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Analysis of Heat Transfer and Natural Convective of a Phase Change Material

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Abstract: A phase-change material (PCM) is a substance with a high latent heat storage capacity which on melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Various PCM like Paraffin wax, stearic acid are considered which are used to absorb heat from the coolant water from the engine. The conduction and convection criterion of heat transfer enable the PCM to store this heat as latent heat. The amount of convection and temperature change brought about due to the heat flux has been simulated and studied in detail using FLUENT.

The thermal energy storage device (TESD) works on the effect of absorption and rejection of heat during the solid-liquid phase change of heat storage material. The overall function of the TESS is dominated by the PCM. The PCM material should be selected considering the application and the working conditions. Depending on the applications, the PCMs should first be selected based on their melting temperature for heat recovery system.

Keywords: PCM, Temperature, Latent heat, phase change.

I. INTRODUCTION

Originally, buildings were commonly constructed using local materials. This helped to protect them from local climate conditions and respond to the ambient environment. Traditional buildings were more climate-responsible as they were built to ensure the best control and utilization of climate factors for the inhabitants' comfort based on the available materials and technologies. Therefore, they showed a better indoor environment and less energy consumption. During the industrial revolution, with people migrating to urban areas, which caused overcrowding, the focus of the building construction sector changed from climatic requirements to economical consideration. This resulted in a high dependency on mechanical systems to achieve thermal comfort. However, due to the energy crisis and the negative effects associated with massive energy use, such as climate change, global warming, and greenhouse gas emissions, humans should reduce energy consumption for the sustainability of the planet. Buildings are responsible for 40% of global energy consumption, with as much as 60% of this energy being used for heating and cooling. The building envelop plays a major role in the heat gains and/or losses in buildings. Therefore, buildings provide a great opportunity through their envelope to minimize this high energy consumption by introducing more promising solutions, like passive design strategies. Thermal energy storage, particularly phase change materials (PCMs) is useful sustainable passive technologies that can be used in the building fabric to improve heat exchange and energy efficiency and minimize energy consumption. They can store a high density of thermal energy with slighter temperature change. The favourability of using PCMs lies in the ability of a thin layer of PCMs to store a large amount of heat. Many researchers implemented them in buildings to improve the thermal performance of building materials and minimize energy consumption. Previous studies extensively reviewed TES and PCMs in terms of materials' development, type, properties, performance, methods of testing, and methods of application. It was observed that some works examined the application of PCMs in different positions within the building walls (i.e., two positions—internally and externally—and up to 16 different positions) looking for the optimum position, which guarantees the best performance.

A. Phase Change Material

Materials that can store latent heat during the phase transition are known as phase change materials. Due to the compactness of PCMs the latent heat is much higher than the sensible heat. These materials are still a point of interest for researchers. Lorsch et. al., Lane et. al and Humphries and Griggs have suggested a wide range of PCMs that can be selected as a storage media keeping following attributes under consideration. In order to select the best qualified PCM as a storage media some criteria's are also mentioned by Furbo and Svendsen High latent heat of fusion per unit volume so that a lesser amount of material stores a given amount of energy. High specific heat that provides additional sensible heat storage effect and also avoidsub-cooling.

High thermal conductivity so that the temperature gradient required for charging the storage material is small. High density so that a smaller container volume holds the material. A melting point is desired operating temperature range. The PCM should be non-poisonous, non-flammable and non-explosive No chemical decomposition so that the system life is assure No corrosiveness to construction material. PCM should exhibit little or no sub-cooling during freezing. Also, it should be economically viable to make the system cost effective.

II. LITERATUER REVIEW

Numerically investigated the effects of filling bricks' holes with macro encapsulated PCMs on improving the thermal inertia of the wall. The numerical results were validated with an experimental model. After that, the effects of the PCMs type, position and amount were investigated. PCMs (i.e., five types with melting temperatures of 29.9–52 °C) were filled in the holes of the bricks in one of three positions: external, middle or internal holes (Figure 9). The results showed that the middle position achieved the highest reduction in the total heat flux (i.e., 82.1%) compared to the brick without PCMs. In addition, they increased the amount of PCMs in the bricks by filling another row of holes, which can be either the internal or external holes. The results showed that the bricks with PCMs in the middle and external holes achieved the highest reduction in the total heat flux, though the increase was only 7.92% with double PCM quantity.

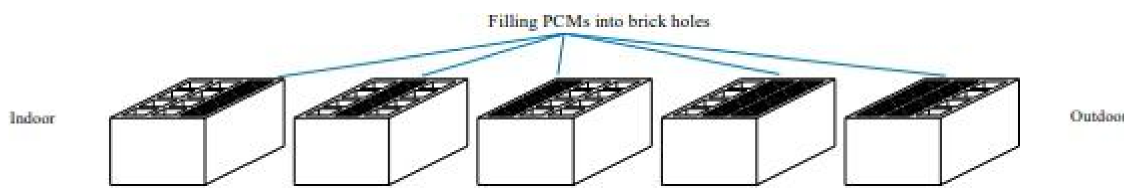

Fig 1. : Bricks filled with PCMs

Experimentally investigated the effects of applying macro-encapsulated PCM in different positions within concrete walls on the indoor temperature and humidity. The PCM (i.e., paraffin with a melting temperature of 20.78 ◦C) was macro-encapsulated in a stainless- steel box in order to increase thermal conductivity, and was tested in three positions.
externally bonded, laminated within the wall or internally bonded.

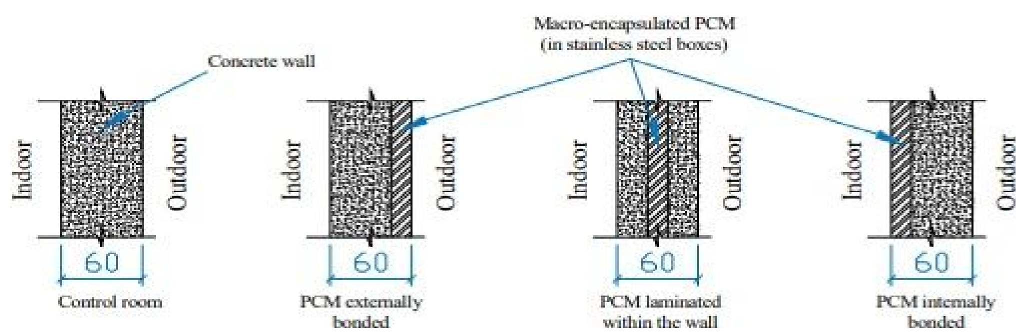

Fig 2: Macro encapsulation of PCMs

Maximum temperatures, compared to the control model, especially during sunny days, while the effects were limited during cloudy days. In addition, the model with PCM laminated within the wall achieved the best temperature reduction (i.e., 4°C) amongst the three models compared to the control model, while the model with the internally bonded PCM achieved a better reduction in relative humidity (i.e., 16%). However, the authors mentioned that the three PCM models were tested on different days and for different durations and suggested carrying out the test on the same days to achieve a better comparison. In another work, Jin, Medina, and Zhang experimentally investigated the thermal performance of three different positions of PCMTS using the dynamic wall simulator. A typical North American residential wall system was selected for the test, which consists of 12.7 mm gypsum wallboard, cardboard, PCMTS two layers of 44.5 mm fiberglass insulation and a 20.5 mm oriented strand board (OSB). A PCMTS layer with cardboard was placed near to the gypsum wallboard, near to the OSB and between the two insulation layers.

The experimental setup was similar to the previous work. The results showed that the higher reduction in the peak heat fluxes was 11%, with the PCMTS layer near to the gypsum wallboard within the cavity. However, the reduction in the peak heat fluxes was smaller when the PCMTS layer was placed between the two insulation layers, while there was no effect with the PCMTS layer placed within the cavity near to OSB. They concluded that PCMTS should be placed closer to the space.

III. MATERIALS

A. Paraffin Wax

It is used as a PCM (product code is U391) and was supplied by Oztin Chemical Company, Turkey. The melting point and latent heat of the paraffin wax are 52.8 °C and 180 J/g, respectively. Paraffin wax is a solid crystalline mixture of straight-chain (normal) hydrocarbons ranging from C_{20} to C_{30} and possibly higher, that is, $CH_3(CH_2)_n CH_3$ where $n \geq 18$. It is distinguished by its solid state at ordinary temperatures (25°C, 77°F) and low viscosity (35–45 SUS at 99°C, 210°F) when melted. However, in contrast to petroleum wax, petrolatum (*petroleum jelly*), although solid at ordinary temperatures, does in fact contain both solid and liquid hydrocarbons. It is essentially a low-melting, ductile, microcrystalline wax. Although many natural waxes contain esters, paraffin waxes are hydrocarbon derivatives, mixtures of alkane derivatives usually in a homologous series of chain lengths. These materials represent a significant fraction of crude oil and are refined by vacuum distillation. Paraffin waxes are mixtures of saturated *n*- and iso-alkanes, naphthenes, and alkyl- substituted and naphthene-substituted aromatic compounds. A typical alkane paraffin wax's chemical composition comprises hydrocarbons with the general formula C_nH_{2n+2}. The degree of branching has an important influence on the properties.

B. Stearic Acid

In view of the soft texture of the sodium salt, which is the main component of soap, other salts are also useful for their lubricating properties. Lithium stearate is an important component of grease. The stearate salts of zinc, calcium, cadmium, and lead are used to soften PVC. Stearic acid is used along with castor oil for preparing softeners in textile sizing. They are heated and mixed with caustic potash or caustic soda. Related salts are also commonly used as release agents, e.g. in the production of automobile tires. As an example, it can be used to make castings from a plaster *piece* mold or waste mold, and to make a mold from a shellacked clay original. In this use, powdered stearic acid is mixed in water and the suspension is brushed onto the surface to be parted after casting. This reacts with the calcium in the plaster to form a thin layer of calcium stearate, which functions as a release agent. When reacted with zinc it forms zinc stearate, which is used as a lubricant for playing cards (fanning powder) to ensure a smooth motion when fanning. Stearic acid is a common lubricant during injection molding and pressing of ceramic powders.[19] It is also used as a mold release for foam latex that is baked in stone molds.

C. RT 27

The established PCMs of the RT category are organic materials. They use their melting process from solid to liquid (and vice versa) in order to store and release large amounts of heat in an approximately constant temperature range. Depending on their melting point, a variety of applications at different temperatures can be considered for heat storage. Due to their purity and specific composition our PCMs show up a remarkable latent heat capacity in narrow temperature ranges. In addition, they are chemically inert and have an unlimited lifetime.

Our RT products are available for a wide temperature range of about -10 °C to 90 °C (14°F to 194 °F). If you are not able to retrieve the desired temperature for your application, please do not hesitate to contact us. PCMs can be produced for almost all temperatures.

For certain temperatures also high capacity RTs (e.g. Rubitherm RT 5 HC) are available. The RTHC products possess a higher latent heat capacity of 25 - 30% compared to classic RT materials and melt in a narrower temperature range. These PCMs are also advantageous in cases in which a limited volume exists. The PCM materials can be received in the liquid state, as solid blocks, granulate material or flakes. For any questions concerning our products or for further possible heat storage temperatures please contact our staff. We are looking forward to assisting you. RT materials are also offered in combination with the compact storage module (CSM) or macro encapsulations. RT materials are also the basis for our bound or microencapsulated PCMs. On request more melting point are available.

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IV. NUMERICAL METHOD

Numerical methods, is approximation fast solution for mathematical problems. Such problems can be in any field in engineering. So any result you get from it is approximated not exact, it give you the solution faster than normal ones, also it's easy to be programmed. Here is some issues that numerical analysis is used in: Solving linear/non-linear equations and finding the real roots, many methods exist like: Bisection, Newton-Raphson ... etc. Fit some points to curve, good approximation and simple solution. Interpolation, great to get any value in between a table of values. It can solve the equally spaced readings for unequally spaced methods, Newton general method is implied. Solve definite integration, simple methods is used to compute an integration based on idea that the definite integration is the bounded area by the given curve, these methods approximate the area with great approximation. Many methods there, like Simpson's rule. Solving initial value 1st and 2nd order differential equations, good approximation and simpler than normal analysis. Solving partial differential equations like laplace equation for wave equation, very fastsolution.

V. MODELING IN SPACE CLAIM WITH CFD

Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical analysis and data structures to analyze and solve problems that involve fluid flows. Computers are used to perform the calculations required to simulate the free-stream flow of the fluid, and the interaction of the fluid (liquids and gases) with surfaces defined by boundary conditions. With high-speed supercomputers, better solutions can be achieved, and are often required to solve the largest and most complex problems. Ongoing research yields software that improves the accuracy and speed of complex simulation scenarios such as transonic or turbulent flows. Initial validation of such software is typically performed using experimental apparatus such as wind tunnels. In addition, previously performed analytical or empirical analysis of a particular problem can be used for comparison. A final validation is often performed using full-scale testing, such as flight tests. embedded in a program as complex as a CFD code or the accuracy of its final results by any means other than comparison with experimental test work. Anyone wishing to use CFD in a serious way must realise that it is no substitute for experimentation, but a very powerful additional problem solving tool. Validation of a CFD code requires highly detailed information concerning the boundary conditions of a problem, and generates a large volume of results. To validate these in a meaningful way it is necessary to produce experimental data of similar scope. This may involve a programme of flow velocity measurements with hot-wire anemometry, laser Doppler anemometry or particle image velocimetry. However, if the environment is too hostile for such delicate laboratory equipment or if it is simply not available, static pressure and temperature measurements complemented by pitot-static tube traverses can also be useful to validate some aspects ofa flow field.

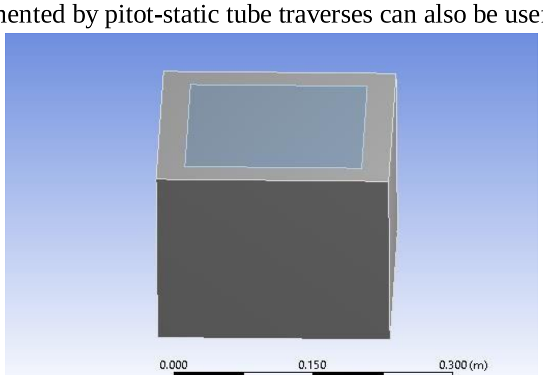

Fig 2.1: BUCKET

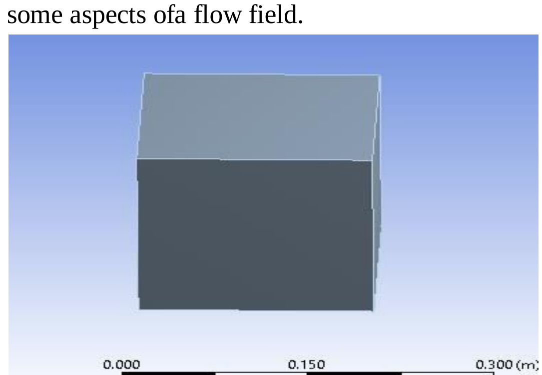

Fig 2.2: WATER

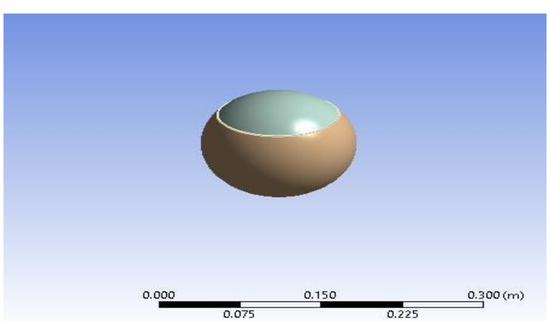

Fig 2.3: PCM SPHERE

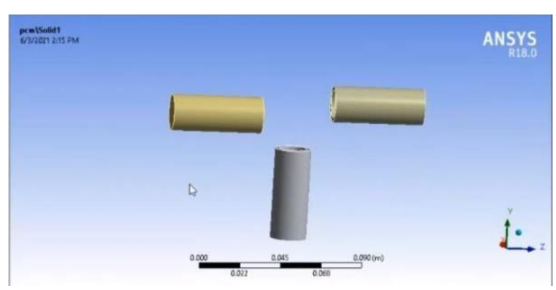

Fig 2.4: Fins

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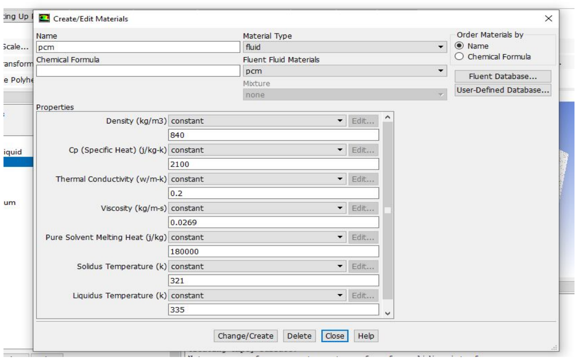
A. Boundary Conditions

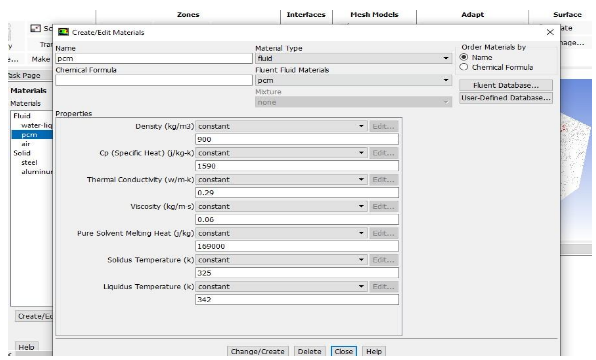
S.NO	PCM MATERIAL USED	Mass flow rate (kg/sec)	Temperature (k)	Heat transfer coefficient (w/m2-k)	Free stream temperature (k)	Initial gauge pressure (PASCAL):
1.	PARAFFIN WAX	2	310	30	300	0
2.	STEARIC ACID	2	310	30	300	0
3.	RT27	2	310	30	300	0

Table 6.1: Input Boundary Condotions

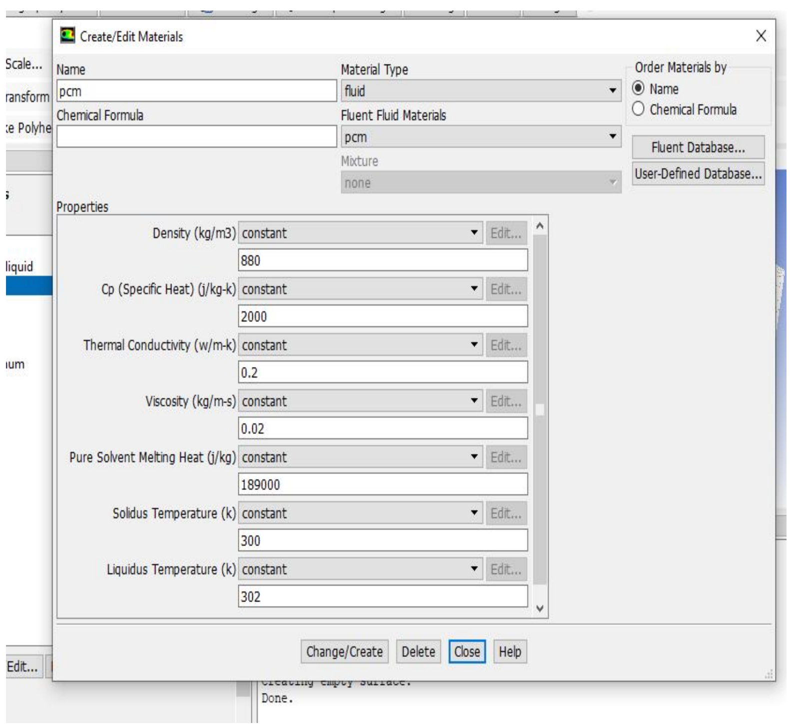
B. Material Properties Input



Paraffin Wax Input Properties



Setric Acid Inout Properties



RT 27 Input Properties

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VI. RESULT AND ANALYSIS

A. Temperatuer Results

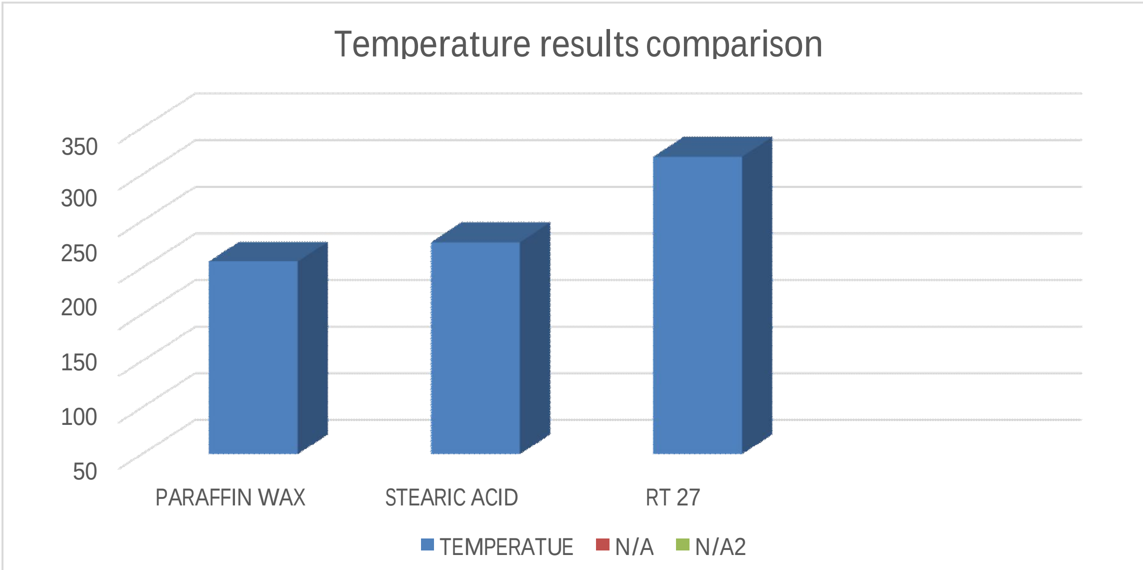

Fig 7.1.1: Temperature Results GRAPH

S.NO	MATERIAL USED FOR ANALYSIS	TEMPERATURE (k)
1	PARAFFIN WAX	207
2	STEARIC ACID	227.5508
3	RT 27	319.31894

Table 7.1.2: Result Table Temperature

B. Pressure Results

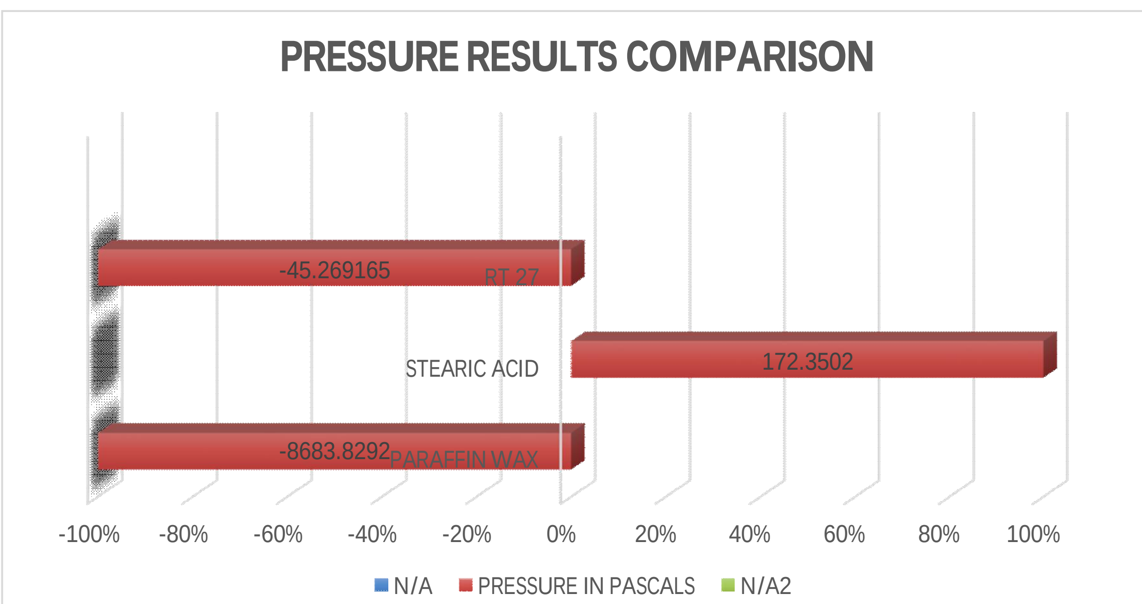

Fig 7.2.1: Pressure Results GRAPH

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S.NO	MATERIALUSED FOR ANALYSIS	PRESSURE(PASCAL)
1	PARAFFIN WAX	-8683.8292
2	STEARIC ACID	172.3502
3	RT 27	-45.269165

Table 7.2.2: Pressure Results

C. *Velocity Results*

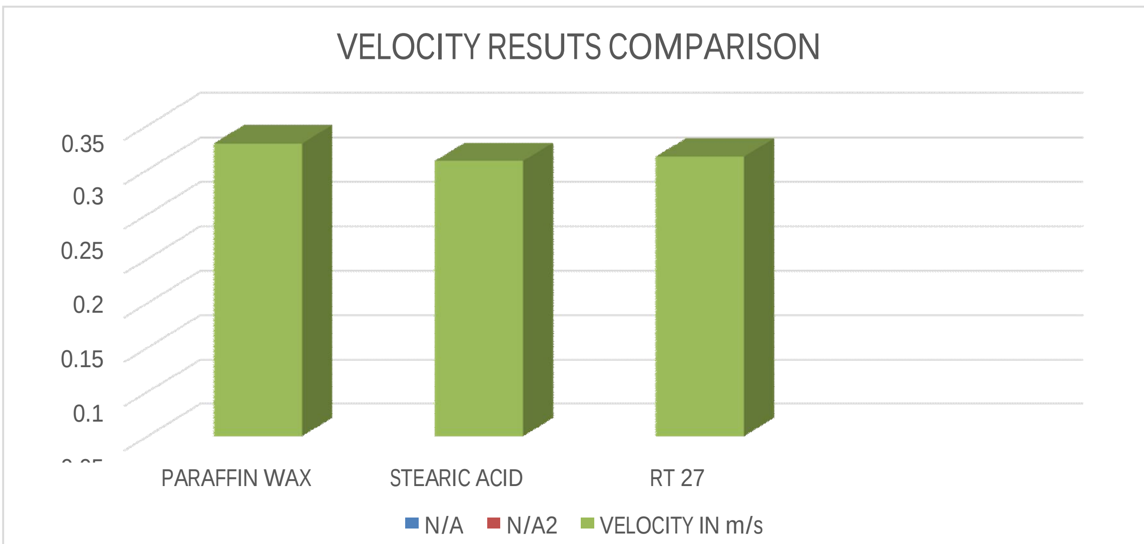

Fig 7.3.1: Velocity Results Graph

S.NO	MATERIAL USED FOR ANALYSIS	VELOCITY (m/s)
1	PARAFFIN WAX	0.33
2	STEARIC ACID	0.31
3	RT 27	0.315

Table 7.3.2: Velocity Results

D. *Paraffin wax*

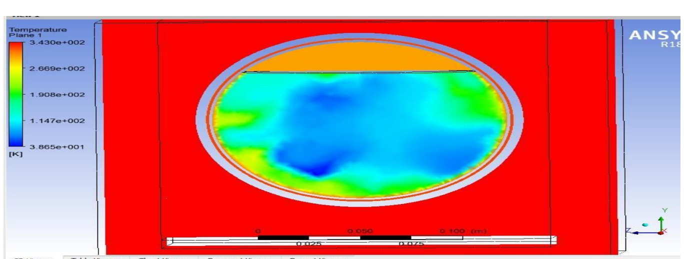

Fig 7.4.1: paraffin wax analysis output temperature

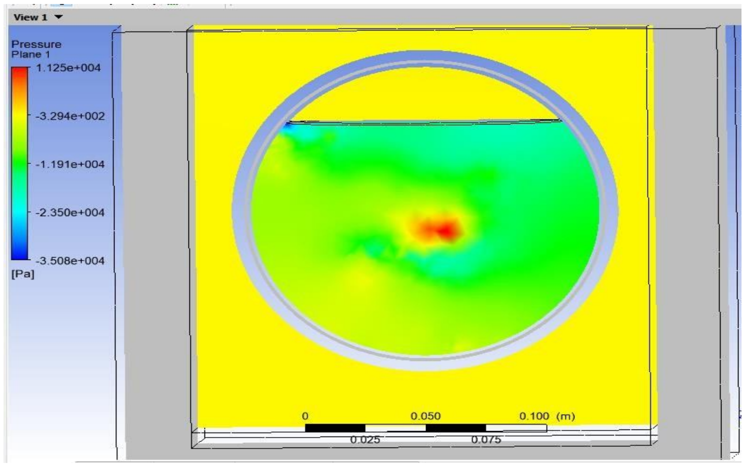

Fig 7.4.2: paraffin wax analysis output Pressure

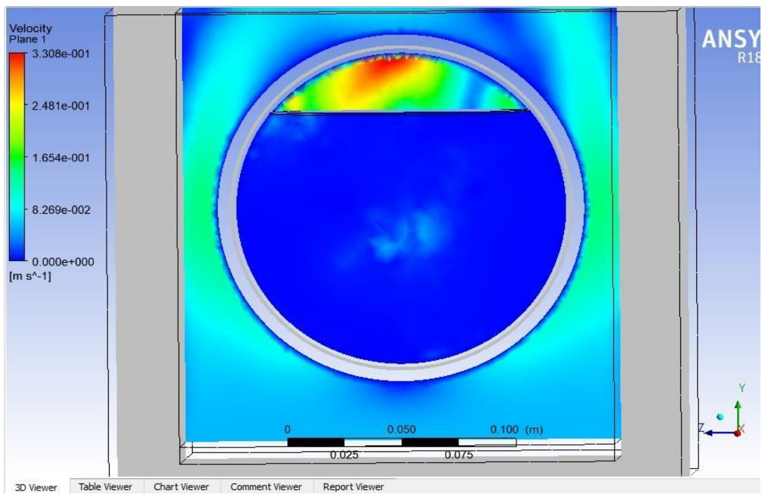

Fig 7.4.3: Paraffin Wax Analysis Output Velocity

E. Stearic Acid

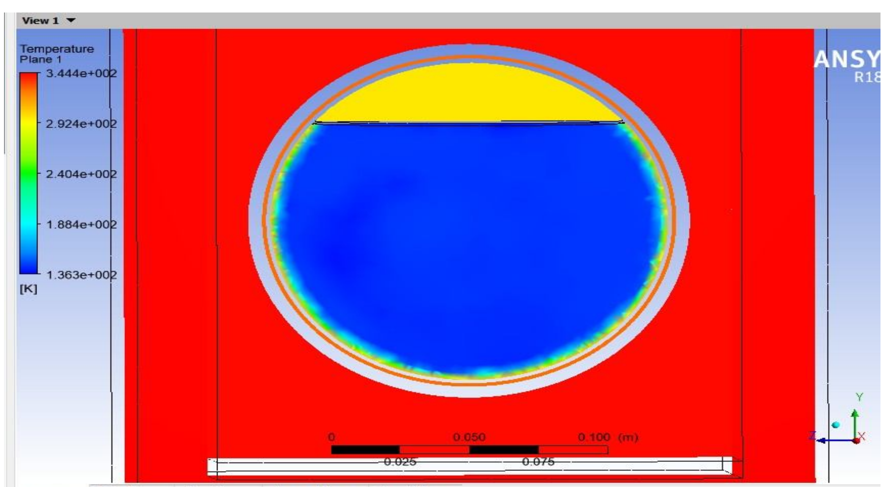

Fig 7.5.1: Stearic Acid Analysis Output Temperature

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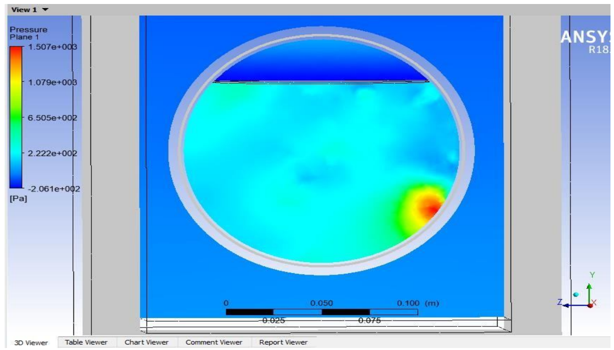

Fig 7.5.2: Stearic Acid Analysis Output Pressure

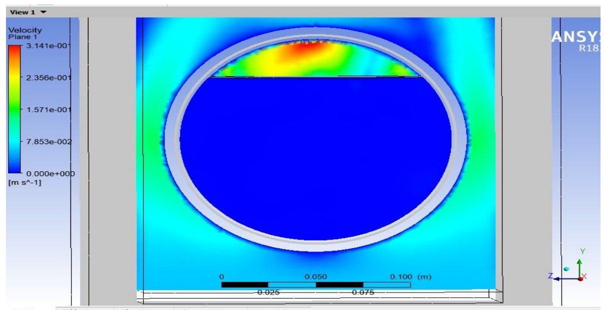

Fig 7.5.3: Stearic Acid Analysis Output Velocity

F. RT 27

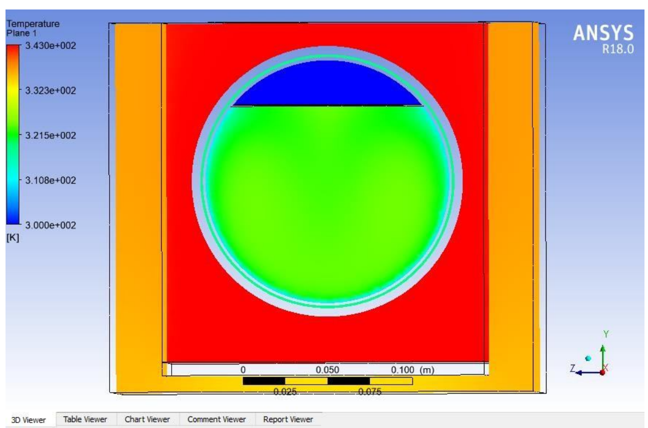

Fig 7.6.1: RT 27 Analysis Output Temperature

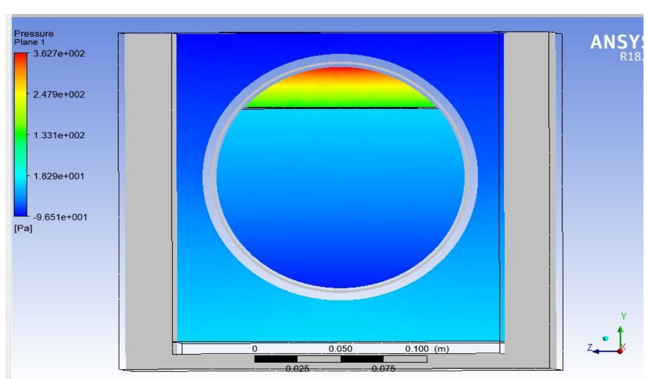

Fig 7.6.2: RT 27 ANALYSIS OUTPUT PRESSURE

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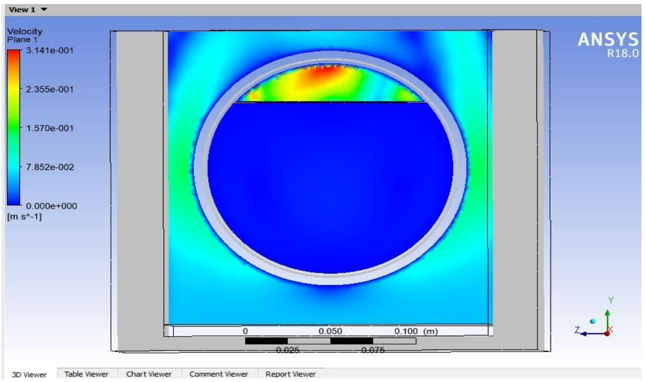

Fig 7.6.3: RT 27 Analysis Output Velocity

VII. CONCLUSION

The use of phase change materials in Thermal Energy storage (TES) is well known. By incorporating the PCM, improves thermal comfort of the inside room and also it increases the energy efficiency of the object. If the thermal mass of the object is low, the PCM encapsulation will help to reduce the temperature fluctuations. In this analysis it is proved that, by applying a PCM in the middle of the object, the inside temperature is nearly reduced by 5^0c. This method is very effective in case of high rise temperatures, where a considerable amount of cooling load is entered through wall. This method also helps to shifts the peak temperature time. But during the cooling cycle of the PCM, there is a chance to release the heat into the interior space. This can be avoided by offsetting the PCM application distance t towards the exterior side.

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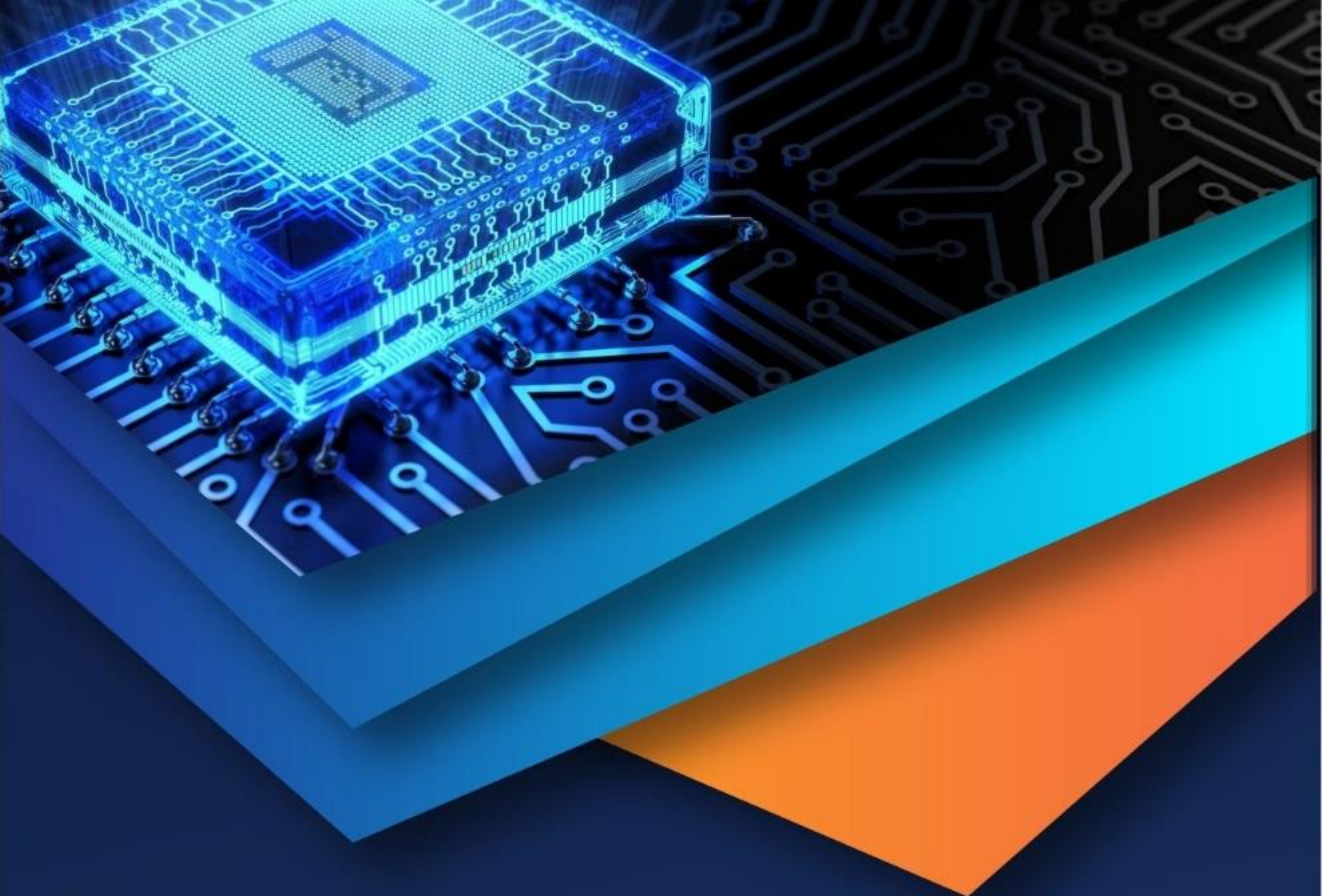

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