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Analyzing the thermal energy storage in PCM through simulation for building purpose

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Abstract

In the operating phase of the buildings, the improvement in energy efficiency is an active area of research. The business sectors are searching for new advancements, to be specific new systems of storage of thermal energy (TES) frameworks, which can be utilized to decrease structures' reliance on petroleum derivatives, to utilize sustainable power sources, and to add to coordinate with energy market interest productively. Hence phase-changing materials (PCM) are being used in our present work for storing thermal energy and the material methyl silylidyne is being used in our simulation model which is designed as a double pipe heat exchanger and the simulations are being carried out in ANSYS workbench. The variation of temperature is being noted along with the proportion of solid or liquid of PCM material to study the response of heat transfer and finally conclude with the effectiveness of the use of these materials in building purposes. The proportion of PCM's solid and liquid quantity is noted at time T=0 Sec and Time T=200 sec. Contour plots along with numerical values are shown in this project to analyze the mass fraction of the PCM material at a different time interval. The result shows as with the time when the heat is transferred from PCM material to the liquid (water) flowing inside the inner fluid.

Keywords: thermal energy storage, latent heat, energy efficiency, ansys, mass fraction

1. Introduction

The improvement of the energy utilization and management of buildings throughout their operational section is a lively domain if required. Research is being made for new technologies, specifically new thermal energy storage (TES) systems, which may be used to decline dependency on fossil fuels, to make use of renewable energy sources, and to contribute to matching energy offer and demand expeditiously.

Renewable energy is a sector of great importance and with the need for power in the current era of technology and the major concern is the storage of such energy which has created major concern in the field of study. In this, the thermal energy is stored and saved or preserved which can be used effectively and efficiently for cooling and heating demands in the future. Xin Wang, Yin Ping Zhang, Wei Xiao, Ruo Lang Zeng, Qun Li Zhang, and HongFa Di showed Improving the warm execution of building envelope is a significant method to save building energy utilization. The phase change energy affecting the building envelope is useful to successful utilization of environment-friendly power, reducing building operational energy utilization, expanding building heat solace, and diminishing climate contamination and ozone-depleting substance outflow. This paper introduced the idea of an ideal energy-saving structure envelope, which is utilized to direct the structure envelope material choice and heat transfer plan. This paper audits some accessible investigates on phase change building material and phase change energy-storing building envelope. Finally, this paper presents some flow issues that required further exploration.

Akeiber HJ, Wahid MA, Hussen HM, Mohammad AT gave the utilization of Phase change materials (PCMs) in green structures has been expanding quickly. PCM applications in green structures incorporate a few advancement models. This paper momentarily studies the new initiative to work exercises of PCM in building applications. Right off the bat, an essential simulation of phase change and their standards is given; the characterization and uses of PCMs are additionally included. Furthermore, PCM models in structures are investigated and examined by the divider, rooftop, floor, and cooling frameworks. At last, conclusions are introduced dependent on the gathered information.

José Luis Reyez-Araiza, Jorge Pineda-Piñón, José M López-Romero, José Ramón Gasca-Tirado, Moises Arroyo Contreras, Juan Carlos Jáuregui Correa discussed about the energy area is one of the fields of interest for various countries all throughout the planet. Because of the current petroleum derivative emergency, mainstream researchers grow new energy-saving encounters to address this worry. Structures are one of the components of higher energy utilization, so the age of information and mechanical advancement may offer answers for this energy interest, which are very gladly received. Phase change materials (PCMs) remembered for building components, for example, divider boards, squares, boards, or coatings, for warming and cooling applications have been appeared, when warming, to expand the heat-storing limit by retaining heat as dormant energy. Consequently, the utilization of inactive heat-storing frameworks utilizing phase change materials (PCMs) has been researched inside the most recent twenty years.

2. Submission of the paper PCM (Phase Change Material)

Phase-changing materials are utilized for storing latent heat. (Niyas and Muthukumar 2018) (Elias and Stathopoulos 2019). PCM materials are those materials that sore a specific amount of heat energy to use in the future as per demand. Further, sensible heat outside their temperature window is also exchanged by PCMs. Mostly Solid-Liquid and solid-solid PCM's are used out of several available PCM materials. With the huge volume being altered in Solid-gas and liquid Gas, these PCM Materials cannot be used in practical implementations even though they have a larger amount of heat energy required. In the last decade, the field of PCMs are broadly researched for TES since the requirement for efficient energy increased and demand for effective TES needed for applications. (Du *et al.* 2018). A research article published in September 2018 entitled "phase change materials" in addition to restricting under "thermal energy storage systems" provided 1392 hits in that year. (Applied and Science 2018) Phase change materials can be effectively implemented on regulating thermal energy systems as well as plain thermal energy storage systems. The thermal-based energy systems incorporating phase change materials have great utility in maintaining thermal comfort in large spaces and buildings since they overcome huge alterations in temperature. Several other engineering fields have a big advantage in regulating temperatures such as aerospace (Kim *et al.* 2013), textiles and photovoltaic (Ling *et al.* 2014), and batteries (Khateeb *et al.* 2005). Phase Change Material is used as waste heat storage in the following applications agriculture applications, building applications, thermal industrial storage, or in fuel cells (Koukou *et al.* 2018), (Kumar *et al.* 2011). Based on Chemical quality PCM can be divided into the following categories, for instance, organic-based, in addition with inorganic based and eutectics, or basis of their phase of transitions which they undergo as solid-solid PCM, liquid-gas PCM, Solid-Liquid PCM, Solid-Gas PCMs.

Further based on the organic nature of PCMs they have been divided into (i) Paraffin or Non-paraffin for example glycols, polymers, fatty acids, esters, or alcohols, (ii) Inorganic PCMs includes alloys and metals or salt hydrates. (iii) Eutectics include organic-inorganic, inorganic-inorganic, and organic-organic. After the first application of Phase Change Material in aerospace by NASA, a huge quantity of material or a mixture of two or more materials are included in researches for use as a Phase change Material. By utilizing traditional trends of chemistry as well as biocatalysts to convert animal fat into eutectic organic phase change materials (Gallart-Sirvent *et al.* 2017). A complete list of available and studied PSMs can be found here (Veera Kumar and Sree Kumar 2016). Working temperature ranges (-20 ℃ to +200 ℃) under which range PCMs are used. Four temperature ranges are used mainly for the PCMs. Four different ranges vary for their applications; low temperature (-20 °C to +5 °C) on this temperature range phase change material is used for domestic and refrigeration. Medium-low temperature range (+5 °C to +40 °C) on this range of PCM, they mostly used in cooling and heating applications in commercial buildings, A range for solar-based heating electronic application and cooling lies from (+40 °C to +80 °C), and for the absorption cooling electricity generation and waste heat recovery temperature range lies from (+80 °C to +200 °C or above) (Zheng, Zhang, and Liang 2017).

3. Literature review

(Bista *et al.* 2018) In this review paper, they studied various research papers and investigate the available approaches of PCMs in the field of refrigeration systems. On studying the applications of PCM in refrigeration cycles based on vapor compression, it elaborates significant changes on several functions of the system, such as on-off cycle and declination in the utilization of electrical energy. The materials used for PCM should be very stable in terms of chemical reactivity and thermal behaviors so that it can conserve a huge amount of freezing as well as melting point temperatures. Due to this, it can strongly work under conditions of the refrigerator. The temperature of phase change material and the thickness of the PCM are investigated in the research based on the working efficiency of the refrigeration system and their impacts on the complete system. Later, a review of different components including their benefits and disadvantages are discussed such as the evaporator, condenser in addition with compressor, etc. The fluctuations in the thermal load can be stabilized with help of PCM in the evaporator and further the variation in the temperature within the compartment degrades. During the consolidating of PCM at the evaporator that expands the running time of the compressor at the starting point and upsurges the condensation temperature, numerous researches have been functioning for the incorporation of PCM at the condensation segments. As the danger and harmful effects were increasing by the increased use of refrigeration, the use of PCMs on refrigeration plays a successful part to elevate the effectiveness of refrigerators and additionally depressing the utilization of energy. (Saeed *et al.* 2019) In this review, load-shifting is studied by using a thermal energy storage vessel through experimental investigation. Within this framework, the PCM is operating as a medium for storing energy, and a plating vessel is a unit of heat exchanger comprised of working fluid which is water. Several conditions of inlet such as the temperature of water at the exit, coefficient of heat transfer, the rate of storing heat, efficiency, time for storage, the overall capacity of storage, and effectiveness which are complete thermal features of the heat exchanger were categorized as functions. The research showed that 83.1% effectiveness was obtained despite utilizing low thermal conductivity PCM. It is also found that the suggested design of energy storage system not only delivers significant results working as a thermal energy storage medium, but it is also providing other benefits like saving infrastructure, equipment's and operation compared to conventional systems (Royo *et al.* 2019) In this research paper, it has been reviewed that how feasible to implement PCM-TES in energy-intensive industries at high-temperature range. The motive of stored energy is to pre-heat the air which is entering into the furnace by the means of phase change material that has a melting point of 885 ℃. By this approach, a suitable design found on mass and energy conservation equations is explained by heat transfer simulation. The thermal execution is examined for solidification and melting processes, the phase transition, and its impact on the process of heat transference. Further, the results were obtained from the temperature profile exemplified for the phase change material and combustion air stream. These results will show the presence of high-temperature levels (from 700 ℃ to 800 ℃) of combustion air which is preheated in a ceramic furnace. So, it confirms that the energy and natural efficiency increase to the initial condition, showing an air outlet at 65. (Vivekananthan and Amirtham 2019) to elevate the properties which are thermo-physical regarding the PCM, by the means of dispersed nano-particles termed as NDPCM (Nano-particle dispersed phase change material) is investigated. The present research work comprises energy as well as improvement in thermal conductivity of suspended Graphene constituents having a varying mass fraction of 0.1%, 0.5%, and 1% in addition to erythritol base. The particles of graphene mixed with erythritol base isolate the chemical properties, which is escorted by the FITR method. Further, the results from DSC analysis depicted that the temperature of the phase change and the NDPCM latent heat temperature degraded before and after 100% solid phase change and the cycle of melting. About 6.1% of the decline in the enthalpy of latent heat is observed by adding 1% wt. graphene which resulted in 53.1% elevation in the thermal conductivity. Further, there is an 18.7% rise in the temperature of solidification which is linked to erythritol and a 5.8% decline in the melting temperature. (Roccamena, El Mankibi, and Stathopoulos 2019) a numerical-based model is generated comprising developed water and heat exchanger with PCM for cooling, in which exclusive energy is utilized. The model is validated on a numerical basis using ANSYS. The work includes a balanced heat approach and the solution is obtained by finite difference method. All around the process, it is validated using computational fluid dynamics.

In the evaluation, the results depicted variation in coefficient of the Root Mean Squared Error and Normalized Mean Bias Error which was used in the analysis, in addition with it provides the option for the present model in establishing a right model that can generate PCM with a heat exchanger with greater accuracy

4. Problem statement

In recent years, the use of energy has increased to a higher extend due to the rise in usage of utilities for human comfort. Renewable energy sources have emerged as a source of energy in the recent past due to extensive availability and form the cheapest mode of energy provider. Among the renewable energy sources, solar energy has been utilized more adequately due to its wide availability and being a reliable source of energy source. Solar cooling and refrigeration have emerged as a basic need for human comfort along with food conservation. However, since renewable energy sources are time-dependent, some problems occur due to a mismatch of energy supply and energy demand. Hence to resolve the issues, thermal energy storage techniques were used which store the energy and provide uninterrupted energy based on the requirement. Phase change materials were used for this purpose since PCM has better capacity in terms of storing energy and isothermal behavior during both charging and discharging processes. The major problem that exists in Thermal energy storage based on PCM is related to the consistency in supplying energy based on the demand. Here we intend to propose a model which makes use of microencapsulated phase change materials for the thermal storage process. We define various optimal parameters which are to be considered while designing the approach along with various thermal and rheological properties of the material for proper energy utilization.

5. Methodology

In the present study, the following methodology has been used; in the present work, computational fluid dynamics (CFD) analysis on the thermal storage system is performed considering the temperature range of 300 °C. For the modeling of the thermal storage system, two concentric pipes of the same length but different diameters were modeled shown in fig 1 having the length as 1000 mm and inner diameter of the inside pipe as 25mm and outer diameter as 27mm having the constant thickness of 2mm throughout. Whereas outside pipe of the thermal storage system was modeled with an inner diameter as 50mm and outer diameter as 52mm with a constant thickness of 2mm throughout the length. Both the pipes were designed considering the insulation to trap the heat produced inside the thermal storage system providing no loss of energy during the working procedure (Ghahramani Zarajabad and Ahmadi 2018b). After the modeling procedure, the model is imported into the meshing workbench to perform the meshing operation on it. In the meshing workbench, grid independence is performed to find the behavior of mesh generation in our study. Similar analyses were performed on the geometry having fine meshing and course meshing respectively. From the grid independence study, it is seen that there is no significant change observed in the analysis having fine and course meshing so it can be concluded that our geometry is meshed independent. Below figure 1 shows the fine mesh geometry used for the further analysis procedure.

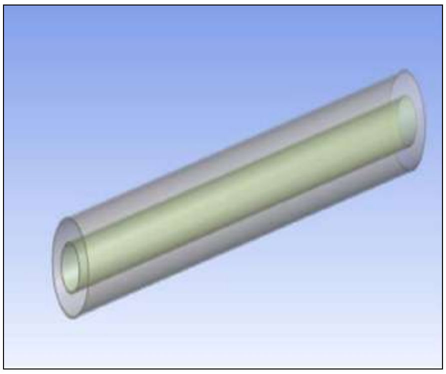

Fig 1: Proposed 3D model in ANSYS

Inner pipe Dimensions:	Outer pipe dimensions:
Diameter: 25mm	inner dia: 50mm
Outer diameter: 27mm	outer dia: 52mm
Length: 1000mm	length: 1000mm

In the performed analysis of the model, required analysis reports were are as follows,

1. Temperature vs time graph (Showing the charging and discharging process) when PCM is used
2. Temperature vs time graph (Showing the time and temperature of the charging process for PCM)
3. Energy vs time graph (Showing, Stored energy during the charging process for PCM)
4. Final PCM vs energy storage difference graph.

For the analysis, we have modeled two concentric pipes in which the working fluid will flow in the inner pipe and the PCM will present in between the outer and the inner pipe the modeled geometry as per figure 1. The generated 3D model is saved in Standard temperature and pressure (STP) format to make it compatible with the ANSYS tool. From the generated model, we perform analysis in the ANSYS design modular. For carrying out of analysis we need to mesh the generated model. For meshing, we have used the Ansys inbuilt meshing software. The meshed model is shown below in figure2

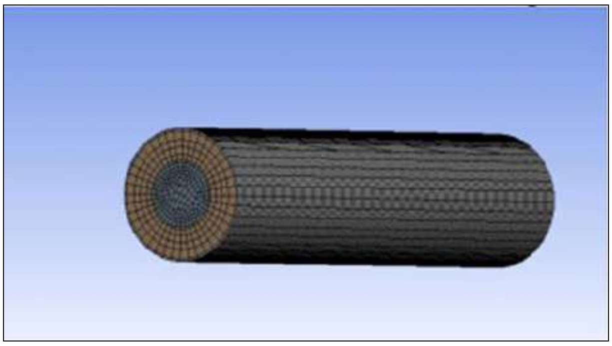

Fig 2: Mesh Model of the proposed work

6. Result

As the cooling liquid starts to flow inside the inner tube in our simulation the process of discharging/melting starts the liquid fraction is noted at t=0.the simulation is run for 100 seconds with a time interval of 1 sec. the liquid fraction after 100 seconds comes out to be PCM (liquid) = 0.87834587. Now the simulation is again started and run for the time 100 seconds again and the fraction of the PCM is noted as =0.8133822 which can be seen in fig 3 and fig 4.

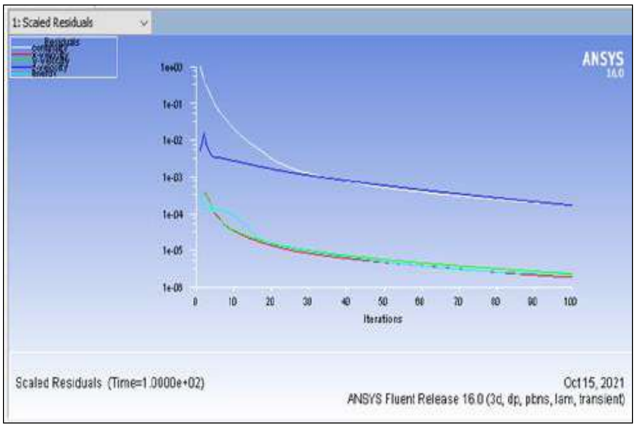

Fig 3: Solidification of PCM at time T=100 sec

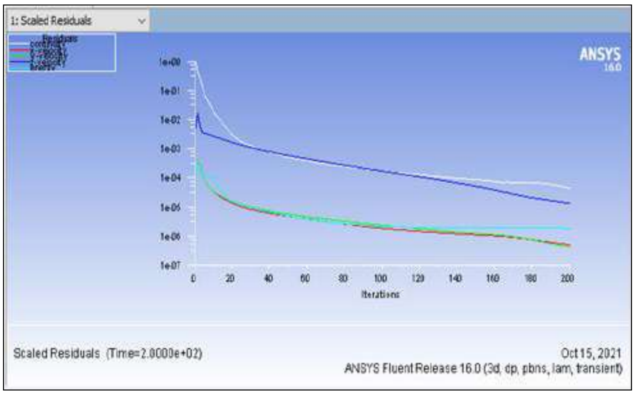

Fig 4: Solidification of PCM at time T=200 sec

In the meantime, the temperature of the water coming out of the outlet of the inner tube is noted which comes out to be 303 °C.

So, it can be calculated for the given change in temperature, the amount of phase of PCM changing in the given material.

6.1 Final PCM vs Energy storage difference

Showing that the PCM has got the better energy generation, by observing the results obtained from the analysis it can be concluded that under the same operating conditions and time PCM has stored the higher energy as compared to the other building material. From these obtained results we can suggest that the PCM is suited for the thermal energy storage process.

6.2 Other plots/Images and explanation: A thermal storage system is nothing but the collection of individual units of the geometry which we have considered for the analysis a full thermal energy storage system has a huge number of considered models. For the ease of the computational analysis, we have considered the individual unit for analysis we can dub that every unit will work similarly, and further reducing the computational load here we are discharging the PCM for 100 and 200 sec in both cases and comparing the PCMs liquid fraction for the energy storage from this we can understand that PCM can be used for the best storage of the energy in a thermal energy storage system. Below we can understand how the charging and discharging of the PCM take place with the help of contours. This contour is captured at the time t=50 sec as shown in figure 5.

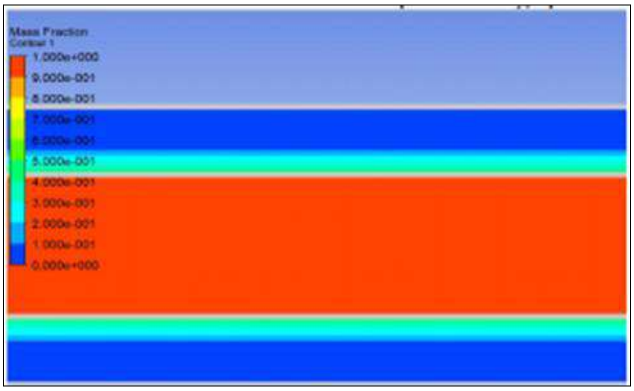

Fig 5: Contour Plot at time T=50 Sec

This contour is captured at the time t=100 sec, as shown in figure 6, here we can see that the PCM near to the wall is melted and converted into the liquid phase and the phase change region is penetrated further into the PCM.

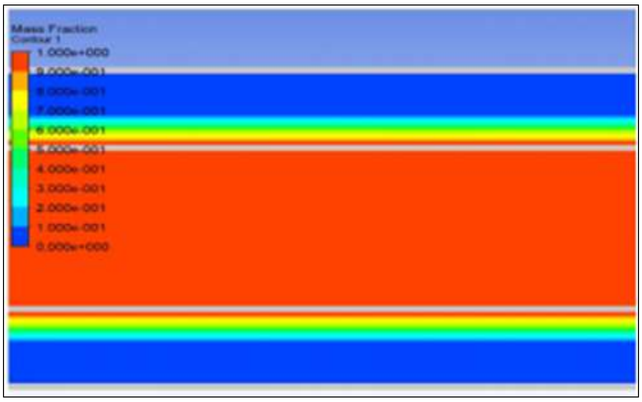

Fig 6: Contour Plot at time t=100 sec

This contour is captured at t=150 sec as shown in figure 7, where the thickness of the melted region is increased and the phase change region is further penetrated into the PCM heating more PCM. This process will continue for 150 sec and then the cooling process will start.

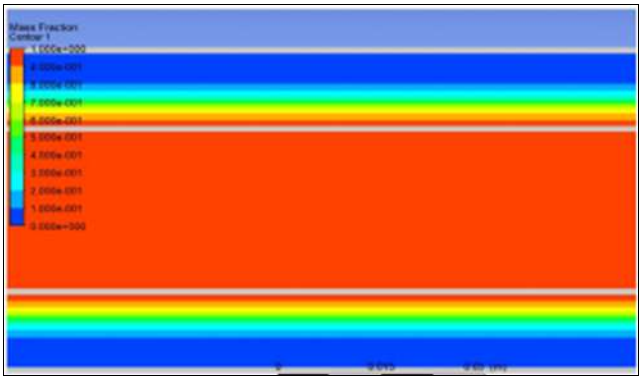

Fig 7: Contour Plot at time T=150 Sec

This contour is captured during cooling at the time instance of t=200 sec as shown in figure 8, here we can see that the bright orange color which is present in the near-wall is completely disappeared and the phase change region is getting down towards the inner pipe wall.

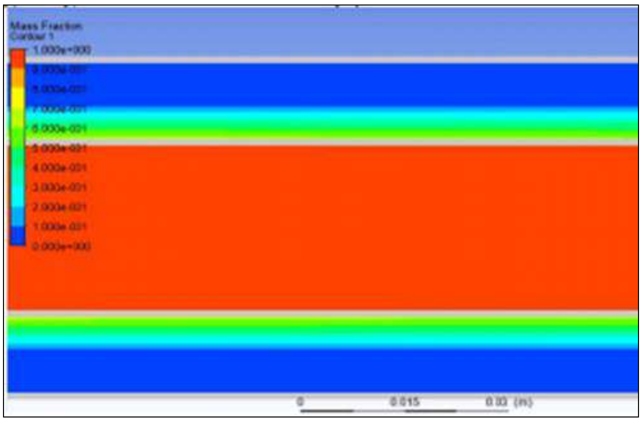

Fig 8: Contour Plot at time T=200 Sec

From these contours, we can understand how charging and the discharging of the PCM takes place in the TES.

7. Conclusion

In past years there is a huge demand in the supply of energy with an increase in the usage of utilities for human comfort. However, Renewable source of energy has been emerged as a high source of energy in the recent past due to their extensive availability and considered the cheapest energy mode. But these renewable energy sources are time-dependent and lead by the mismatch of energy supply and energy demand. Hence to resolve these issues, thermal energy storage techniques were used that can store the energy and provide uninterrupted energy which is based on the requirement. Phase change materials (PCM) were used for this purpose since they have better capacity in terms of storing energy and elevating isothermal behavior during both charging and discharging processes. This research study can also contribute immensely to the Neuro-fuzzy hybridization by the deployment of various statistical and machine learning techniques relevant to our proposed model. Future work can be contributed to the extension of this research work by connecting through the techniques of statistical analysis and machine learning approach to make the output more accurate and systematic.

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