IOP Conf. Series: Materials Science and Engineering **197** (2017) 012039 doi:10.1088/1757-899X/197/1/012039

Analysis of Thermal Energy Storage Tank by ANSYS and Comparison with Experimental Results to Improve its Thermal Efficiency

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Abstract. The discontinuous temperament of the solar power forces to consider about the energy storage. This work is to analyze the tank, amount of energy stored and its storage time. The thermal and flow analysis has been done by ANSYS with different set temperature values. The experimentation is done for various encapsulating materials with different phase change material (PCM). Findings: The results obtained from experimental work are compared with ANSYS output. The competence of the TES is calculated and further improvements are made to enhance its performance. During charging process the temperature distribution from heat transfer fluid (HTF) to PCM is maximum in copper encapsulations followed by aluminium encapsulations and brass encapsulations. The comparison shows only when the electrical power as an input source. The efficient way of captivating solar energy could be a better replacement for electrical input.

1. Introduction

A hot water storage system is used in many houses for domestic purposes to provide a reliable source of energy and this small step has given a major impact as it can be used as a substitute for many renewable resources of energy. Though there are many non-renewable source of energy, there is always a tendency to look for heated fluid to use as a source of energy [1]-[5]. This is because of the easily available solar energy. The main important feature is that it can function as a storage system in the morning during the morning by storing the energy and liberating it at off sun times when it is needed in order to run the system continuously. There is always a misconception that the liquid in the tank and its temperature is not distributed in a uniform way [6]. In real situations, the cooler, denser fluid is settled at bottom of the tank whereas the hot lighter fluid will go up to the top, provided that the water within the tank is not mixed or agitated in any way.

There is also a factor of human comfort that is there in solar energy sources as it is the cheapest source of energy [7]. One of the ways to learn the solar energy processes as well as to develop their effectiveness and performances from the process viewpoint is to pass through the dynamic modeling and numeric simulation especially which consists of strong dynamics such as huge solar tanks and collectors [8]. Recent studies have proved that usage of molten salts in the tank would increase the efficiency [9]. In recent years powerful commercial computational fluid dynamics (CFD) packages become available allowing it to deal with the complex 3D flows and mixing problems. In this way the local structure can be clearly revealed. As compared toward investigational measurements and

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observations, the CFD technique turns out to be a more efficient diagnosis device for thermal energy system design and analysis, a better insight at a reasonable cost, into how these systems operate. The CFD results confirmed the importance of combined effects on the performance of thermal storage tanks and showed that a properly calculated storage tank can provide improved stratification conditions. Moreover, 3D transient CFD simulations can be used as an effectual tool to optimize thermal storage tank parameters at early design stages, therefore it may add to the value of the storage tank presentation and efficiency, by optimizing the whole solar thermal energy storage system design and size [10].

The main use of Therminol-66 is the application of heat transfer fluid. There are many properties that emphasis Therminol-66 as a Heat Transfer Fluid.Therminol-66 is a high stability synthetic heat transfer fluid contribution is extensive life and very low-top up rates resulting in reduced running costs and minimal downtime for operations at downtime at 345°C. The Project aims to study the heat transfer characteristics of solar energy by comparing the results obtained in ANSYS and the results are compared with the experimental ones. In this project we are using balls of different materials i.e. copper, aluminium and brass with dissimilar PCM’s such as D-Mannitol, D-Sorbitol and Paraffin wax. The heat transfer rate between Therminol-66 oil, water and PCM is studied and the results are compiled. The purpose of using different balls is to estimate which out of these balls has the maximum energy (heat) exchange rate.

2. Experimental Setup and Methodology

The experimental setup consist of three PCM tanks to store D-mannitol, D-sorbitol and paraffin wax, one heater tank for giving heat to the HTF in charging mode, one process unit to verify the harvest of the cascaded system, one oil pump, one flow meter and 12 thermocouples to sense the HTF temperature.

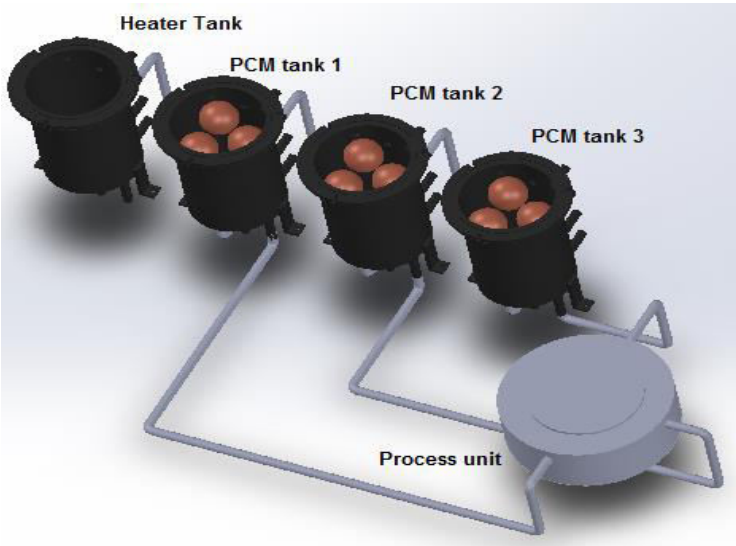

Figure 1. Experimental layout.

The heater and pump are turned in to on position. The temperature of HTF in all three tanks is noted after regular intervals of 10 minutes. This is the charging process. After attaining a temperature of about 250°C the heater is switched off. Keeping the flow rate on, the above process is repeated. This is the discharging process. Hence heat is subsequently stored and recovered in these processes. The above process is conducted for all the three type of encapsulations (aluminium, brass and copper) using therminol-66 as HTF. The figure 1 shows the arrangements of experimental setup, thermocouple of 10 in numbers are used to quantify the temperature of HTF at various locations. Oil circulation rate

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is maintained by flow meter around 26 LPM. The heat transfer rate in PCM is explained by two stages namely charging and discharging mode.

2.1. Charging mode
The HTF has been circulated through the heater source during day time. The oil passing through the heater tank absorbed heat and then sent to phase change material tanks, then it was distributed back to the heater tank. This cyclic process was continued such that PCMs are attained their corresponding melting point. The heat energy thus received by the HTF was given to the PCM encapsulations while passing through the PCMs tank. PCM received the heat from HTF during the charging mode and it gradually changed its phase from solid to liquid and stored the latent heat. This process continued until the PCMs are reached the specific melting point every 5 minutes interval the PCMs temperatures are noted using thermocouple arrangements.

2.2. Discharging mode
The circulation of HTF through the heater tank is stopped and by-passed. The temperature of the HTF gradually decreased and so the PCM inside the encapsulations released the heat outside. The oil surrounds the PCM tank gets heated up again by changing its phase from liquid to solid. This process of PCM made the HTF to maintain the temperature again for a longer time. The discharging mode enabled the thermal energy storage system to stock up the energy for a longer time that can be utilized for the evening or late night applications. This process continued until the oil temperature reaches around atmospheric condition. The time taken by the HTF to attain atmospheric condition was noted at regular intervals of 10 minutes during the Discharging mode.

The results obtained from the experimental work is compared with ANSYS output. Initially, the 3-D model of the setup is drawn with Solid Works and then imported to ANSYS window. The following inputs are given to perform the analysis.

- Input temperature- The input temperature is $90^{o}C$ and it is applied on the surface of the walls of the heater.
- Time- The time mentioned here is 10 minutes which is represented in seconds (600).
- Rate of flow- The rate of flow of oil is supposed to be mentioned and it is mentioned as 26 LPM.
- Thermal coefficient of oil- The thermal coefficient of oil is 5*10-6W/m^2K.

The meshing is generated; divide a particular part into a number of nodes. The advantage of this meshing is that it can give an exact result. The meshed generated multi-temperature thermal energy storage system design is shown in the figure 2.

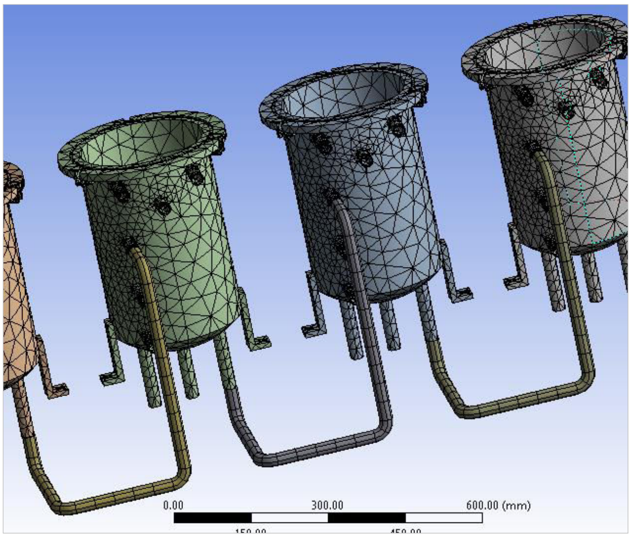

Figure 2. Mesh generated TES.

Thermal analysis is used to find out the temperature distribution and related thermal quantities in the model. The temperature distribution, sum of heat loss or gain, thermal gradients- It is the rate of change of temperature per unit in a material, thermal fluxes- it is defined as the rate of energy exchange per unit cross sectional area.

3. Results and argument

The performance of multi-temperature thermal energy storage system was analyzed with brass, aluminium, and copper encapsulations. The values obtained from the analysis are compared with experimental results.

3.1. Analysis of brass encapsulations with different PCMs

In stage 1 brass material is used to encapsulate the PCMs. The tank1 is occupied with 9 spherical brass encapsulations where D-mannitol is used as a PCM. Similarly tank 2 is occupied with 9 spherical brass encapsulations where D-sorbitol is used as a PCM. Finally tank 3 is occupied with 9 spherical brass encapsulations where paraffin wax is used as a PCM.

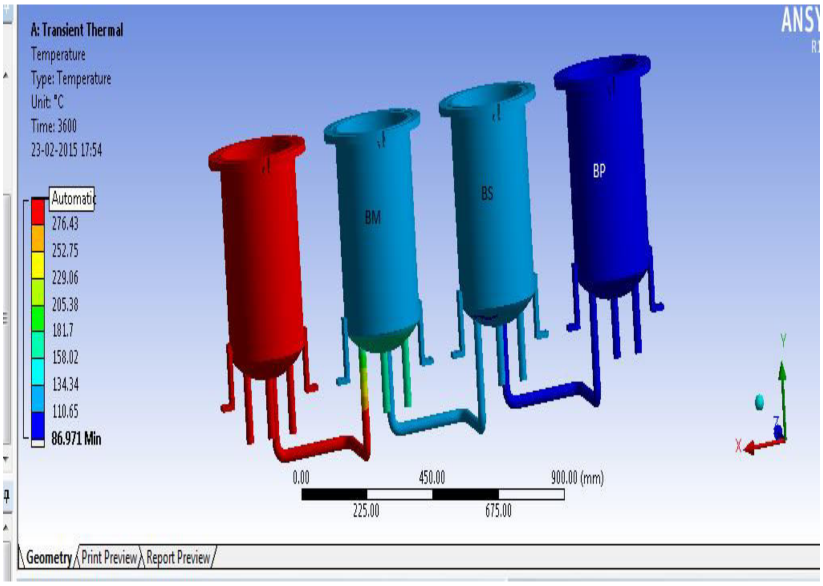

Figure 3. Temperature distribution with brass encapsulation.

The image presented in figure 3 represents the temperature distribution for brass with different encapsulations (D-Mannitol, D-Sorbitol, and Paraffin Wax). It is clearly seen that the highest temperature occurs in tank 1 which has Mannitol as a PCM in it. The temperature ranges from 120°C to 125°C (approximately). This tank is represented as BM, Brass encapsulation with D-Mannitol as PCM. The second tank which consists of D-Sorbitol has a slightly lower temperature distribution compared to that of the first. The temperature range is around 110°C to 120°C. This tank is represented as BS, Brass encapsulation with Sorbitol as PCM. The last tank consisting of Paraffin wax has the lowest range of temperature of less than 90°C. This tank is represented as BP, Brass encapsulation with Paraffin Wax as PCM.

3.2. Analysis of Aluminium encapsulation with different PCMs

In stage 2 aluminium is used as spherical encapsulation material. The tank 1 is occupied with 9 spherical aluminium encapsulations where D-mannitol is used as a PCM. Similarly tank 2 is occupied with 9 spherical aluminium encapsulations where D-sorbitol is used as a PCM. Finally tank 3 is occupied with 9 spherical aluminium encapsulations where paraffin wax is used as a PCM.

The figure 4 indicates the temperature distribution of aluminium encapsulations with different PCMs. It is found that the first tank which consists of D-Mannitol in it possesses the maximum temperature of more than 125°C which is a touch higher than brass encapsulation. This tank is represented as AM, aluminium encapsulation with D-Mannitol as PCM. The temperature distribution across the second tank having D-Sorbitol in it has an approximate temperature of 115°C or even less than that which is comparatively higher than the same encapsulation in Brass. This tank is represented as AS, aluminium encapsulation with D-Sorbitol as PCM. The last tank which consists of Paraffin wax possesses the minimum temperature of 89°C (approximately). This tank is represented as AP, aluminium encapsulation with paraffin Wax as PCM.

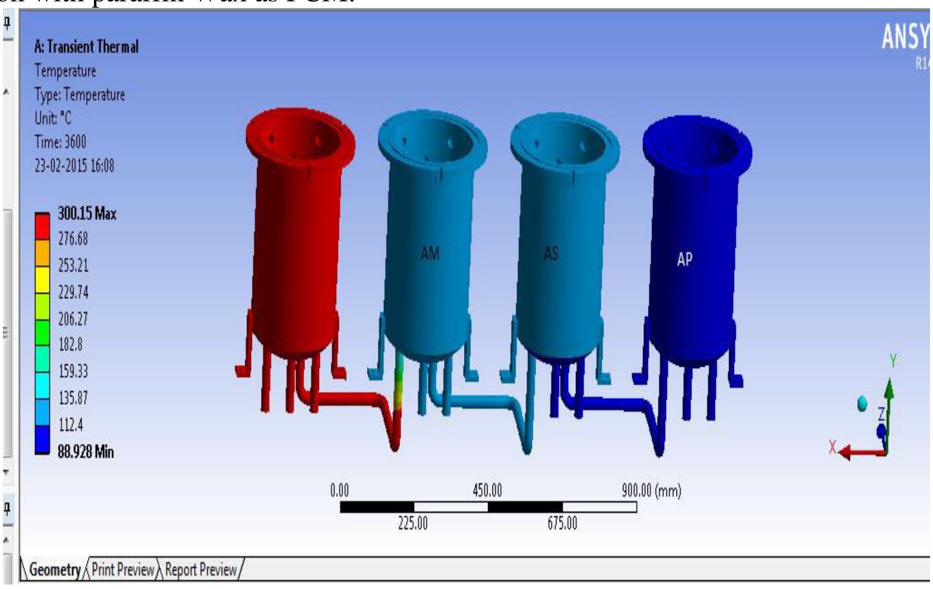

Figure 4. Temperature distribution with aluimium encapsulation.

3.3. Heat transfer effect between fixed bed and fluidized bed LHTES system

In stage 3 copper is used as spherical encapsulation material. The tank 1 is occupied with 9 spherical copper encapsulations where mannitol is used as a PCM. Similarly tank 2 is occupied with 9 spherical copper encapsulations where sorbitol is used as a PCM. Finally tank 3 is occupied with 9 spherical copper encapsulations where paraffin wax is used as a PCM.

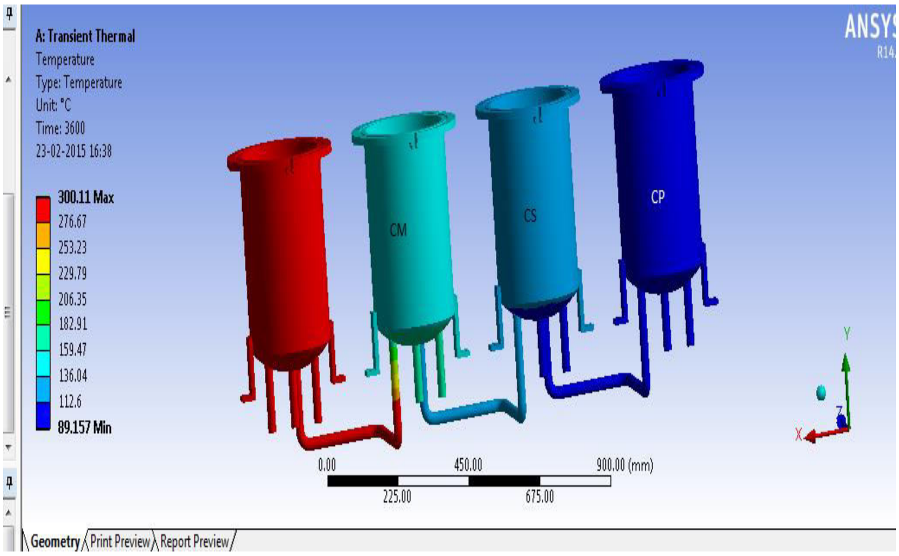

Figure 5. Temperature distribution with copper encapsulation.

The temperature distribution of copper encapsulations with different PCM is shown in the figure 5. It can be an easily concluded that copper would be the ideal material as it possesses the maximum temperature of even more than 150°C in the first tank which consists of D-Mannitol under same conditions. This tank is represented as CM, copper encapsulation with D-Mannitol as PCM. However, there is a slight drop in temperature in the second tank which possesses a temperature range from 112°C to 130°C which has D-Sorbitol in it. This tank is represented as CS, copper encapsulation with D-Sorbitol as PCM. The final tank however possesses a healthy 90°C which is still the highest compared to the other two. This tank is represented as CP, copper encapsulation with paraffin wax as PCM

3.4. Comparison between ANSYS solutions and experimental values – Brass encapsulation

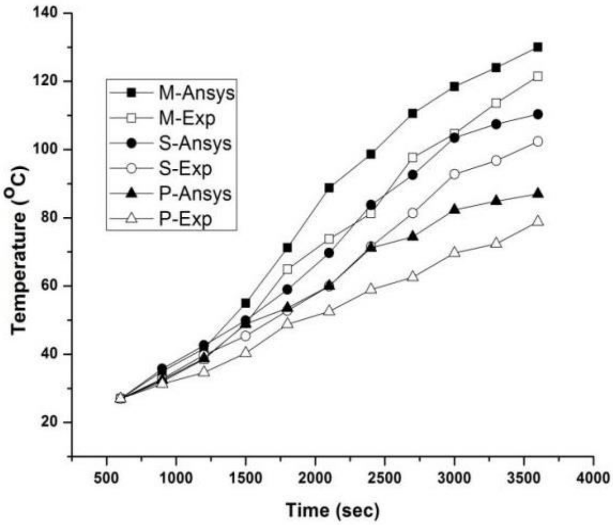

Figure 6. Comparison in brass encapsulation.

The figure 6 represents the comparison of temperature distribution when brass encapsulation filled in all tanks. M represents D-mannitol, S represents D-sorbitol, and P represents Paraffin wax. The analysis of D-Mannitol shows that the both Ansys and experimental values tend to follow the same curve with Ansys heading slightly. Although a small variation in the curve is seen exactly after 1800 seconds. The value obtained from the software which has a slightly larger value compared with experimental one. The software value after 1 hour shows it is at 130°C where as the experimental value after 1 hour is 120°C. The analysis of D-sorbitol shows that at the begining, both are started at the same temperature (27°C) which depicts the room temperature. The end temperature of Ansys software after an hour is approximately 110°C. The analysis of paraffin wax shows that the end temperature of Ansys software after an hour is approximately 85°C which is much higher than experimental ones (70°C).

3.5. Comparison between ANSYS solutions and experimental values – Aluminium encapsulation

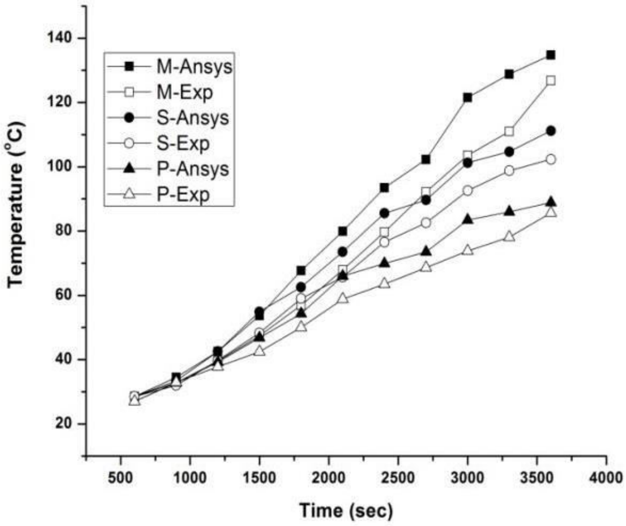

Figure 7. Comparison in alminium encapsulation.

The figure 7 represents the comparison of temperature distribution when alumium encapsulation filled in all tanks. The analysis of D-Mannitol shows that both (Analysis tool and experimental) are started at the same temperature (28°C) which depicts the room temperature. Then both follow a parallel curve where software solution has a higher value than the experimental ones. The end temperature values are approximately 135°C and 125°C in ansys solution and experimental solution respectively. The analysis of D-sorbitol shows that both curves follow the parallel curve where ansys solution has a temperature of 115°C (approximately) compared with experimental value around 102°C. The Ansys temperature is comparatively higher than the end temperature of the brass with D-Sorbitol. Similarly the paraffin wax also follows the same pattern.

3.6. Comparison between ANSYS solutions and experimental values – Copper encapsulation

The temperature distribution with the use of copper encapsulated balls is shown in the figure 8. The ansys solution temperature is comparatively higher than the end temperature of the brass encapsulation and aluminium encapsulation. The analysis of D-sorbitol shows the both experimental and ansys values are varying parallel. The analysis of paraffin wax shows that the end temperature of around 90°C which is higher than experimental values of 85°C.

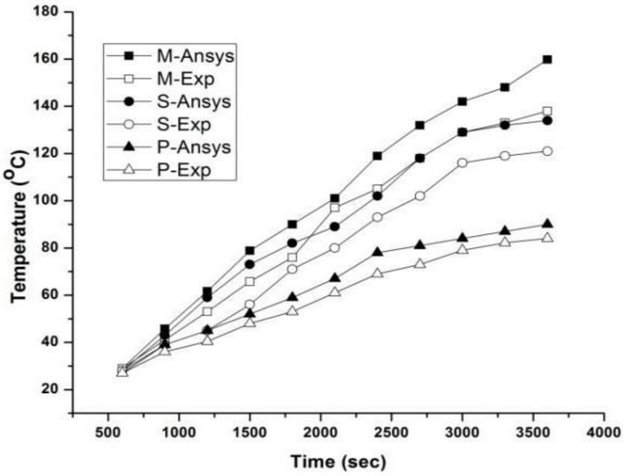

Figure 8. Comparison in copper encapsulation.

Based on the temperatures the overall system efficiency was calculated and the results are showed that the copper encapsulated D-mannitol as PCM has the highest efficiency when compared to other two PCMs namely D-sorbitol and paraffin wax.

4. Conclusion

A detailed survey has been done on the use of solar energy to meet the thermal requirement of different purposes. From detailed study designing of the apparatus according to the standard conditions and specifications are done to increase the efficiency and to reduce the heat loss. Thermal analysis is done on the model and the results were analysed and compared. The results showed that the copper encapsulation with D-Mannitol as a PCM gave the better result compared to other two (Aluminium and Brass). Similarly, D-Mannitol has the highest hidden (latent) heat of fusion compared to the other two; hence the temperature distribution of copper encapsulated with D-Mannitol as PCM reaches a maximum temperature.

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