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# Thermal Effects of Using Various Metal Disks inside Liquid-PCM Thermal Storage System

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ABSTRACT: The storage of thermal energy in liquid-phase change material is one of the most promising renewable energy technologies. In this work, a developed liquid tank as a thermal energy storage by using phase change material (PCM) was analysed, fabricated and tested. The developed model was fitted with various types of metal disks (smooth or perforated) inside the PCM cylindrical container. Experimental test rig was constructed and tested at various values of the water flow rate and inlet water temperatures. Numerical analysis was carried out with ANSYS Fluent software to simulate the system. The thermal effect of using smooth and perforated metal disks was investigated experimentally and numerically. A good agreement between the experimental and theoretical results was observed. Results indicated that the smooth disk could satisfy decrease the melting time of the PCM in the charging period. The influence of disk diameter which was investigated showed that system with 7.5 cm disk diameter produces the best thermal response. It was also found that the optimum flow rate for the current model is about 0.03 L/s. The recommended use of the metal smooth disk inside liquid-PCM containers will add a significant mean to gain more heat in large-scale systems.

KEYWORDS: smooth disks, perforated disks, ANSYS, thermal energy storage, water tank, heat transfer.

## INTRODUCTION

Many thermal applications have used thermal energy storage for recovering the excess thermal energy. Several researchers have described the potential benefit of including this type of systems for accounting the temporal variations during the thermal demand [1-3]. Using a phase change material (PCM) inside the liquid heat storage system makes these materials act as a heat exchanger. The PCM material inside this tank absorbs a lot of heat from the fluid in the tank during a phase change process. This process ends when the fluid temperature decreases. A phase change from the solid state to the liquid state (melting) is known as the charge process with a heat gain; whereas the process changes from a liquid state to a solid-state (freezing) is known as the discharge process with a PCM heat loss[4-6].

Zhang et al. investigated Latent Thermal Energy Storage (LTES) unit performance [1]. The researchers carried out experiments using the spiral tube-embedded LTES tank, which contains the composite of paraffin as a PCM. They determined the temperature distribution in the PCM for both charging and discharging processes. Results indicated that the charging process, the upper region of the PCM showed a faster temperature increase compared to the lower region. They showed that this variation is attributed to the effect of the natural convection reaction of the PCM which dominates the charging procedure.

Rahman, developed a simple mathematical model for analysing the storage tank which contains a stationary fluid along with the cold and hot heat exchanger coils [7]. The model was used in the screening process to determine the tank size and operational configurations for a specified power generation unit in the Combined Cooling Heating and Power (CCHP) systems. This computational model was compared to the detailed model which considers the variations noted in the thermo-physical properties and the effects of the heat loss and thermal destratification process than the ambient. They showed that this simplified model offers an accurate temperature prediction used for designing the stratified tank system in the CCHP application.

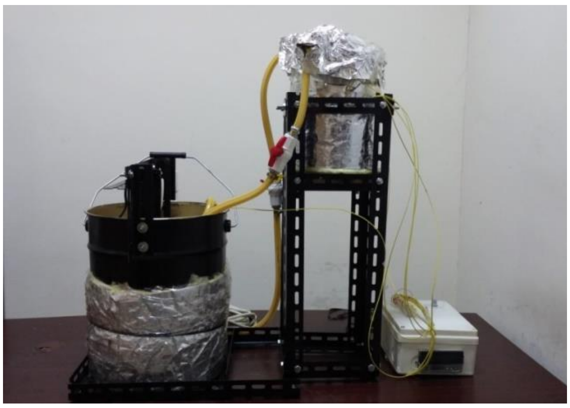
Wang, et al. showed that a Thermal Energy Storage (TES) system with PCM could be used for the combined power and heat plants in order to improve the ability of the electricity regulation process and maintaining stable heat supply, simultaneously [8]. The author investigated the thermocline in TES with the help of the paraffin wax-packed bed (encapsulated) as a heat storage media, while water was used as a heat transfer fluid. It was seen that the performance of the cyclic operations is dependent on the completion status of the charging/discharging processes. Results indicated the significance and benefits of using the TES technology, along with the advances noted in the auxiliary system.

According to Lu et al., a low-temperature thermal storage system can be used in residential complexes for controlling their energy supply [9]. The researchers proposed a novel storage system included in the modular units. They used hydrated salt as a PCM, which is packed in the spherical capsules. Phase changes occurring in the PCM balls were assessed using the numerical simulation technique. Their results indicated that these PCM balls in different positions show a varying change rate. During the charging process, the researchers noted the thermal stratification process after the middle region of this unit, whereas the lower region of the PCM balls requires 30% longer time compared to the upper layers to melt completely. During the discharging process, they also noted that the thermal stratification is very obvious during the middle region.

Nagarajana et al. analysed the effect of including the PCM, which was encapsulated in the spherical capsules in the hot water storage tank [10]. They studied the enhancements in stratification that would occur in the charging process. Their experimental results indicated that a lower charging time is needed in the sensible TES system with the PCM capsules. These authors concluded that the difference in the charging time decreases significantly with the increase in the heat transfer fluid inlet temperature.

## EXPERIMENTAL WORK

A test rig was constructed and tested during this study. The main component parts of the liquid-PCM TES under investigation is shown in Figure 1. A 18 L cylindrical metal tank (300 mm wide and 360 mm height) was used, to maintain the water in a closed-loop (charging or discharging) connected to a water pump and contains an electrical heater inside it. The water pump was used to raise the water from the reservoir to a Pyrex cylinder. The maximal flow rate (Q) of the water pump was about 0.12 L/s. **A** water heater of 1000W was used to heat the temperature of the water during the charging process. The heater was connected to a thermostat in order to control the water temperature. A graduated cylinder (5 L; 200 mm diameter and 290 mm height) was used as a liquid water tank. This cylinder contained another smaller cylinder filled with the PCM and made from glass and could withstand high temperatures. The outer cylinder was filled with water until the desired height was reached.



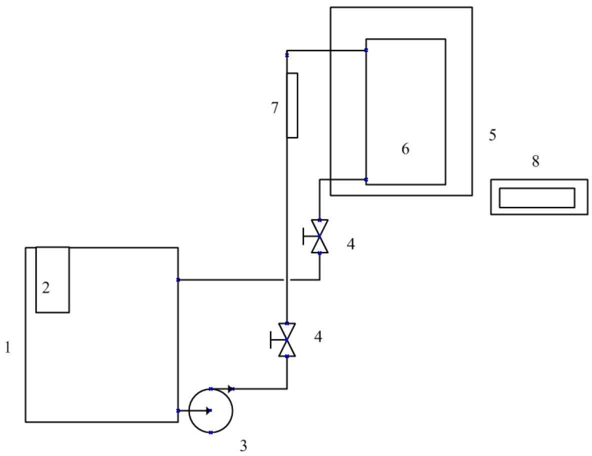



**Figure 1.** Liquid-PCM Thermal Energy Storage System:

1-hot water tank, 2-heater, 3-pump, 4-valves, 5-charging tank, 6- PCM storage tank, 7- flow meter, 8-temperature recorder.

## NUMERICAL SIMULATIONS

In the present work, the CFD package code of ANSYS Fluent was implemented. The Ansys fluent was seen to be popularly used for modelling the fluid flow and heat transfers in various complex geometries. The fluent solver relied on a finite volume discretization in space. Different mesh geometries were generated in 2-D, (triangular or quadrilateral), or 3-D (tetrahedral, hexahedral, pyramidal, polyhedral or wedge) [11, 12].

PHYSICAL MODEL

Figure **2** presents the first domain of interest that includes a 3D storage tank with no inserts.

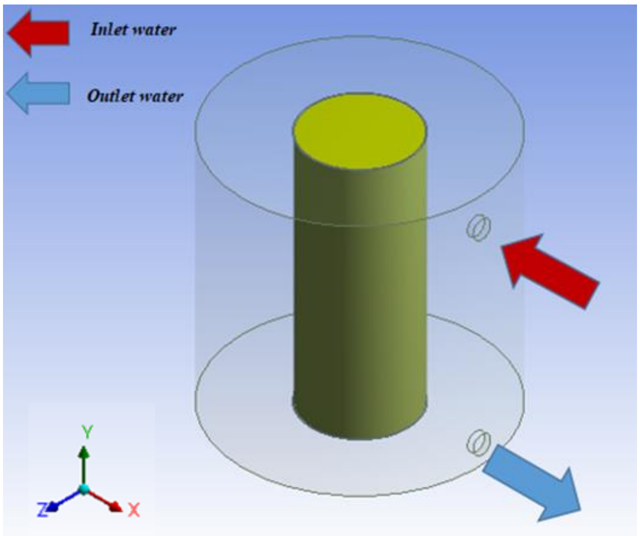



**Figure 2.** Water-PCM TES base model

Figure 3 presents the 2nd domain of interest, which includes five disks (2, 4 and 7.5 cm diameter) inserted in the PCM tank.

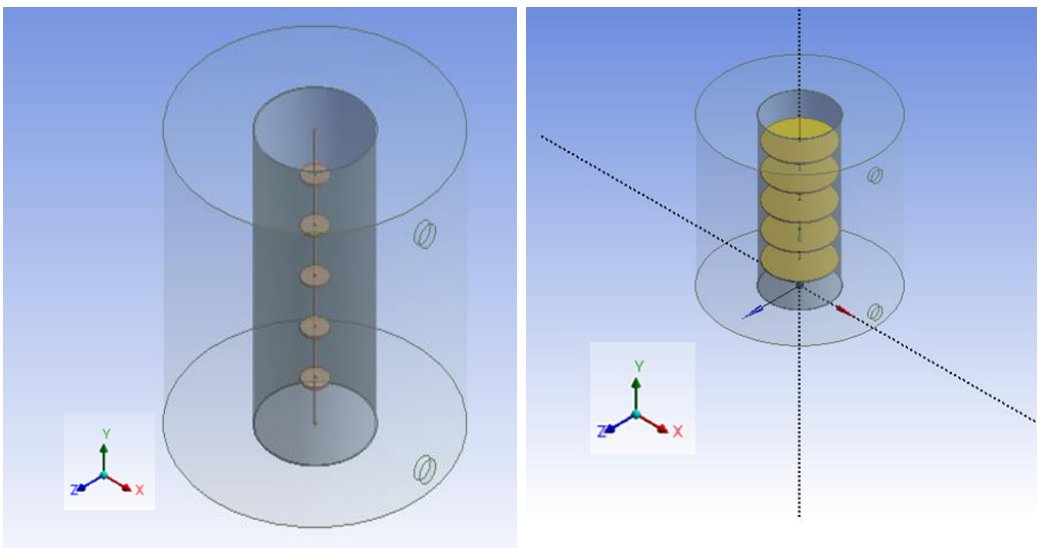



**Figure 3.** Water-PCM TES (with smooth disk) model

Figure 4 describes the 3rd domain, which includes five perforated disks inserted in the PCM tank.

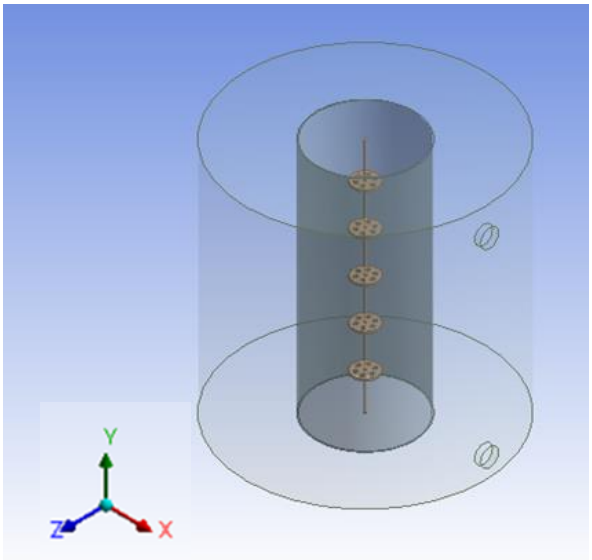



**Figure 4.** Water-PCM TES (with perforated disks) model.

Governing Equations

- Continuity Equation

$$\nabla . \vec{V} = 0 \qquad (1)$$

- Momentum Equation

The momentum equation in the mushy zone is[12]:

$$S = \frac{(1-\text{Ɓ})^2}{(\text{ß}^3 + \varepsilon)} A_{mush} (\vec{V} - \vec{V}_P) \qquad (2)$$

where:

Ɓ= liquid volume fraction.

$\varepsilon$= 0.001.

$\vec{V}$= velocity of solid.

$A_{mush}$= constant (mush zone).

- Energy Equation [12]

$$H = h + \Delta H \qquad (3)$$

where

$h = h_{ref} + \int_{T_{ref}}^{T} C_p d\,T$

$h_{ref}$= enthalpy (reference)

$T_{ref}$= temperature (reference)

$C_P$= constant pressure specific heat

The liquid fraction, Ɓ, can be defined as[12]

$$Ƀ=0 \qquad \text{if } T<T_{solidus}$$

$$Ƀ=1 \qquad \text{if } T>\boldsymbol{T_{liquidus}} \tag{4}$$

$$Ƀ=\frac{T-T_{solidus}}{T_{liquidus}-T_{solidus}} \qquad \text{if, } T_{solidus} < T < T_{liquidus}$$

$$\Delta H=ß.L \tag{5}$$

where:

$\Delta H$= latent heat (material)

For solidification /melting problems, the energy equation can be written as[12]

$$\frac{\boldsymbol{\delta}}{\boldsymbol{\delta t}}(\rho.H)+ \boldsymbol{\nabla}.(\rho.\, \vec{\boldsymbol{V}}.\, H) =\nabla.(k.\nabla T)+S \quad (6)$$

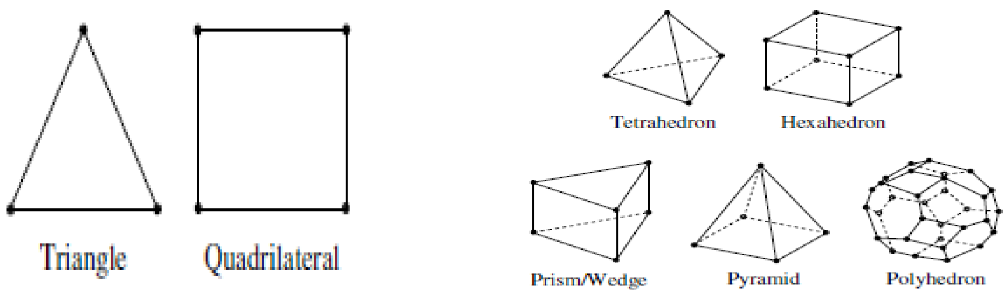
where:

$H$=enthalpy $\vec{V}$= velocity (fluid)

$\rho$=density $S$= term (heat source)

Grid Generation

The size of the divided control volume must be very small so that it could derive a numerical solution. An inappropriate mesh indicates unsatisfactory or inaccurate results. Thus, several ways of mesh quality were considered, which depend on the skewness and aspect ratio. Figure 5 presents 2 and 3 dimensions of the cell geometry [11].




a: 2-D b: 3-D

**Figure 5.** Types of cell geometries.

The initial and boundary conditions for the three models included the water in a domain of interest at zero time, which was assumed to be quiescent initially at the temperature of 30℃. The hot water used during the charging process was at the temperatures of 66.85, 76.85, and 86.85 ºC (340, 350 and 360 K), while the flow rates of the water were 0.0281, 0.0303, and 0.0505 L/s and the inlet elbow or diffuser was adiabatic.

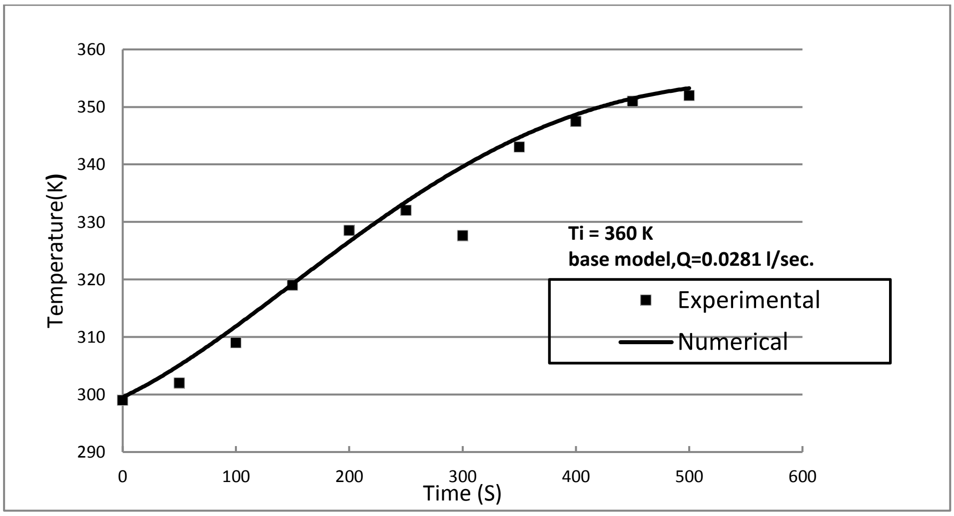
The current study used a pressure-based approach for solving the discretization equations for the stratified and chilled water storage tank having inlet geometries. This included the 2$^{nd}$-order upwind scheme.

RESULTS AND DISCUSSION

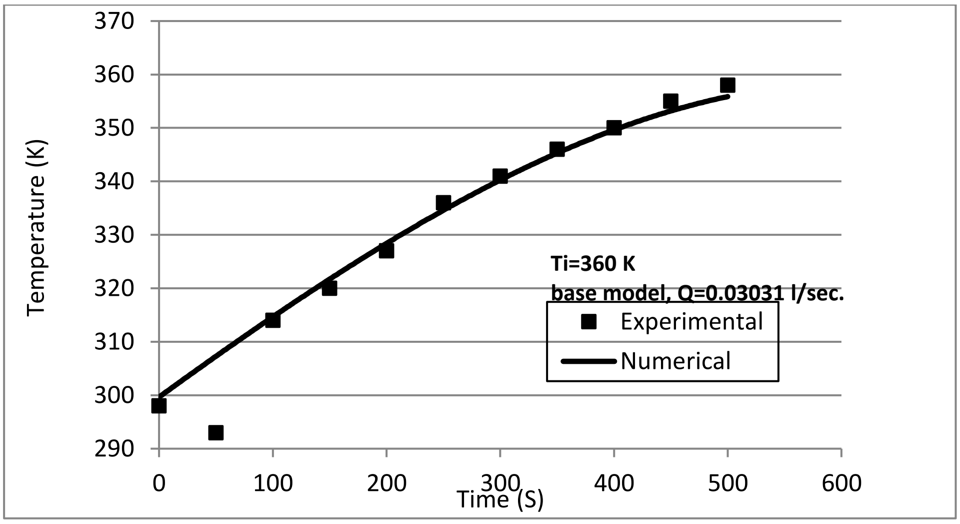
Validation

In the present study, the experimental and numerical results of the base water-PCM model with two enhanced were compared. The enhanced cases include the insertion of 5flat disks in a PCM tank. Second case includes insertion of a perforated disk in the inner water- PCM tank.

Figure 6 presents a comparison between experimental and numerical results for the base model. The temperature values in the experimental cases were lower as compared to those obtained by applying the numerical analysis, since an actual loss of heat seems to occur in the experimental tests, due to the efficiency of the tank insulation. The optimal water flow rate was seen to be 0.0281 L/s.




a

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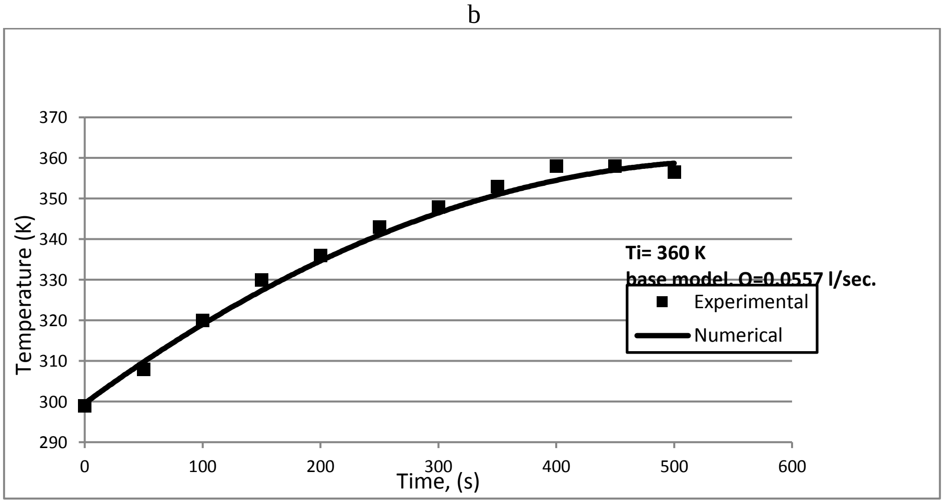


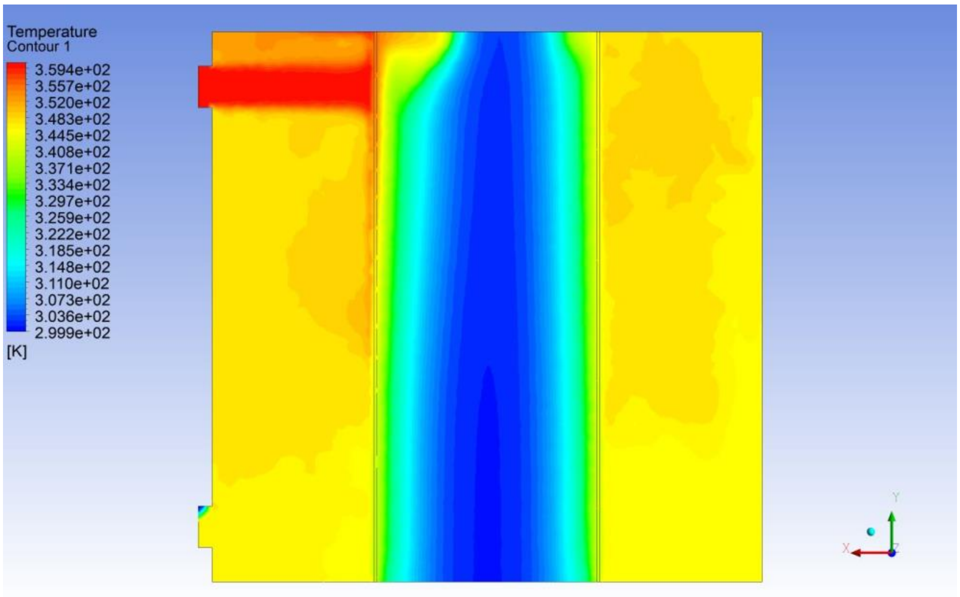
c

**Figure 6.** Comparison between experimental and numerical results for base model

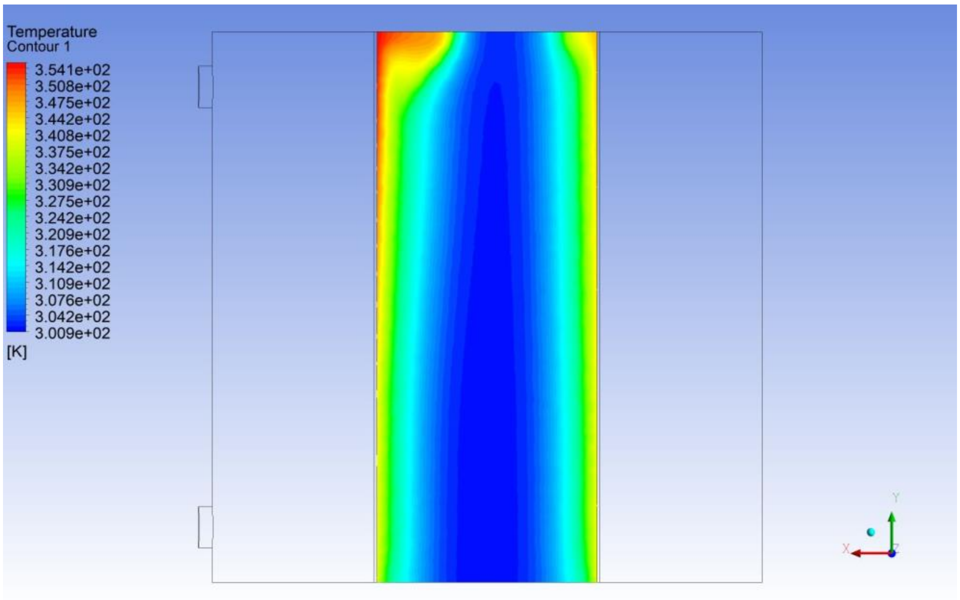
(a) Q=0.028l/sec, (b) Q=0.03031l/sec, (c) Q=0.0557 l/sec.

RESULTS

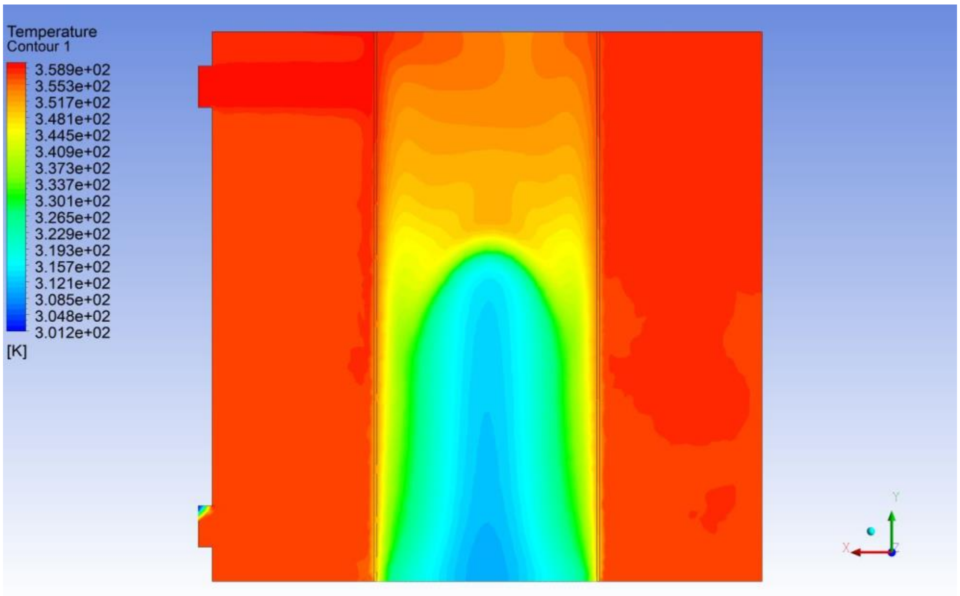
Figure 7 describes the temperature contours during the charging process for the base model at 0.0281 L/sec water flow rate.  It can be noticed that the temperature contours are non-uniform in the PCM material owing to its density variation and low thermal conductivity. The heat transfer due to conduction is predominant in this system, right from the initial step in the process until the initial phase change occurring in the PCM after melting. After that, conduction and convection processes take place inside the PCM. This investigation is also performed at water flow rates of 0.0303 and 0.0557 L/s as shown in Figure 7. It is noted that an increase in the water flow rate could increase the PCM temperature and hence the energy stored in the PCM.



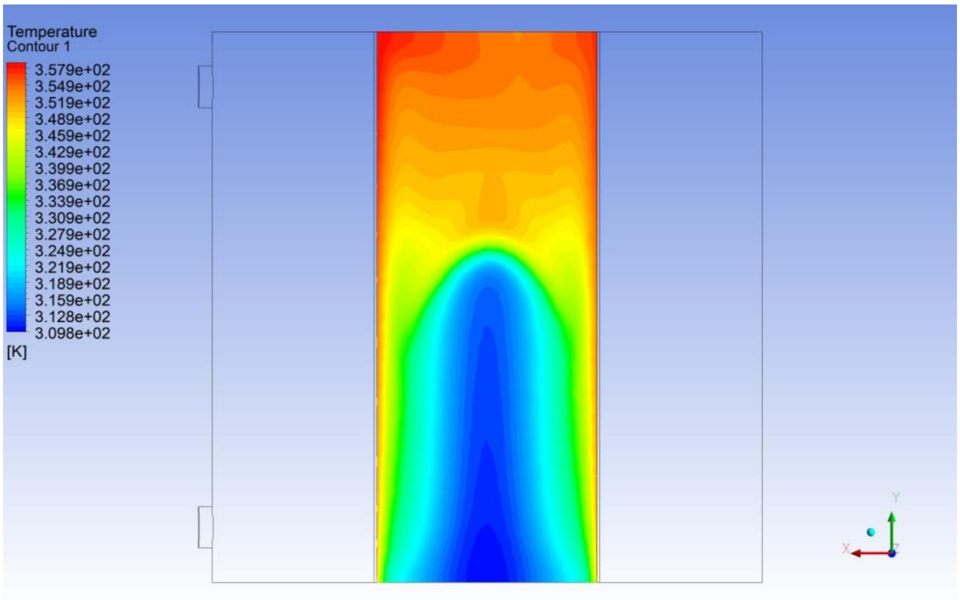

charging time= 150s



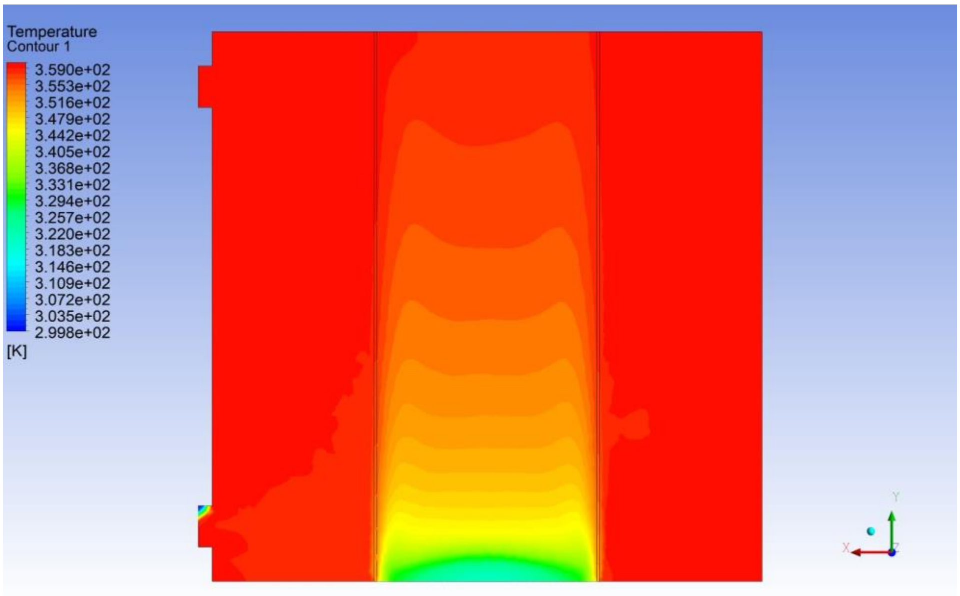

charging time= 200s



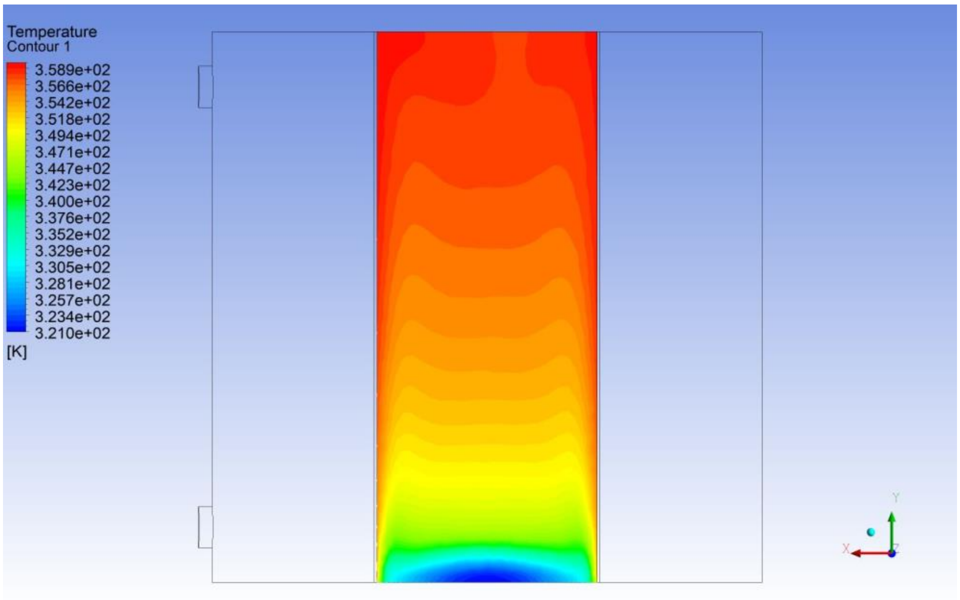

charging time= 250s



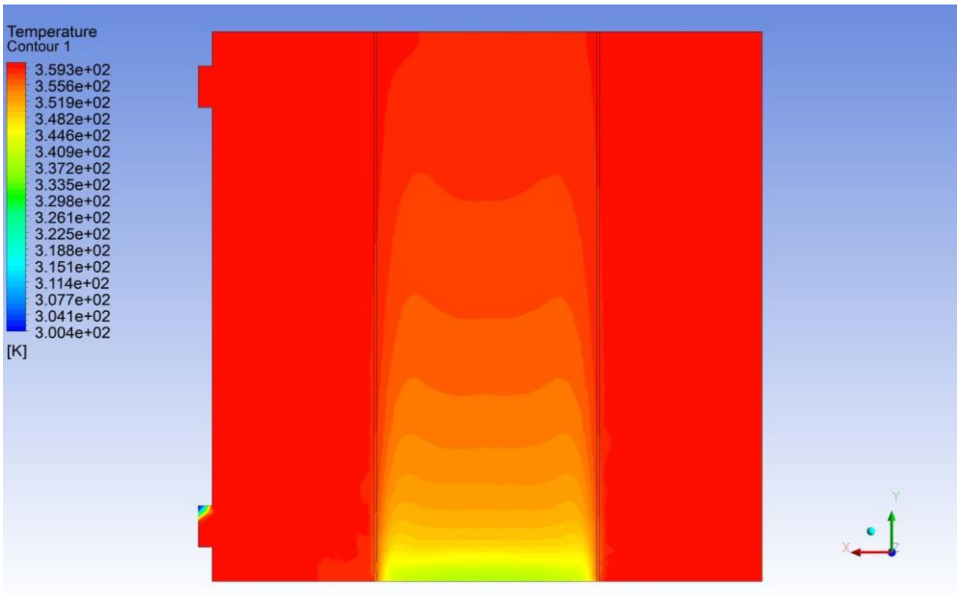

charging time= 300 s




charging time= 350s




charging time =450s




charging time= 500s

**Figure 7.** Temperature distribution inside base model of water-PCM TES.

Figure 8 presents the relationship between the liquid fractions of PCM with charging time. It can be seen that an increase in the water flow rate could cause a faster melting of the PCM. It was found that the optimum liquid value flow rate is about 0.03 L/sec for the base model under investigation.

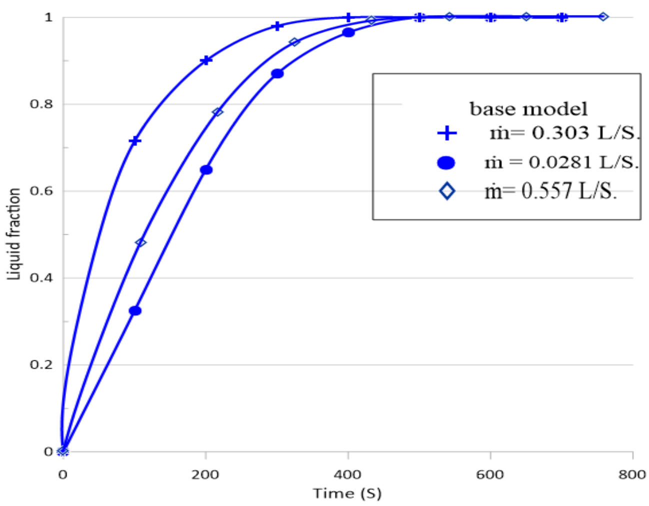



**Figure 8.** The relationship between the PCM liquid fraction and time of charging of a base model.

Figure 9 shows a comparison between transient temperatures for TES at the three models under investigation. It can be observed that the perforated disk model has no effects on the average temperature; however, the smooth disk model shows a slight effect on the exit transient temperature.

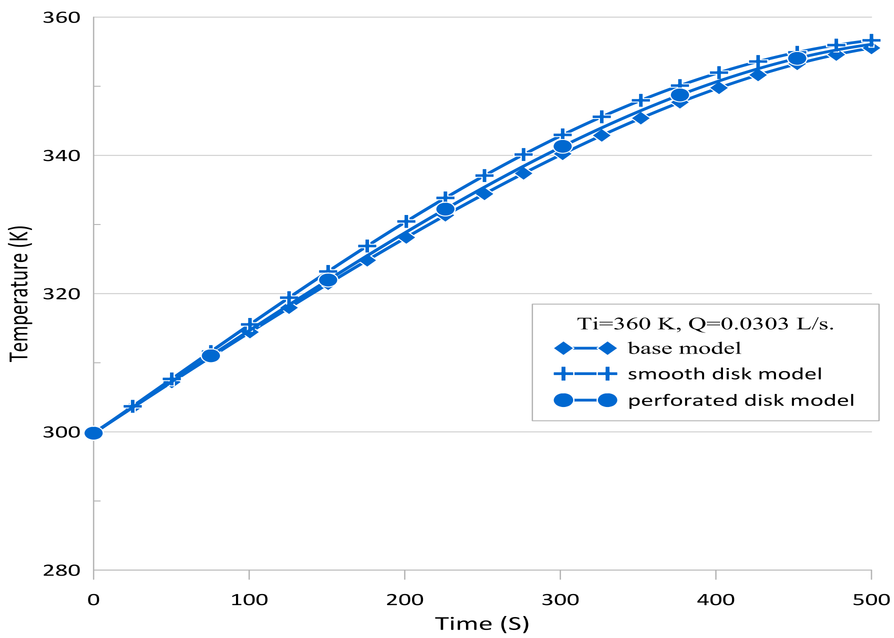



**Figure 9.** Temperature vs. time

Figure 10**Figure 1** indicates the impact of disk diameter over time on a TES system. It is clear that the diameters of 2 and 4 cm exhibit insignificant impact on the temperature, whilst the diameter of 7.5 indicates a clear increase in the temperature of the PCM from the other diameters.

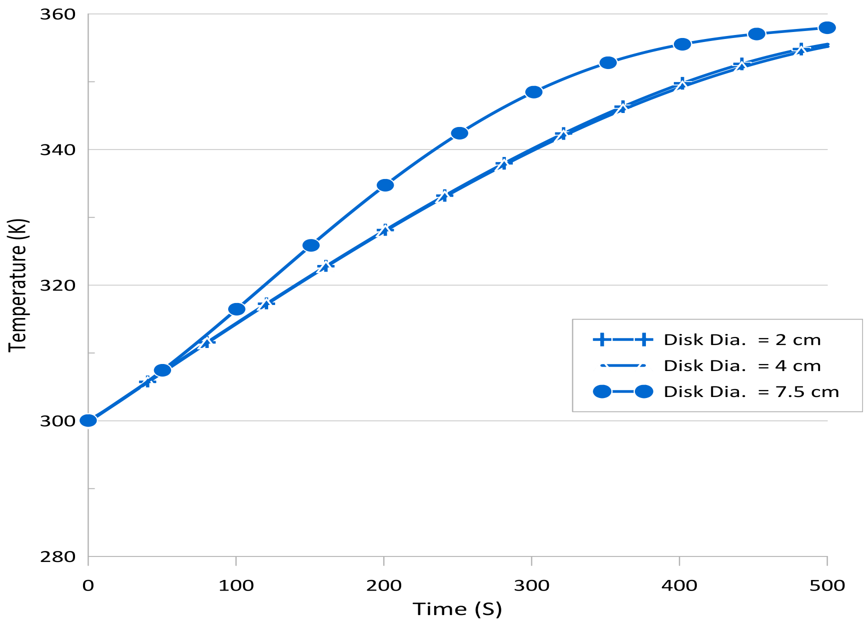



**Figure 11.** Effect of disk diameter.

## CONCLUSIONS

An experimental and numerical study of TES during charging process was carried out in the present work. A comparison between the experimental and numerical results which show a good agreement was adopted. Temperature of the PCM in the TES at different inlet water temperatures (340, 350 and 360K) was measured. Basic, smooth disk and perforated disks were studied with three values of water flow rates (0.0281, 0.0303 and 0.0557 L/s). It was noticed that an increase in the water flow rate could cause a faster melting of the PCM. It was found that the optimum liquid value flow rate is about 0.0303 L/sec. It could be concluded that the smooth disk gives better performance. The effect of the disk diameters investigating for smooth disk model reveals that the diameter of 7.5 cm causes an increase in the temperature of the PCM faster than other diameters which are considered as the impact of convection (natural) effect. It is recommended to test various types of solid material inside both PCM and liquid tanks. In addition, the double effect of using both sold materials and Nano-particles should be also tested inside Liquid-PCM containers.

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