UDC621
DOI: 10.15587/1729-4061.2022.268288

NUMERICAL ANALYSIS ON TEMPERATURE DISTRIBUTION AND MASS FRACTION OF AN EVACUATED TUBE USING PHASE-CHANGING

Ahmed Kareem Khudhair
Master of Science in Automated Manufacturing Engineering
Ministry of Higher Education and Scientific Research
Rusafa side, 52nd str., Baghdad, Iraq, 55509
E-mail: eng.ahmed.iiot@gmail.com

With the advancement of environmentally friendly power innovations and the utilization of phase changing materials in the upkeep of nuclear power, it was important to attempt to further develop the intensity move of stage evolving materials.

A 2D CFD recreation was performed to mimic the softening system of a phase Change material (PCM) which fills a round and hollow pit that incorporates warming sources. CFD model in light of the actual enthalpy equation was utilized to reenact the phase change of strong gallium and for the mathematical timing of the warming sources as per the working circumstances regarding the applied temperatures. Mathematical impact of warming sources, as well as limit conditions for heat move the attributes be analyzed exhaustively.

The Arrangement with balances upgrades heat move and further develops PCM liquefying time. The theory of heat spread in a fin is based on the fact that temperatures rise and fall with the length of the fin. Temperatures reach 316 K at a time of 300 seconds, which is 100 seconds less than when the fin is 7 mm shorter.

The best case for a fin length of 14 mm is the best case compared to the others.

Where has been utilized Fourfold warm blades encompass the intensity pipe in two lengths: 14 mm and 7 mm, with various thicknesses 1, 2, 3 mm and the estimation are mathematically assessed for a few explicit focuses situated inside the concentrated-on developments decide the impact of overhauling warming sources.

As a matter of fact, temperature development and fluid part work on highlights of the concentrated-on developments, which are round and hollow warming sources and finned warming hotspots for the applied temperature (Th=40 °C) the applied temperature

Keyword: Evacuated tube, Fin dimensions, Liquefying time, Phase Change Materials, Blades

Received date 14.10.2022
Accepted date 16.12.2022
Published date 30.12.2022

How to Cite: *Kareem Khudhair, A. (2022). Numerical analysis on temperature distribution and mass fraction of an evacuated tube using phase-changing. Eastern-European Journal of Enterprise Technologies, 6 (8 (120)), 84–90. doi: https://doi.org/10.15587/1729-4061.2022.268288*

1. Introduction

Work to upgrade the intensity transmission of stage changing materials was fundamental with the development of environmentally friendly power advances and the utilization of stage changing materials in the upkeep of nuclear power. The liquefying system of a phase change material (PCM) that fills a chamber molded chamber with warming sources was mimicked utilizing a 2D computational liquid elements (CFD) reproduction. To reproduce the stage progress of strong gallium and the mathematical timing of the warming sources as per the working conditions with regards to the applied temperatures, a CFD model was developed using the physical enthalpy formula. The properties of the geometry, including the influence of heating sources, and the boundary conditions for heat transmission are analyzed in depth. Using the abundant, year-round solar radiation, solar water heating (SWH) systems have long been recognized as a reliable, eco-friendly means of providing hot water for human use. There are limitations to this method, notably during periods of variable solar energy density. As a result, the SWH system usually needs a backup booster unit in order to function. Recent research has demonstrated that the influence of the booster unit may be reduced by using phase change material (PCM) as the energy storage medium in SWH systems.

This article explores the improvement of the thermal efficiency of solar collectors to benefit from them in renewable energies and reduce the use of fossil energy. Therefore, research devoted to the development, for the present time, of the use of fins with phase changing materials to spread heat well in the evacuated tube and thus increase the thermal efficiency of solar collectors.

2. Literature review and problem statement

The paper [1] runs two-dimensional computational fluid dynamics (CFD) simulations to model the melting of a phase change material (PCM) within a heated cylinder. The finned structure has been shown to increase heat transmission and decrease PCM melting time. For the purpose of calculating the impact of a redesign on the heating source, it measured temperature and liquid fraction at selected places within the configurations under consideration and performed a numerical assessment. Folded tube sun-based gatherer expands its effectiveness by 21.55 % compared to smooth cylinder and holds the activity temperature up to 40.55 °C. The fact that the varied fin dimensions were not compared and utilized in the previous research report was one of its most critical issues, but it was fixed in the current study. The paper [2] prompts lower execution in off-pick long periods of daylight using nuclear power stockpiling using CFD. Tritriacontane paraffin (C33H68), was incorporated inside the dual-PCM EUTC for direct intensity stockpiling on the framework

Copyright © 2022, Authors. This is an open access article under the Creative Commons CC BY license

and postponed arrival of intensity. Fins, which greatly boost heat transfer, were not addressed in this research work; instead, the twisted tube with varying dimensions was. The paper [3] combines heat move and capacity both in a solitary unit as well as the investigation of PCM as a heat move liquid (HTF). The impacts of sun powered energy and Stage Change Material (PCM) on the energy saving of a desiccant constrained air framework have been numerically inspected. Fins that aid in increasing thermal energy transfer to increase efficiency were not used to improve phase-changing materials used as thermal energy storage. The paper [4] investigates three plans of forced air systems (Type A, Type B, and Type C) at comparable encompassing circumstances. Admittance to eco-accommodating energy assets has become fundamental for fulfill the developing need for clean energy. Abuse of non-renewable energy sources, in actuality, applications has caused their quick exhaustion and quick environmental change. This study is a review of earlier studies that did not address the issue of using variable fin dimensions to boost thermal efficiency, as is the case with this study. The paper [5] shows sun-oriented energy to be a compelling other option and clean wellspring of energy for the general public. Sun-based gatherer can give 52.5–80.4 °C heated water from 9:00–19:00 under summer and August circumstances. N2 isotherm adsorption-desorption properties of MOF were explored. Results show that MOF has simultaneousness of micropores and mesopores with for the most part huge explicit surface district and pore volume. For the earlier studies, where fins were used to their full potential and phase-changing materials weren't a concern, the fins were analytically examined. The paper [6] assesses ecological effects of a trial Solar Absorption Air-Conditioning System in light of a Life-cycle Assessment. A Commercial Air Conditioning System that utilizes power from non-renewable energy sources was likewise assessed. The study examines a statistical analysis of locations for solar radiation. The paper [7] accomplish for the petroleum derivative exhaustion and ecotoxicity influence classifications, a lessening of 85 % and 20 %. Cooling frameworks address the biggest power shopper in private, business and modern structures. Two unique frameworks, variable refrigerant stream and chillers, were examined in two urban communities in Brazil. The study looks at how solar energy may be used to produce electricity, and the research article that is being presented discusses how variable-dimensional fins can make it easier to acquire thermal energy. The paper [8] presents a financial examination of the coordinated utilization of sun powered photovoltaic and cooling frameworks. This research article analyzes a study on how much thermal energy should be used to produce thermal energy. The paper [9] expand proposed framework lessens the blower work by 34 % and the COP by 4.59 % compared with the customary cooling framework. A survey on sunlight based controlled strong desiccant – fume pressure half-and-half cooling framework has been completed. The paper [10] conduct on the performance of a hybrid solar PV-grid powered air conditioner for daytime office cooling in hot humid climates with a case study in Kumasi city, Ghana. It was found that the strong parching coordinated mixture cooling frameworks are great than the customary fume pressure cooling.

A review of earlier studies did not address the issue of using variable fin dimensions to boost thermal efficiency, or theses studies examine a statistical analysis of locations for solar radiation, or it looks at how solar energy may be used to produce electricity, or how variable-dimensional fins can make it easier to acquire thermal energy.

Whereas, the main problem that was discovered in the previous research, which will be developed, is to follow the methodology of changing the dimensions of the fins that help the transmission of thermal energy.

3. The aim and objectives of the study

The aim of this research paper is to solve the problem of changing the dimensions of the fins, which is a problem that has not been addressed in previous research. Where a thermal collector was developed using phase changing materials, and the heat absorption tubes were developed by adding fins of variable dimensions to obtain better results in the transfer of thermal energy.

It is expected to obtain a transfer of thermal energy through phase change materials using fins, which in turn increases the thermal efficiency of the thermal collector.

To achieve this aim, the following objectives are accomplished:

– to analyze effect of fin thickness on temperature distribution and mass fraction of PCM;

– to analyze effect of fin length on temperature distribution and mass fraction of PCM;

– to validate the model.

4. Materials and methods

4. 1. Object and hypothesis of the study

CFD model in light of the actual enthalpy equation was utilized to reenact the stage change of strong gallium and for the mathematical timing of the warming sources as per the working circumstances with regards to the applied temperatures. Mathematical impact of warming sources, as well as limit conditions for heat move the attributes are analyzed exhaustively.

The simulation of the thermal optimization model by forced heat transfer requires a design engineering program, the model was designed using Solidworks software with dimensions of an outer glass tube 160 mm and an inner glass tube of 20 mm. The thickness of the fins used are variable from 1 mm to 3 mm with a change of 1 mm for each case, as for the length of the fin, it changes in two cases, once 7 mm and another 14 mm, as shown in the following Fig. 1.

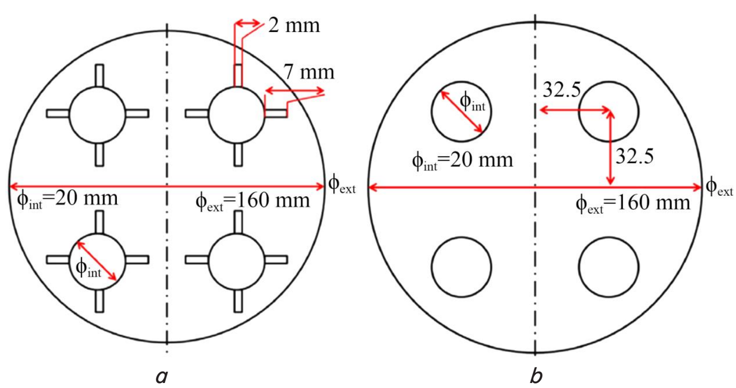


Fig. 1. Geometry dimension: *a* – fins; *b* – holes [1]

After completing the model design process and starting the simulation using ANSYS CFD program, an engineering program simulates heat and fluid flow systems. Where a suitable mesh must be made for obtaining accurate results that can be compared with practical applications, where the mesh reliability is increased and the mesh is increased until a stable result is reached as shown in Table 1. A hexahedral grid was used with a number of elements up to 940345 since the maximum temperature in this case was stable and its value was 317.46 K, as shown in Fig. 2.

Table 1

Mesh independency

Case	Nodes	Element	Maximum temperature (K)
1	263497	212705	318.35
2	541298	521308	317.78
3	780442	734345	317.47
4	944052	940345	317.46

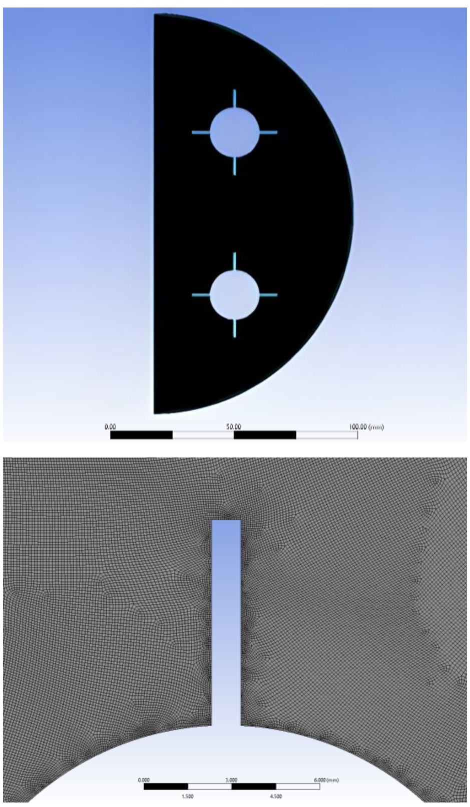


Fig. 2. Geometry mesh

The simulation was carried out using ANSYS19.1 CFD program, which is a program dedicated to studying fluids and their kinetic and thermal effects. The solidification and melting model were used, which proved its effectiveness in simulating fluid mass fraction and its compatibility with reality. Where all the ruling conditions and materials used from the previous research were used, with the addition of nanomaterial concentrations to them, as shown in Table 2.

Two-layered stream models of intensity move during the dissolving system of PCM inside a round and hollow depression were represented by the general following presumptions:

– the softening of the PCM will be symmetric;

– the thermophysical properties of the PCM are consistent aside from the thickness variety with temperature, which is answerable for the age of warm lightness, for utilizing the Boussinesq estimation;

– the liquid is Newtonian and incompressible;

– the thick dissemination is unimportant;

– smooth movement in the dissolve is laminar and two-layered;

– the energy and Navier-Stirs up conditions were utilized to tackle the transient hydrodynamic and warm fields.

The boundary conditions are shown in Fig. 3.

Table 2

Thermo-physical properties of PCM (pure gallium) and HTF [1]

Density (liquid)	6093 kg/m^3
Reference density	6095 kg/m^3
Reference temperature	29.78 °C
Thermal expansion coefficient of liquid	0.00012 1/K
Thermal conductivity	32 W/K·m
Melting temperature	29.78 1/°C
Latent heat of fusion	80160 J/kg
Specific heat capacity	381.5 J/kg
Dynamic viscosity	0.00181 kg/m·s
Prandtl number	0.0216

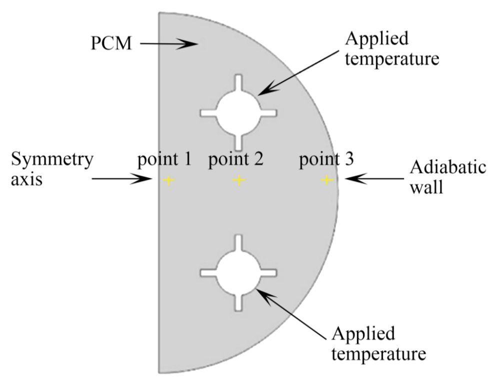


Fig. 3. Boundary conditions

Consequently, the subsequent overseeing conditions with thought of gravity impact can be composed as follows considering the previous presumptions.

The simulation of fins with small dimensions and phase-changing materials requires a complex simulation process.

4. 2. Governing equations

Continuity equation:

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

Momentum equation:

$$\frac{\partial \vec{V}}{\partial t} + \vec{V} \cdot \nabla \vec{V} = \frac{1}{\rho}\left(-\nabla P + \mu \nabla^2 \vec{V} + \rho \vec{g} \beta \left(T - T_{ref}\right)\right) + S_m. \qquad (2)$$

Energy equation:

$$\frac{\partial h_{sens}}{\partial t} + \frac{\partial h_{lat}}{\partial t} + \nabla \cdot \left(\vec{V} h_{sens}\right) = \nabla \cdot \left(\frac{k}{\rho c_p} \nabla h_{sens}\right). \qquad (3)$$

The all-out enthalpy was acquired by summation of the reasonable and inert intensity:

$$h_{tot} = h_{sens} + h_{lat}. \quad (4)$$

The enthalpy porosity strategy was utilized to reproduce the freezing system of water. The reasonable and idle intensity:

$$h_{sens} = h_{fer} + \int_{T_{ref}}^{T} c_p \mathrm{d}T = h_{ref} + c_p \int_{T_{ref}}^{T} \mathrm{d}T,$$

$$h_{lat} = \sum_{i=1}^{n} \lambda_i h_{sf}, \quad (5)$$

where ρ, V and P are address thickness, speed and tension of liquid stream, individually. The condition for thickness variety is introduced as ρ=1/(β(T–T_l)+1), Boussinesq presumption. Additionally, μ, β and T_"ref" are shown thickness, warm development and reference temperature, individually. What's more, S_m is energy source that add to force condition and characterize as:

$$S_m = -A_m \frac{(1-\gamma)}{(\gamma^3+\varepsilon)} (u - \nu_p). \quad (6)$$

Above condition, in light of enthalpy-porosity strategy, decides the separation among fluid and strong periods of PCM. A_m is soft zone coefficient, as a consistent number, and its sum is for the most part between 10^4 to 10^7. v_p is strong speed because of solids extraction and ∊ is a steady modest number of 0.001 for forestall zero division. Besides, γ characterized as fluid part and portrayed as:

$$\gamma = \begin{cases} 0 & T \prec T_s, \\ \dfrac{T-T_s}{1-T_s} & T_5 \le T \le T_1, \\ 1 & T \succ T_1. \end{cases} \quad (7)$$

The corrugated tube hydraulic diameter defined as:

$$D_h = (D_b + D_{en})/2, \quad (8)$$

where D_b and D_{en} are bore and envelope distance across of creased tube, individually. Moreover, the Reynolds number determined from following condition:

$$\mathrm{Re} = (\rho u D_h)/\mu. \quad (9)$$

The helpful intensity rate moved to HTF characterized as:

$$\dot{Q}_{us} = \dot{m}_p (T_{out} - T_{in}). \quad (10)$$

These set of equations are obtained from the simulation program's website.

5. Results of effect of fins characteristics

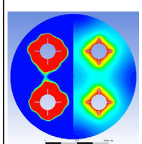
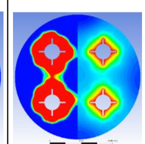
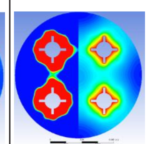
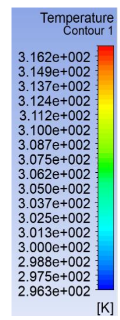
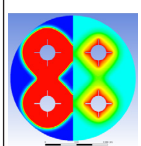
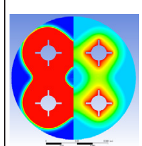
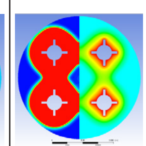
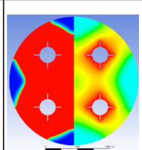
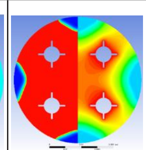
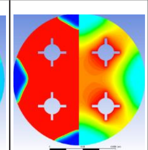
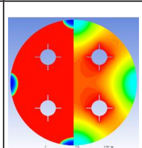
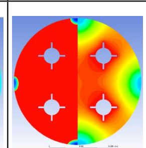
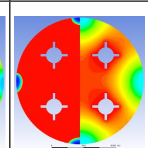
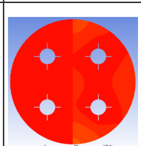
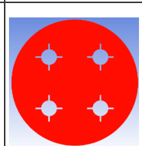
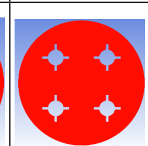
5. 1. Effect of fin thickness on temperature distribution and mass fraction

The process of improving the solubility of phase-changing materials is one of the basic issues related to heat transfer by convection, so changing the thickness of the fin increases the area of transmission of thermal energy and thus increases the amount of heat distributed to phase-changing materials.

Where we notice from Table 3 that the temperature value increases gradually and greater during the time than the second case, although the thickness of the fin is 2 mm. Moreover, this improvement is not observed in the thickness of the fin 3 mm. Large, but it impedes the fluid movement from the phase changing material and thus impedes the transfer of heat to successive layers during time. As for the mass fraction, it is noted that the value of the fracture and the fluid diffusion of the phase changer material is greater in the case where the thickness of the fin is 2 mm, which is the best case compared to the remaining cases, as shown in Table 3.

Table 3

Temperature and mass fraction contour through time

Time (s)	Fin thickness 1 mm	Fin thickness 2 mm	Fin thickness 3 mm	
5				
250				
500				
750				
1000				

In order to verify the validity of the theory, certain points mentioned previously were taken to obtain a chart showing temperatures over time in these known points. Whereas through Fig. 4, which represents the first point, we note the speed of heat spread in the case where the thickness of the fin is 2 mm much faster compared to the thickness The other, where temperatures reached 316 K at a time of 380 seconds, which is 40 seconds less than the thickness of the fin 1 mm. In Fig. 5, which represents the second point, it is noted that the difference is the same and that the thickness of 2 mm is the best case compared to the remaining cases, and the same is noted in Fig. 6.

As for Fig. 7–9, which represent the mass fraction of the phase-changing material through the three points. It is noticed that the case in which the thickness of the fin is 2 mm, in which the melting of the phase-changing material is faster than the rest of the cases.

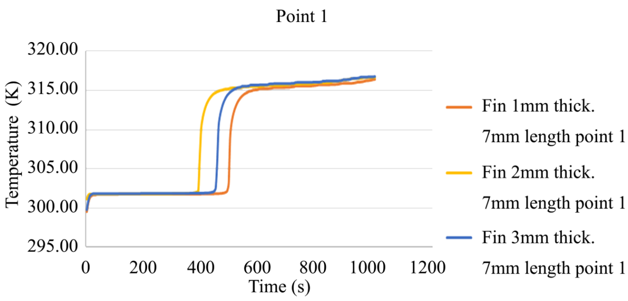


Fig. 4. Temperature distribution at point 1 with deferent thickness of fins

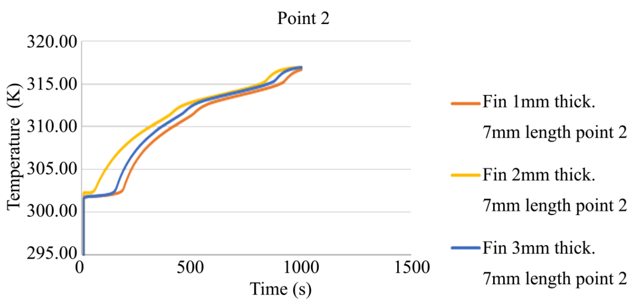


Fig. 5. Temperature distribution at point 2 with deferent thickness of fins

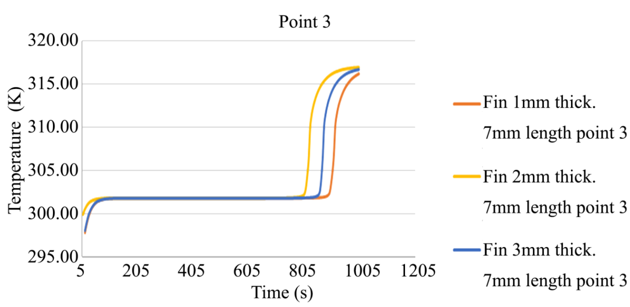


Fig. 6. Temperature distribution at point 3 with deferent thickness of fins

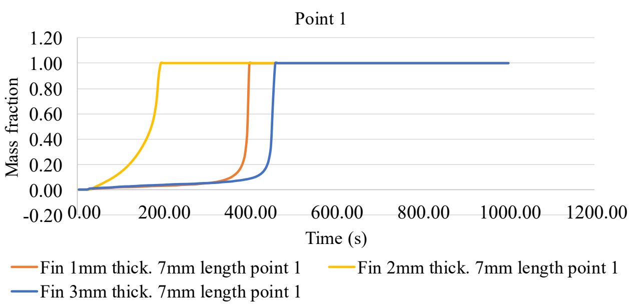


Fig. 7. Mass fraction distribution at point 1 with deferent thickness of fins

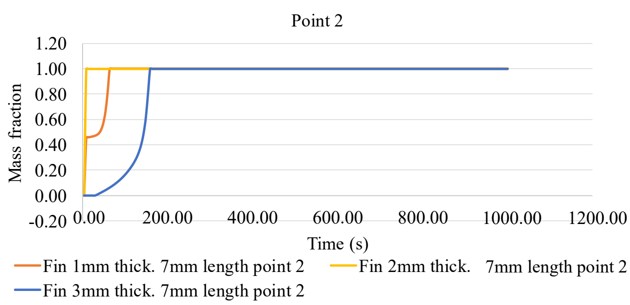


Fig. 8. Mass fraction distribution at point 2 with deferent thickness of fins

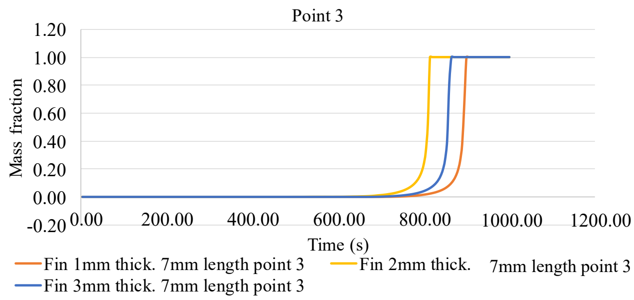


Fig. 9. Mass fraction distribution at point 3 with deferent thickness of fins

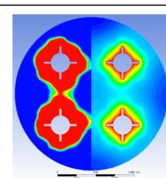
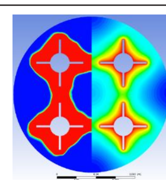
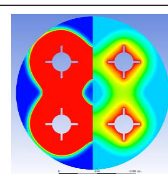
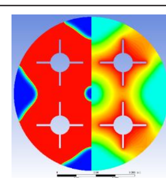
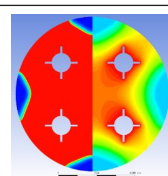
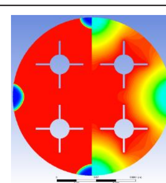
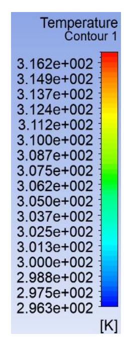
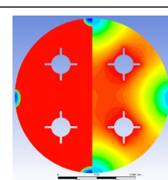
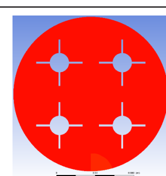
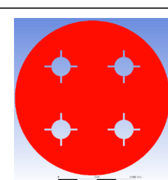
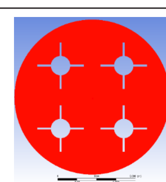
In point 1, the time of complete eruption is at the time of 200 s. As for at point 2, the time is 5 s to the proximity of the point to the heat source. As for point 3, the time is 780 s.

5. 2. Effect of fin length on temperature distribution and mass fraction

The effect of increasing the length of the fins is not limited to increasing the surface area of transmission, but also helps in the spread of heat transfer areas and its delivery to multiple places in a way. Through Table 4, which shows temperatures over time with different fin lengths, it is noted that the longer the fins increase, the higher the temperature value and its spread, and thus increases the solubility of phase-changing materials significantly.

Table 4

Temperature and mass fraction contour through time

Time (s)	Fin length 7 mm	Fin length 14 mm	
5			
250			
500			
750			
1000			

Where the case in which the length of the fins is 14 mm reached to complete melting in a time of 750 seconds, while in the other case it did not reach this stage at the same time.

In order to verify the validity of the theory, certain points mentioned previously were taken to obtain a chart showing temperatures over time in these known points. Whereas through Fig. 10, which represents the first point, note the speed of heat spread in the case where the length of the fin is 14 mm much faster compared to the length The other, where temperatures reached 316 K at a time of 300 seconds, which is 100 seconds less than the length of the fin 7 mm. In Fig. 11, which represents the second point, it is noted that the difference is the same and that the length of 14 mm is the best case compared to the remaining cases, and the same is noted in Fig. 12.

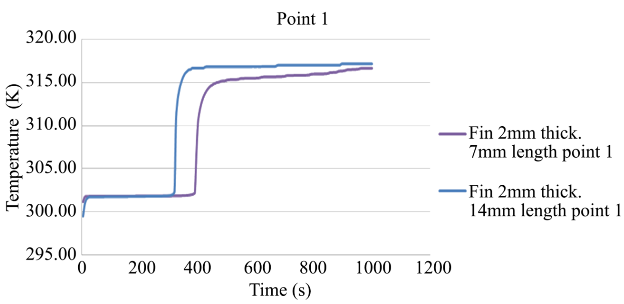


Fig. 10. Temperature distribution at point 1 with deferent length of fins

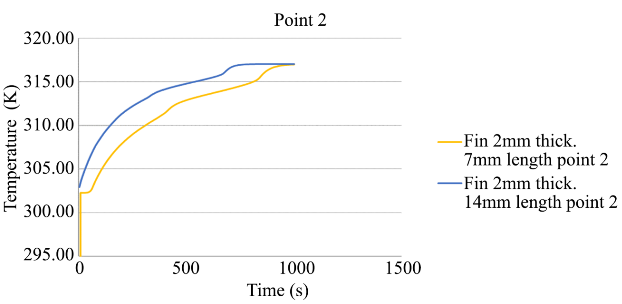


Fig. 11. Temperature distribution at point 2 with deferent length of fins

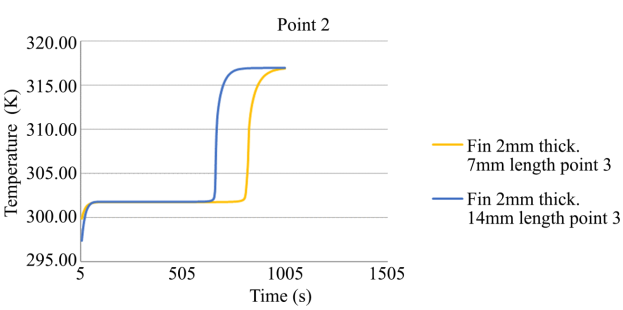


Fig. 12. Temperature distribution at point 3 with deferent length of fins

Which represent the mass fraction of the phase-changing material through the three points. It is noticed that the case in which the length of the fin is 14 mm, in which the melting of the phase-changing material is faster than the rest of the cases. In point 1, the time of complete eruption is at the time of 170 s. As for at point 2, the time is 5 s to the proximity of the point to the heat source. As for point 3, the time is 630 s.

5. 3. Validate the model

The comparison process was carried out on the base case of the previous research, from which the concept of optimization started by changing the dimensions of the fins. Where a case compared with the previous research was at the expense of breaking the mass for point 12, which is located under the fin [1]. The use of fins reduced the melting time. It was discovered that utilizing a heating source configuration with fins, it takes 2 minutes to equalize the applied temperature, compared to 4 minutes when using a cylindrical heating source. The same data, dimensions and conditions governing the case were made to extract the mass fraction value and compare it with the previous research paper as shown in Fig. 13.

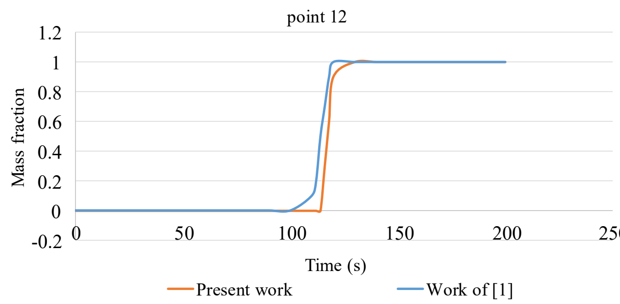


Fig. 13. Liquid fraction with time validation between present work and [1]

Through the previous Fig. 13 shows the percentage of convergence between the previous research paper and the work that was done. The error rate was 6 %, which is very acceptable.

6. Discussion of effect of fins characteristics

In Fig. 4–9 and Table 3 the value of the fracture and fluid diffusion of the phase changer material is greater in the case where the thickness of the fin is 2 mm, which is the best case compared to the remaining cases. Large, but it impedes fluid movement from the phase changing material and thus impedes transfer of heat to successive layers. The theory of heat spread in a fin is based on the fact that temperatures rise and fall with the length of the fin. Temperatures reach 316 K at a time of 300 seconds, which is 100 seconds less than when the fin is 7 mm shorter. The best case for a fin length of 14 mm is the best case compared to the others Fig. 10–12 and Table 4. An optimization process was carried out to extract the mass fraction value and compare it with the previous research paper. The error rate was 6 %, which is very acceptable Fig. 13.

Through the Fig. 13, it shows the percentage of convergence between the previous research paper and the work that was done. The error rate was 6 %, which is very acceptable.

The main limitation in this research paper is the simulation work of the two-dimensional model and not the three-dimensional one, and the reason is due to the increase in the number of elements, in which the equations cannot be solved easily due to the lack of large compute.

The disadvantages of this study are it was done in 2D dimensions, not in 3D. The development of this study may be by using different types of fins and conditions that differ from one shape to another with the use of three-dimensional work.

7. Conclusions

1. The value of the fracture and fluid diffusion of the phase changer material is greater in the case where the thickness of the fin is 2 mm, which is the best case compared to the remaining cases. Large, but it impedes fluid movement from the phase changing material and thus impedes transfer of heat to successive layers.

2. The theory of heat spread in a fin is based on the fact that temperatures rise and fall with the length of the fin. Temperatures reach 316 K at a time of 300 seconds, which is 100 seconds less than when the fin is 7 mm shorter. The best case for a fin length of 14 mm is the best case compared to the others.

3. A comparison of the mass fraction value with the previous research paper is done. The error was 6 %, which is acceptable.

Financing

The study was performed without financial support.

Data availability

Manuscript has no associated data.

References

1. Bouhal, T., ed-Dîn Fertahi, S., Kousksou, T., Jamil, A. (2018). CFD thermal energy storage enhancement of PCM filling a cylindrical cavity equipped with submerged heating sources. Journal of Energy Storage, 18, 360–370. doi: https://doi.org/10.1016/j.est.2018.05.015
2. Olfian, H., Ajarostaghi, S. S. M., Farhadi, M., Ramiar, A. (2021). Melting and solidification processes of phase change material in evacuated tube solar collector with U-shaped spirally corrugated tube. Applied Thermal Engineering, 182, 116149. doi: https://doi.org/10.1016/j.applthermaleng.2020.116149
3. Kabeel, A. E., Abdelgaied, M. (2018). Solar energy assisted desiccant air conditioning system with PCM as a thermal storage medium. Renewable Energy, 122, 632–642. doi: https://doi.org/10.1016/j.renene.2018.02.020
4. Sansaniwal, S. K., Sharma, V., Mathur, J. (2018). Energy and exergy analyses of various typical solar energy applications: A comprehensive review. Renewable and Sustainable Energy Reviews, 82, 1576–1601. doi: https://doi.org/10.1016/j.rser.2017.07.003
5. Xu, F., Bian, Z. F., Ge, T. S., Dai, Y. J., Wang, C. H., Kawi, S. (2019). Analysis on solar energy powered cooling system based on desiccant coated heat exchanger using metal-organic framework. Energy, 177, 211–221. doi: https://doi.org/10.1016/j.energy.2019.04.090
6. Solano-Olivares, K., Romero, R. J., Santoyo, E., Herrera, I., Galindo–Luna, Y. R., Rodríguez–Martínez, A. et al. (2019). Life cycle assessment of a solar absorption air-conditioning system. Journal of Cleaner Production, 240, 118206. doi: https://doi.org/10.1016/j.jclepro.2019.118206
7. Novaes Pires Leite, G. de, Weschenfelder, F., Araújo, A. M., Villa Ochoa, Á. A., Franca Prestrelo Neto, N. da, Kraj, A. (2019). An economic analysis of the integration between air-conditioning and solar photovoltaic systems. Energy Conversion and Management, 185, 836–849. doi: https://doi.org/10.1016/j.enconman.2019.02.037
8. Rahman, S., Issa, S., Said, Z., El Haj Assad, M., Zadeh, R., Barani, Y. (2019). Performance enhancement of a solar powered air conditioning system using passive techniques and SWCNT/R-407c nano refrigerant. Case Studies in Thermal Engineering, 16, 100565. doi: https://doi.org/10.1016/j.csite.2019.100565
9. Jani, D. B., Mishra, M., Sahoo, P. K. (2018). A critical review on application of solar energy as renewable regeneration heat source in solid desiccant – vapor compression hybrid cooling system. Journal of Building Engineering, 18, 107–124. doi: https://doi.org/10.1016/j.jobe.2018.03.012
10. Opoku, R., Mensah-Darkwa, K., Samed Muntaka, A. (2018). Techno-economic analysis of a hybrid solar PV-grid powered air-conditioner for daytime office use in hot humid climates – A case study in Kumasi city, Ghana. Solar Energy, 165, 65–74. doi: https://doi.org/10.1016/j.solener.2018.03.013