	Name of the PhD candidate : Muhammad Asaad Keilany Title of the PhD thesis: **Experimental and modeling study of a thermocline with combined latent and sensible heat storage system integrated with a cylindrical-parabolic concentrated solar power plant (CSP)** Dates (start/end):Dates (start/end): 01/02/2017 - 31/01/2020
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Context and objectives

In growing global demand for energy, concentrated solar power (CSP) is projected to provide 10% of energy demand by 2050. The main advantage of CSP technology compared to other renewable resources is the possibility to implement thermal energy storage (TES) systems allowing an increase or a shifting in power production time. Thermocline systems using low cost filler materials might reduce the cost of TES in CSP plants compared to the most common TES solution of two tank molten salts. However, due to a temperature gradient formation inside the thermocline, the efficiency of the system decreases. Beside when this layer reaches the outlet of the thermocline it temperature is degraded to lower temperature than required constant temperature, although it is higher than the cut-off temperature of the discharge (

Figure ***1***-a). Previous work were conducted both experimentally and numerically on a packed bed thermocline TES using 2 cm. alumina spheres (Thomas Fasquelle PhD thesis).

A layer of encapsulated phase change material (PCM) as latent heat is suggested at the top of the thermocline, in order to extend the discharge time with the required constant temperature (

Figure ***1***-b). The main scientific issue is that in this configuration, thermocline modeling becomes a multi-scale problem, because of the generally low thermal conductivity of PCMs: the system must be modeled at the tank scale as well as at the PCM capsule scale in order to take into account thermal gradients inside. The main objectives of the represent work are:

- Select PCM with suitable melting point, and select a compatible envelop materials that could be safely used in the thermocline with the heat transfer fluid (HTF) at the chosen working temperature.
- Model the combined latent sensible TES, using appropriate one-dimension 2 phases (fluid- solid) model that takes into account thermal losses through the tanks wall.
- Estimate the added value this solution, by observing minimum required PCM quantity at the top of the thermocline with constant outlet temperature, to reach similar storage capacity of the same thermocline filled only with alumina spheres.
- Validate the thermal behavior of the combined sensible and latent heat storage on a pilot-scale installation
- Optimize the envelop design: spherical, cylindrical, with or without fins, by providing multi scale modelling leading to the best techno-economical solution.
- Reduce the encapsulated PCM model to include the radial effects in an effective value that could reduce the complexity of whole thermocline model.

Approach

Alumina spheres with 2cm diameter is chosen as reference filler materials since it has very good volumetric heat capacity, in addition to its regular spherical shape which allows for solid assumptions during calculation. On the other hand, in order to elaborate economically feasible filler materials for the thermocline, COFALIT® is evaluated

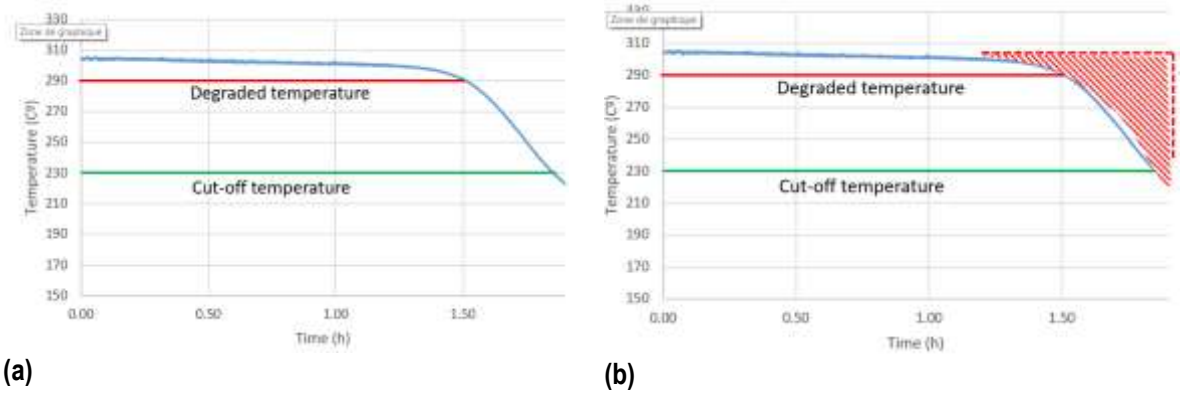
as recycled low cost material for sensible heat storage. The behavior of the thermocline filled with irregular shape COFALIT® rocks is required to be tested and compared to alumina reference material.

There are different approaches to evaluate the thermocline behavior numerically; therefore, a suitable and representative model is required to be build and validated to simulate the behavior of the thermocline with combined latent to sensible TES, using MATLAB® code.

The complexity of modelling such problem requires deconstructing to relatively simpler approaches before reconstructing more solid simulation. Therefore, it requires a 3D model of heat transfer in encapsulated PCM using commercial software (Ansys®), in order to optimize the design of the encapsulation and select suitable configurations that could fit the physical purpose and the ease of fabrication for further experimental investigation.

Main results

- Comprehensive literature review of all approaches that had been used to model thermocline behavior with sensible heat only, latent heat only and combined latent to sensible solutions, in order to develop the best approach that could fit with the studied case, with various assumptions and correlations.
- COFALIT® rocks was evaluated against reference material of alumina spheres ceramic with definitely much lower cost and a slightly lower volumetric heat capacity of 2.99 MJ/m3.K for COFALIT® and 3.30 MJ/m3K with alumina spheres for operating conditions between 200 and 300 °C.
- The performance of COFALIT® rocks as filler material inside pilot scale thermocline was tested, where charge and discharge operation was performed using MICRO-Sole Odeillo installation, and the results are being compared to the alumina spheres.
- $NaNO_3$ was found suitable candidate as PCM with melting temperature around 306ºC, and stability up to 380ºC. Stainless steel L316 is recommended for the $NaNO_3$ envelop material with acceptable corrosion rate at the required working temperature.



(a) **(b)**

Figure 1. (a) Thermocline outlet temperature profile during discharge, (b) Thermocline outlet temperature profile with required behavior after adding PCM.

Publications in international conferences

Keilany A et al. “Vitrified asbestos waste used as filler material in a thermocline storage tank.” (oral presentation and conference paper) 7th International Conference on Engineering for Waste and Biomass Valorization – July 2-5 2018 – Prague, Czech Republic