including the heat exchanger filled with thermal oil, dropped down with 60 °C meanwhile the internal average temperature drop was around 10°C for 16 hours. The interior temperature fluctuation during the storage phase was more stable than the superficial temperature affected by the external thermal effects.

In order to determine the heat loss coefficient of the concrete module the next equation was used:

$$\Lambda = \frac{\rho \cdot C_p \cdot v}{\Delta t} \log \left(\frac{T_i - T_{amb.m}}{T_f - T_{amb.m}} \right) \tag{1}$$

Where ρ: the density (kg/m^3); Cp: specific heat capacity (J/kg.K); v: concrete volume; Δt: the storage period(s) and Ti, Tf, Tamb.m are the initial temperature, the final temperature of the concrete volume and the average ambient temperature.
The calculated value of the heat loss coefficient for the concrete module was equal to 8,31 W/°C this value reflected a relevant thermal inertia for the system during the night time storage.

3. Conclusion

A medium temperature thermal storage concrete module was realized and tested in order to be integrated to a 16 kW parabolic trough solar collector used to drive a solar cooling system. Thermal behavior of the storage module during the charging and storage phase was presented. The main results and relevance are the following:

- During the charging phase the concrete volume presented a thermal stratification in the vertical direction with non stable temperature difference.
- The concrete module presented an important thermal inertia during the storage phase even with non stable external thermal conditions.
- Such storage system with a relevant heat loss coefficient could offer an important enhancement for medium temperature solar applications, with extended working time and more stable thermal output.

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