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Heat Transfer Analysis of the Melting Process on Finned Tubes (A Review on performance enhancement)

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ABSTRACT

The performance of thermal systems, like heating and cooling systems, depends on a number of factors such as the geometrical shape, the working fluid used to transfer or store heat, and the operating conditions. Accordingly, many studies concentrated on improving the thermal performance of such systems and raising their thermal efficiency by modifying their geometry or using phase-changing materials. Therefore, this work is reviewing the previous studies that dealt with modifying the geometry, by adding annular or longitudinal fins on the main tube of the heat exchanger, and employing different types of phase change materials. This article also presents the previous scientific articles that investigated the effects of changing the location and the orientation of the fins. For the reviewed studies in this article, it is worth mentioning that the numerical investigations outnumbered the experimental ones as the authors focused on finding the optimal design of the studied thermal systems. Furthermore, the previous studies employed phase-change materials, e.g. fatty acids, waxes, and salts, due to their ability to store energy and reuse it in a wide range of applications.

Keywords:
Heat exchanger, phase change materials, change fin orientations.

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1. Introduction

From the point of view of solving global environmental problems and improving energy efficiency, the thermal energy storage systems, especially Thermal Energy Potential Energy Storage (LHTES) in Phase Changing Materials (PCMS), have gained considerable attention. Phase variables as thermally active materials are utilized increasingly in various engineering applications such as thermal storage, building thermal insulation, outdoor air conditioning, heat recovery, cooling, solar thermal collector, and systems thermoregulation. However, the challenge is storing thermal energy for later use simply and efficiently. Basically, there are three basic types of thermal energy storage systems, as shown in Figure 1, i.e. thermochemical energy storage units, perceptible thermal energy storage units, and potential thermal energy storage units [1].

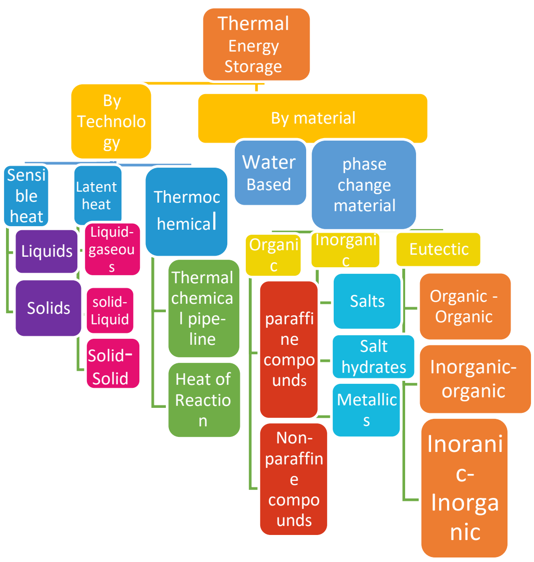

Figure 1: Classification of different types of energy storage

group of finned tubes with longitudinal fins and distributed axiotally to the variable material inside a unit for charging and discharging heat. The effects of coolant temperature, mass flow rate, fin diameter and thickness, solidifying mass and time required for complete solidification were studied . The method of the finite volume was adopted and also a diagram with the equations of the specific differences was adopted for the numerical solution. The researchers concluded that increasing the fin length or number improves the hardening process and reduces the time required to change the phase of the material. Also, increasing half the distribution of the fin tubes inside the loading and unloading unit leads to an increase in the full hardening time, while the results showed that increasing the fin thickness gives little effect on the hardening process.

2.2Addition of annular fins

Ismail, K.A.R. et al. [5] conducted a theoretical study to develop a model for the hardening of a phase variable material (PCM) around a tube with a ring fin and the results of the study were verified through experimental work .The study revealed that increasing the diameter of the fin will increase the speed of phase change on the outside of the tube and fin and reduce the overall hardening time of the phase variable. Reducing the temperature of the liquid used for cooling enhances the rapid formation of hardening on the interface and reduces the full hardening time .It was also found that the thickness of the fin has little effect on the time of the hardening process on the façade. The researchers suggested that despite the high thermal performance, the cost of manufacturing pipes is relatively high due to the welding process, so it was suggested that the alternative would be to use plastic pipes mixed with metal powder to improve effective thermal conductivity.

Nesrine Boulaktout et al.[1] conducted a numerical and practical study to improve the heat transfer of annular tube heat exchangers using fins to accelerate the melting rate of nicosan, which was examined in practice. The thermal potential energy of the porous material in nicosan was calculated and the phase type was changed, and it was found that the melting process of the material when changing the phase needs additional time .She also explained that the use of metal fins improves heat transfer and that changing their direction horizontally and vertically has an impact on thermal performance. The effect of the melting process, the heat transferred and the heat transfer coefficient were studied. The experimental results of the melting process have shown that heat transfer by conduction is predominant .Also, the increasing melting motion of a phase variable material significantly affected the upper half of the model, so these results indicate that the progress of The depletion of the ozone layer and the rise in fuel costs have encouraged researchers to improve the efficiency of systems based on sustainable energy sources such as energy storage devices. Using this technology, the energy is stored inside suitable tanks by changing it to the desired form which is a challenge nowadays. In general, energy storage is the capture of excess energy at a certain time to utilize when needed which helps in reducing energy waste and the cost of capital.

The aim of the current work is to present a general overview of the methods employed to improve the heat transfer performance of the melting process on the finned tubes. Different aspects were considered to enhance the thermal performance of the finned tubes such as adding longitudinal or annular fins, changing the location and direction of the fins, or using different types of phase-change materials.

2. Technologies for improving the thermal performance of the heat exchanger

Improving the performance of thermal systems in general and heat exchangers, in particular, has been the focus for many research groups. Different methods were used for this purpose and the most popular of them are given below.

2.1 Addition of longitudinal fins

Mohammad M. Hosseini and Asghar B. Rahimi [2] conducted a theoretical study on improving the heat transfer of a triple heat exchanger with rectangular fins attached to the solidification process of the phase changing material .The main objective of this study was to arrange and select rectangular fins and this may maintain the balance in heat transfer in the longitudinal and angular directions of the fin and also the phase variable material (PCM) turns from liquid state to solid simultaneously throughout the cross-section of the fin and the solidification process is in the shortest possible time when using other arrangement and lengths of fins (with the fin section area remaining constant). This study enabled the researchers to design more efficient thermal storage systems.

Mohammed Shahid Afridi et al.[3] presented a practical study comparing the use of a longitudinal and annular fin using paraffin as an experimental and numerical phase variable. One of the properties of paraffin wax is that it melts at a temperature of 55°C to 60°C .The heat transfer fluid, which is in the liquid state, passes between the tubes to transfer heat from the liquid to the paraffin of the longitudinal and annular fins. The experimental results showed that the use of longitudinal fin and annular fin has a different heat transfer rate, as heat transfer using longitudinal fins increases the efficiency of the exchanger by 6% compared to the use of annular fins.

Kamal A. R. Ismail et al.[4] also presented a numerical study to improve heat transfer from a positively affect the improvement of system performance.

Hassan M.S. et al. [9] presented a numerical simulation of water freezing around submerged and non-submerged horizontal tubes and fins. The effect of natural convection as well as the reflection of water density with temperature were taken into account. Partial differential equations were solved with dynamic grid generation technology and for validation the results were compared using non-perforated tubes with some experimental studies . The results showed that the similarity of flow patterns in both tubes with one major vortex in the liquid region when there is no reflection in the density of water. The presence of fins complicated the distribution of the local Nusselt number along the solid and liquid interface compared to the unfilled tube. The results also showed improved freezing when using fins.

2.4 Change the location or direction of the fins

S. Khaldi et al.[10] conducted a numerical study of the process of melting a phase variable substance (PCM) based on eccentric horizontal cylinders. The simulation of the symmetrical melting of phase changing materials between the two cylinders was performed using the finite volume method .In this study, the researchers relied on an inner cylinder, which is a finned tube to improve heat transfer between the inner cylinder and the phase changing material. The inner cylindrical wall was considered a hot wall while the outer cylinder was insulated and therefore this simulation shows the melting process from start to finish. The researchers concluded that the use of fins on the inner tube increases the melting process by reducing the melting time by 72.72%.

Sohif Mat et al.[11] conducted a numerical study in the process of melting in a three-tube heat exchanger with a variable phase material. The study included a two-dimensional model using Fluent 6.3.26. Three methods of heating process were used to melt the phase variable material from the inner tube, the outer tube and both tubes .The heat transfer of the phase variable material is improved by placing internal and external fins. A comparison was made when the tube was heated from the inside and heated from the outside and the effect of the fin length on the improvement process was studied using a triple heat exchanger with internal - external fins, the results indicated a reduction in the melting time to 43.3% in the triangular tube without fins, and experiments were conducted to verify the validity of the proposed model and it was found that the simulation results are consistent with the experimental results.

Birlie Fekadu and Mebratu Assaye [12] conducted a study to improve the rate of dissolution of phase variables in a rectangular space by changing the slope of the fins. A number of fins under a fixed length and width of the space and a fixed fin thickness of 4 mm were relied upon to maintain a dissolution at the top of the fin is faster than at the bottom. In the case of horizontal fins, since the material is variable phase, the faster the melting process is at the bottom, the lower the finned tube, the greater the melting process and the better the heat transfer process. The researcher also concluded that placing the fins in the vertical form reduced the melting time compared to the horizontal fins by 2.5% .

Kamal A. R. Ismail ET AL. [6] Conducted A Numerical Study using axial finned tubes to improve heat charging and discharging processes in thermal storage units, where they relied on abstract conduction in the solid and liquid phases. The finite size technique was relied upon in the numerical study and the associated initial and boundary conditions. The numerical results were compared with the experimental results where good agreement was observed .It was also found that increasing the length or number of fins improves the hardening process and reduces the time of total phase change. It has been concluded that increasing the fin radius increases the total hardening time while increasing the fin thickness has little effect on the hardening process.

2.3 Change the direction of the fins

Yanping Yuan et al.[7] conducted a numerical simulation of the effect of heat transfer on a number of annular fins mounted on a wall at different angles and illustrated the fusion properties of the phase variable. The study was also validated by conducting a pilot study. The melting process of PCM around the annular fins was simulated at five different angles with a fixed wall temperature change of three different degrees (60,70,80) °C .Numerical results were compared with the presence and absence of fins. The results showed that although fins weaken the natural heat load, when added they can lead to an increase in the melting rate and a decrease in melting time due to the increase in the total area of heat exchange. When looking at the entire melting process, it was observed that the rate of melting of the phase material is greatest when the fins are fixed at an angle of 0° and until the angle reaches 45° and that any further increase in the angle value has no noticeable effect on the rate of melting .

Mohammad Javad Zarei et al.[8] conducted a numerical study using phase variable materials around a copper-fused tube. The best finning design was studied to achieve the least solidification time and the best improvement of the performance of the thermal energy storage system specified in this numerical study .The results showed that the best performance of the fins is with a connecting angle of 90 degrees and a length and width of 28 mm and 1 mm respectively. Using this condition in this mode can reduce the total hardening time by about 42% compared to a finless system. In addition, it has been concluded that increasing the fin length can with an error rate of 5.58% and the researchers showed that the use of the ANN method was important for practical applications in thermal energy storage .

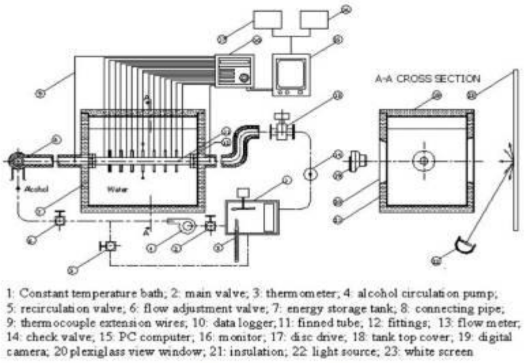

Figure 2: Practical device used

Daniel Bacellar and others [15] conducted a numerical study using a copper tube with circular copper fins installed in the vertical direction as shown in Figure (3) based on computational fluid dynamics (CFD) technique. A phase variable material was used with a melting point of 35 ° C and heat transfer depends on convection heat transfer . The researchers were interested in changing the dimensions of the fin from the length and thickness as well as the distances between the fins. The researcher concluded that increasing the fin length leads to a decrease in the dissolution time of the phase variable. Also, note that there is a difference in the numerical method used compared to the finite volume method in terms of the speed of program implementation.

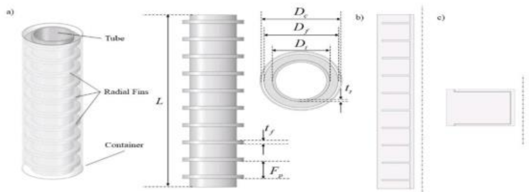

Figure 3 Schematic representation of an inline fin tube heat exchanger

Junting Wu et al.[16] conducted a numerical simulation of the effect of the location and length of a single fin in the Thermal Latent Heat Energy Storage Unit (LHTESU) on the melting and solidification of a phase variable material (PCM) through temperature distribution, solvent transfer velocity, phase change rate, melting and properties of PCM and heat transfer by changing the fin length to height ratio .The results obtained by the researchers showed that the total melting time was significantly reduced when the fin length increased and decreased by simultaneously changing the fin location. On the other hand, lowering the position of the fin causes the temperature to not be distributed uniformly during the hardening process.

2.5 Quality of phase variable materials

constant mass of phase changing material within the space. The length of the fins has been reduced as the number of fins within the space has increased and the space has been maintained at a constant temperature of 333.5 K from the underside . Aluminum fins were used for this study and the optimal number of fins used was two fins. The study was conducted during three cases of finning inclination (60, 45, 35 degrees). Using just two fins would have reduced melting time by 43%. In addition, a melting time reduction of 31%, 5.12% can be obtained by setting two improved fins at an angle of □45θ = and an angle of □60θ = respectively. Finally ,The results of the melting time ratio compared to those obtained through the use of fin-tilt states with the state of non-fins appeared. The melting time of approximately □45□ is 1800 seconds, which is shorter than the melting time of a fin at an angle of inclination of 09□. These results show that if fins can be optimized in terms of the number and inclination specified in a given operational design, the efficiency of the system can be increased by reducing the melting time of the desired phase variables .

Mohammed Bechiri [13] conducted a numerical study of the melting of a phase variable substance (PCM) in a vertically placed cylinder. The upper space of the cylinder is filled with air to take into account the volumetric expansion of the phase variable. The finite volume method was adopted based on the equations of conservation of mass, momentum, and energy .The mathematical model is based on the transfer of heat of the phase variable material to the outer surface of the cylinder, which has a constant temperature on its outer surface. The results obtained were analyzed and compared with previous works and showed good agreement. After that, another study was carried out to determine the total melting time and find some dimensionless parameters such as the number of Krachov and the ratio of the diameter of the wall to the pipe.

Kemal Ermis et al.[14] conducted a numerical study of heat transfer using a finned tube and a phase changing material to store heat based on an artificial neural network (AAN) algorithm. The researchers also added a practical study using the device shown in Figure .(2) To validate the numerical results based on a phase variable material around a finned tube. The effect of some parameters of the fin and the phase variable material, including experiments in different types of finned tubes, different numbers of Reynolds number and different inlet temperatures, were studied by solving some equations governing the transfer of heat from the liquid to the tube and to the phase changeable material .The amount of heat transferred to variable-shaped finned tubes at variable flows was calculated by calculating the number of Reynolds and also different temperatures. The results showed that the compatibility between numerical analysis and the practical study was good performance of the thermal storage unit using fatty acid as a means of heat storage. The unit consists mainly of an electric heating rod placed inside an external pipe ,The heat transfer properties of fatty acid melting processes with different degrees of temperature were studied to determine the effect of heat on melting processes. A new type of finned is designed and installed on the electric heating rod to enhance the thermal response of fatty acid. Experimental results show that the fin can improve heat transfer for the melting process of the thermal volume .The equivalent thermal conductivity of PCM can be increased by a factor of up to 3-fold. Analysis of experimental results shows that the fin-enhancing mechanism is due to its ability to improve both thermal conductivity and natural convection very effectively .

George Dogkas et al.[21] conducted an experimental study of a thermal energy storage system using a phase variable material (PCM) based on solar and geothermal energy. The system consists of a rectangular tank filled with PCM and a fin tube as a heat exchanger .The system is designed to obtain hot household water. The properties studied are the amount of energy stored for the system, the rate of heat transfer during charging and discharging processes, the amount of hot water produced and the storage efficiency of the tank .The system was charged with heat based on solar energy for two hours The results of the experiments confirmed that the system can meet many basic requirements to produce hot domestic water with a temperature of up to 40 degrees Celsius for a quantity ranging from 106 liters to 164 liters. In addition to conducting the operation of the solar collector and geothermal pump with high efficiency.

Zhaoyang Niu et al.[22] conducted an experimental study of the performance of thermal energy storage of a casing-tube-type thermal unit using a superimposed phase variable material (paraffin). An open cylindrical heat storage tank filled with copper foam was proposed to study the characteristics of the melting process .A real-time temperature recording system for paraffin material was established and the results when compared with conventional smooth-tube heat exchangers showed that paraffin dissolves rapidly at the underside over time. Also, temperatures have become more homogeneous with time, and therefore, due to the expansion of the heat transfer area, the heat transfer coefficient has improved .

3. Conclusion

The present work reviewed the experimental and numerical previous studies that focused on the techniques for improving the thermal performance of the heat exchanger and the following conclusions were drawn:

1. The studies showed that the longitudinal fins are better than the ring fins in terms of the efficiency of the heat exchanger.

Jingjing Shao et al. [17] presented a numerical study to improve the thermal performance of a phase variable-phase emulsion in a tube-fin heat exchanger, where the study focused on the theoretical work of thermal performance using a new PCE-10 phase variable phase material inside a finned tube heat exchanger .Which is characterized by the fact that its thermal capacity is twice the heat capacity of water and works within different ranges of temperatures, which range between (4-11) degrees Celsius, which is the temperature range of the chilled water air conditioning system and is characterized by a good level of stability of storage and for a long period of time up to (9) months and also with a viscosity much higher than water, which contributes to a decrease in high pressure in the pumping system ,The heat transfer process and flow behavior of finned tube type heat exchangers were analyzed. The results showed that PCE-10 has several performance advantages as a cold storage medium that provide a basic base for designing a new type of practical cooling for storage devices.

X.Q. Zhai et al.[18] designed and applied a cold storage unit based on a PCM type composed of capric acid and lauric acid with a phase change temperature of 14.97 °C .The charging performance of the cold storage unit was experimentally investigated, and after performing a modulation construction analysis on the charging performance, it was shown that the charging process for the entire optimal scheme is 26.3% faster than the experimental unit operation. In practical applications.

Fatima A. M. Lino and Kamal A.R. Ismail [19] conducted a practical study of the formation of ice around finned tubes. The process was done by freezing the water around a tube with annular fins to illustrate the effect of the fin and the working conditions of the cold liquid on the cohesion of the ice as shown in Figure (4). The experimental results revealed that increasing the diameter of the fin increases the speed of snow hardening. Lowering the temperature of the coolant and increasing its flow rate promotes increased solid mass formation.

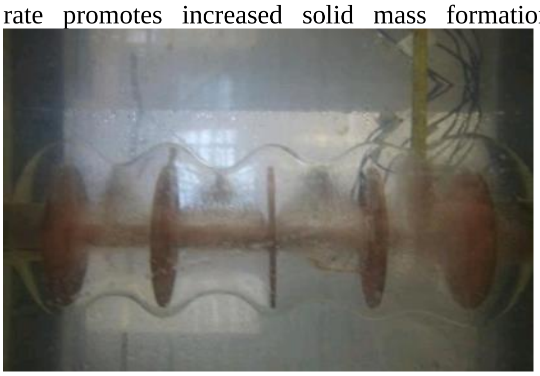

Figure (4) Picture of the fused tube showing PCM hardening

Zhongliang Liu et al.[20] conducted an experimental study in which a device was created to study the

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2. The investigations also demonstrated that although the presence of fins impairs the natural convection, adding fins increases the melting rate and decreases the melting time due to the increase in the total area of heat exchange.
3. The previous studies also proved that the angle of the fins affects the performance of the heat exchanger by reducing the time of completing the melting process of the phase-change material.
4. In addition, a number of studies proved that the use of different types of phase variable materials in some applications increases the efficiency of the heat exchanger due to the high heat capacity for these materials.

List of symbols and terms

(Latent Heat Thermal Energy Storage Unit)	LHTESU
(Phase Change Materials)	PCMS
(Computational Fluid Dynamics)	CFD
(Artificial Neural Network)	ANN

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تحليل انتقال الحرارة لعملية الذوبان على الانابيب المزعنفة
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الخلاصة

يعتمد أداء أي منظومة حرارية سواءاً اكانت منظومة تدفئة او تبريد او غيرها على العديد من العوامل منها تصميم المنظومة او موائع التشغيل المستخدمة لنقل او خزن الحرارة. ان العديد من الدراسات تناولت إمكانية تحسين أداء المنظومات الحرارية ورفع كفاءتها الحرارية من خلال عدد من الإضافات والتحسينات التي تمت اضافتها الى المبادل الحراري او استخدام المواد المتغيرة الطور في المنظومة ومنها إضافة أنواع مختلفة من الزعانف سواء أكانت زعانف حلقية ام طولية على الانبوب الرئيسي للمبادل الحراري وايضاً تغيير اتجاه الزعانف بزوايا مختلفة او تغيير موقع واتجاه الزعانف إضافة الى استخدام أنواع مختلفة من المواد المتغيرة الطور. ان الهدف من هذه الورقة البحثية هو مراجعة الدراسات المختلفة التي تتناول التحسينات انفة الذكر لإجراء التعديلات على التصميم، إضافة إلى تلخيص أهم نتائجها. اعتمادا على المراجع وجد ان العديد من البحوث في هذا المجال كانت في النظرية اكثر مما هي عليه في الجانب العملي، اذ ان تلك البحوث تمحورت حول ايجاد التصميم الامثل من ناحية اضافة الزعانف (حلقية او طولية) وايضا من ناحية الاتجاه وموقع الزعنفة حول الانبوب الرئيسي للمبادل الحراري وباستخدام مواد متغيرة الطور والتي تتمثل بكل من (الحوامض الشحمية أو الشمع أو الاملاح)، حيث تمتلك قابلية متفاوتة في قدرتها على خزن الطاقة وبالتالي الاستفادة من هذه الطاقة الحرارية المخزونة وتسخيرها في استعمالات واسعة في المجالات الحياتية.

الكلمات الداله :

المبادل الحرارى, الموائع متغيرة الطور, توجيه الزعانف