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TO STUDY THE EFFECT OF NANO PARTICLES WITH PCM MATERIAL IN SPIRAL TUBES HEAT EXCHANGER

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Abstract

Demands for energy are growing as the economy grows at an accelerating pace. Due to the fast depletion of non-renewable resources, conservation of energy has been a major focus for scholars. To save fossil fuels, thermal energy storage is one of the most efficient ways of storing waste heat energy from the large field of heat exchangers. With its large latent heat capacity at low temperatures, phase transition material may effectively and efficiently store thermal energy. An energy storage medium called PCM is being tested in this study to see how it impacts the heat transfer rate of a spiral tube heat exchanger. Spiral wired tube heat exchanger performance is improved in this work by including nanoparticles such as Al2O3 into the PCM. Analytical research was conducted utilising simulation tools and software in order to get the final findings.

Keywords: PCM, Nano Particles, Heat Exchanger, CFD, Heat Transfer Rate, Melting, Mass Flow Rate

1. INTRODUCTION

A heat exchanger is a device that may be used to heat and cool an object. Heated fluids may be exchanged across systems. Anyone who uses a device for cooling, heating, condensation, boiling, or evaporation will understand the importance. Before the technique, the fluids may be heated or cooled, and they may also be subjected to physical alteration. Heat exchangers are called in accordance with

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their intended use. Heat exchangers that are used to condense are referred to as condensers, whereas those that are used to boil are called boilers. Heat transfer efficiency and pressure drop are used to evaluate the effectiveness and efficiency of heat exchangers. By calculating all heat transfer constants, a greater presentation of its efficacy may be achieved. The pressure drop and the amount of space required to transport a certain amount of heat provide an idea of a device's capital costs and power requirements (called the "Running cost"). It's common for there to be a plethora of literature and thoughts on how to design a gadget that meets the needs.

1.1. Phase change Material

PCMs (phase change materials) are widely employed in the storage and transport of thermal energy. Heat energy may be stored in PCM material, and it changes phase without changing its temperature. It heats up the surrounding air by altering its phase. It is this capacity to change phase and absorb or release heat at a steady temperature that gives PCM materials their unique advantages over other types of materials. Due to the poor thermal conductivity (less than 0.5 W/mK) of PCM material, heat exchanger system performance would suffer. As a result, new approaches to dealing with phase transition material's poor heat conductivity are required.

1.2. Classification of PCM Material

Organic and inorganic phase change materials (PCMs) may be subdivided into two primary categories.

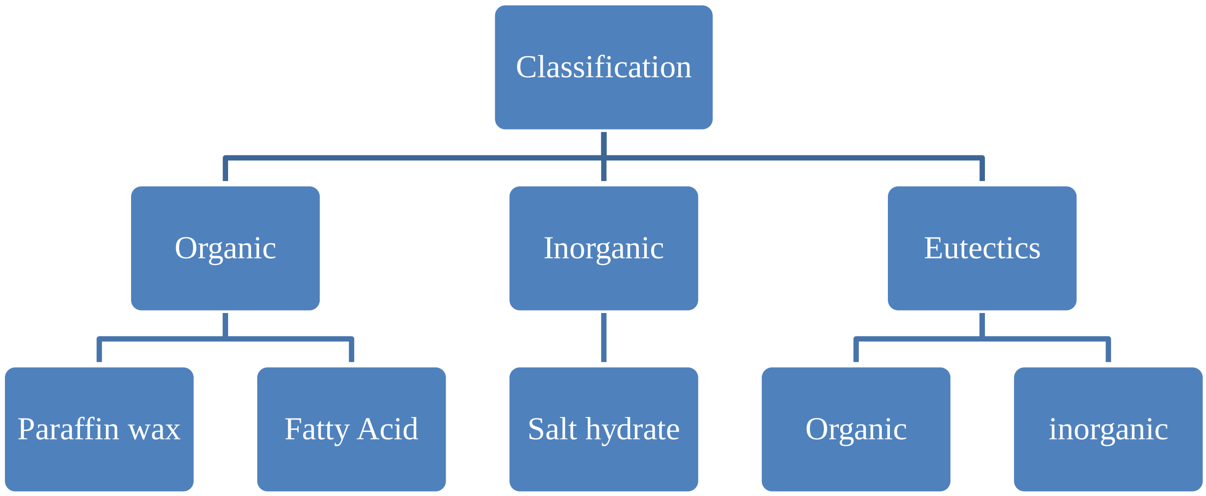

Figure 1 Classification of PCM Material

1.3. Nano particles

Using nanofluids, which are fluids containing nanoparticles (smaller than 100 nm in size), traditional fluids may have their heat transfer capacity increased in an entirely new way. Nano particle physics and thermal engineering converge in this technique. Conventional fluid is replaced with nanofluids, which have a high thermal heat transfer capacity and are employed instead. The thermal performance of nanoparticles is always superior to that of their basic fluids. Thermal conductivity is projected to be improved by this combination of base fluid and nanoparticle. As a result, further research into nanoparticles and nanofluids is needed to take use of their unique features. In addition to eliminating heat, nanofluids may also transmit heat.

1.4. Objectives of the study

The objectives of the following work are:

- To study the effect of A16 PCM Material in spiral tube heat exchanger.
- To study the performance of Nano particles mixed with PCM material.
- To calculate mass fraction of PCM materials using aluminium oxide (Al_2O_3) as nanoparticle in different percentage.
- To calculate Heat transfer rate of PCM materials using aluminum oxide (Al_2O_3) as nanoparticle in different percentage.
- To evaluate the results and performance using different percent of nano particles in PCM material for obtaining optimum percent of nano particles required for improving the performance of spiral tube heat exchanger.
- To compare the results with base paper.

2. LITERATURE REVIEW

(Youssef, Ge and Tassou, 2018) [1] In present study, PCM Material is used for the heat exchanger pipes with different design of and cross section of pipes. By using different pipe design, it is expected that the heat transfer and heat storage performance will increase. To verify this work and understand the process, a detailed 3D design is modeled and by using CFD it is developed for the PCM heat exchanger and with the dimensions, is validated. When charging and discharging the PCM, the temperature changes in PCM are simulated and shown. The effects of different water heat transfer fluid flow rates and temperature on the PCM melting/solidification time are also shown in this research.

(Mahdi *et al.*, 2019) [2] The "Triplex-tube heat exchanger (TTHX)" has been shown to be a particularly efficient thermal energy storage device when using Phase change material. Extendable fins, metals, and other materials have previously been studied. However, there has to be a lot more effort on improving thermal energy storage technologies. Heat may be stored and recovered or charged at the same time in a practical system. Adding an unique fin SCD condition to TTHX increased its performance in this trial. The performance of various fin shapes is studied numerically.

(Aldoss and Rahman, 2018) [3] In comparison to intelligent thermal storage systems, "latent thermal storage systems" are more cost effective and more compact. "Heat transfer fluid (HTF)" temperatures on the bed vary according on the technique of charging and discharging, with a greater intake temperature and a lower output temperature. Researchers recently proposed using numerous PCM's rather of a single PCM in the bed to match the "HTF temperature profile", therefore increasing the heat transfer rate by matching the temperature variance. It is known as "cascaded PCM distribution" when referring to this new approach. The next logical issue is how many steps should be in the cascade. This research addresses the cascading limit situation, which is the continuous linear cascade.

(Esteves *et al.*, 2018a) [4] Two phase transition materials, salt and paraffin, were tested in a laboratory setting to see how they behaved during fusion and solidification cycles. Because the heat transfer medium was thermal oil, the state change material was evaluated during a fusion and hardening cycle, which necessitated the use of thermal oil. To aid in the fusion process, the heat transfer oil provided energy to the phase change material, as well as absorbed energy lost during this process. The effect of the heat transfer fluid's mass rate on the phase change material's reaction, but not its temperature, was investigated.

(Solano *et al.*, 2018) [5] The heat transmission between a fluid, a tube, and a PCM material is being examined in the current research. The heat transfer fluid intake and outflow boundary conditions are coupled with the solar collector, which delivers the thermal energy to the fluid. Using this method, the model can quantify the effect of a particular solar radiation curve on the thermal energy storage capacity. With the employment of rectangular finned tube, the decreased latent heat storage detected under winter settings (peak irradiance of 500 W/m2 and nine hours of sun light) may be overcome. When the heat transfer surface to PCM volume ratio is increased by 5.7 times, thermal energy storage capacity is increased by 2.2 times.

(Al Siyabi *et al.*, 2018) [6] The high latent heat capacity of PCM-based conductors on a small scale will allow them to manage the temperature of electrical equipment. PCM combination, PCM arrangement, PCM thickness, melting temperature, and intensity of heat supply are evaluated in three distinct heat sinks to see how these factors affect the thermal behaviour of the heat sink. The melting profile of PCM may be determined by analysing the heat sink's temperature distribution.

3. RESEARCH METHODOLOGY

3.1. Step of working [7]

- Inquiring into the PCM material-based heat exchanger's data and information.
- The mixing ratio of PCM material and nanofluid is calculated manually.
- It is designed in CATIA V5 in accordance with the base paper's recommendation.

- CATIA V5 file is then converted to step format and loaded into fluent work bench following the conversion.
- The various sections of the system are given further names.
- The 3D model is used for meshing.
- It is applied to the model in accordance with the chosen base paper.
- This is done by assigning properties to materials.
- Results are computed and compared to other instances.

3.2. Governing Equations used in CFD [8]

Continuity Equation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \underset{V}{\rightarrow}) = 0$$

Momentum Equation in x direction

$$\frac{\partial(\rho u)}{\partial t} + \nabla.\ (\rho u \underset{V}{\rightarrow}) = -\frac{\partial p}{\partial x} + \frac{\partial \tau xx}{\partial x} + \frac{\partial \tau yx}{\partial y} + \frac{\partial \tau zx}{\partial z} + \rho f x$$

Momentum Equation in y direction

$$\frac{\partial(\rho v)}{\partial t} + \nabla.\ (\rho v \underset{V}{\rightarrow}) = -\frac{\partial p}{\partial y} + \frac{\partial \tau xy}{\partial x} + \frac{\partial \tau yy}{\partial y} + \frac{\partial \tau zy}{\partial z} + \rho f y$$

Momentum Equation in z direction

$$\frac{\partial(\rho w)}{\partial t} + \nabla.\ (\rho w \underset{V}{\rightarrow}) = -\frac{\partial p}{\partial z} + \frac{\partial \tau xz}{\partial x} + \frac{\partial \tau yz}{\partial y} + \frac{\partial \tau zz}{\partial z} + \rho f z$$

Energy Equation

$$\frac{\partial}{\partial t}\left[\rho\left(e + \frac{v2}{2}\right)\right] + \nabla.\ \left[\rho\left(e + \frac{v2}{2}\ \underset{V}{\rightarrow}\right)\right] = \rho \dot{q} + \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) - \frac{\partial(uP)}{\partial x} - \frac{\partial(vP)}{\partial y} - \frac{\partial(wP)}{\partial z} + \frac{\partial(u\tau xx)}{\partial x} + \frac{\partial(u\tau yx)}{\partial y} + \frac{\partial(u\tau zx)}{\partial z} + \frac{\partial(v\tau xy)}{\partial x} + \frac{\partial(v\tau yy)}{\partial y} + \frac{\partial(v\tau zy)}{\partial z} + \frac{\partial(w\tau xz)}{\partial x} + \frac{\partial(w\tau yz)}{\partial y} + \frac{\partial(w\tau zz)}{\partial z} + \rho f \cdot \underset{V}{\rightarrow}$$

3.3. Boundary Condition

When charging, the PCM and HTF temperatures should be adjusted to 10 and 40 degrees Fahrenheit correspondingly, and the PCM should be solid. The "Velocity-intake" boundary condition for the HTF at the PCM HX inlet is utilised in the CFD model's boundary conditions. It is governed by the input volumetric flow rate and the diameter of the inlet inner pipe. [9] [10]

Table 1: Applied boundary conditions

Inlet Condition	**Parameter**
Inlet Fluid Temperature	40 ^{0}C
Inlet water velocity	0.33 m/s
PCM Initial temperature	10 ^{0}C
Operating environment temperature	27 ^{0}C

4. RESULTS AND DISCUSSION

4.1. Mass Fraction of Different Material

There is a mass fraction between 0 and 1. Solid materials have a range of 0; liquid materials have a range of 1. The red colour indicates that the substance is in a liquid condition, while the blue colour shows that the material is in a solid state. Tables, snaps, and a Bar Chart are used to display the results.

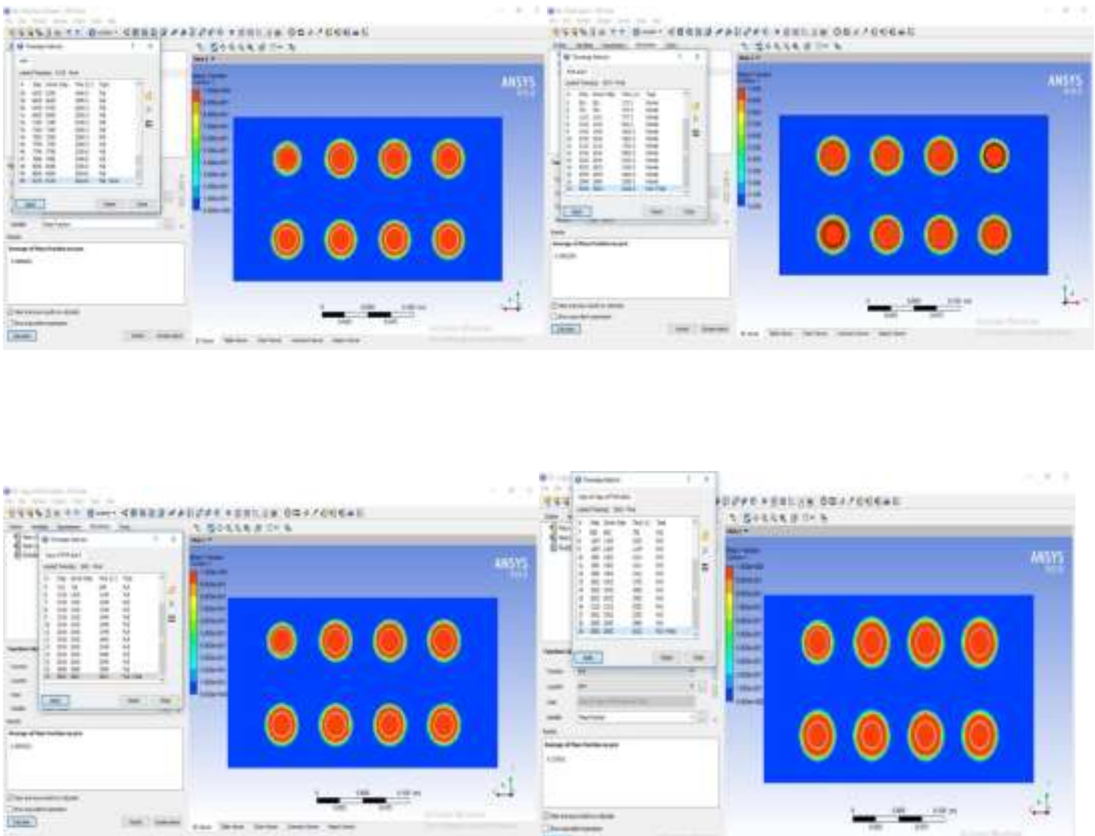

Figure 2: Mass Fraction Contour (a) Only PCM; (b) PCM + 0.5%Al_2O_3 (c) PCM + 1%Al_2O_3 (d) PCM + 2%Al_2O_3

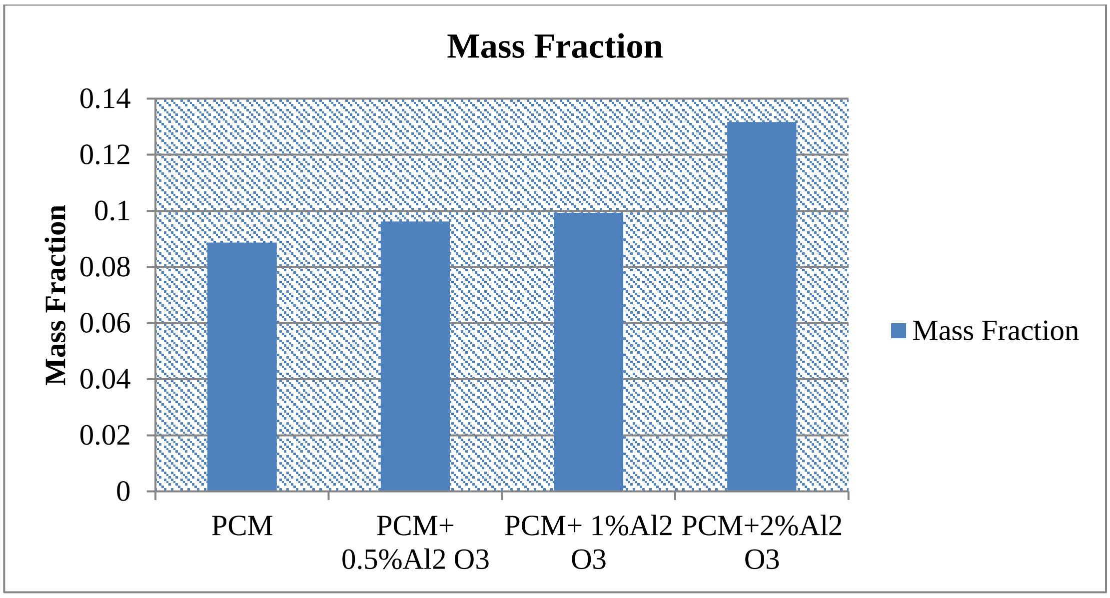

Figure 3: Average of mass fraction Graph

4.2. Total heat transfer rate of Different Material

The total heat transfer rate in calculate by using ANSYS Flux reports interface and select total heat transfer rate in between inlet and outlet of HTF (Heat Transfer Fluid). The positive sign indicate that the heat in inter is system and negative sign indicate that the heat is rejected by the system. All the heat transfer value and graph of PCM material and different percentage of nano fluid is shown in figure.

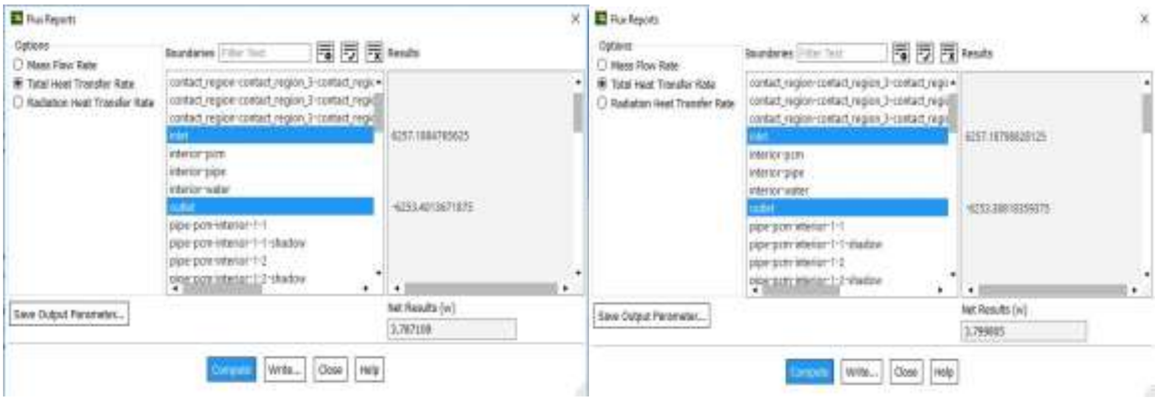

Figure 4: Total heat transfer (a) PCM material; (b) PCM+0.5% Al_2O_3 material; (c) PCM+1% Al2O3 material; (d) PCM+2% Al_2O_3 material

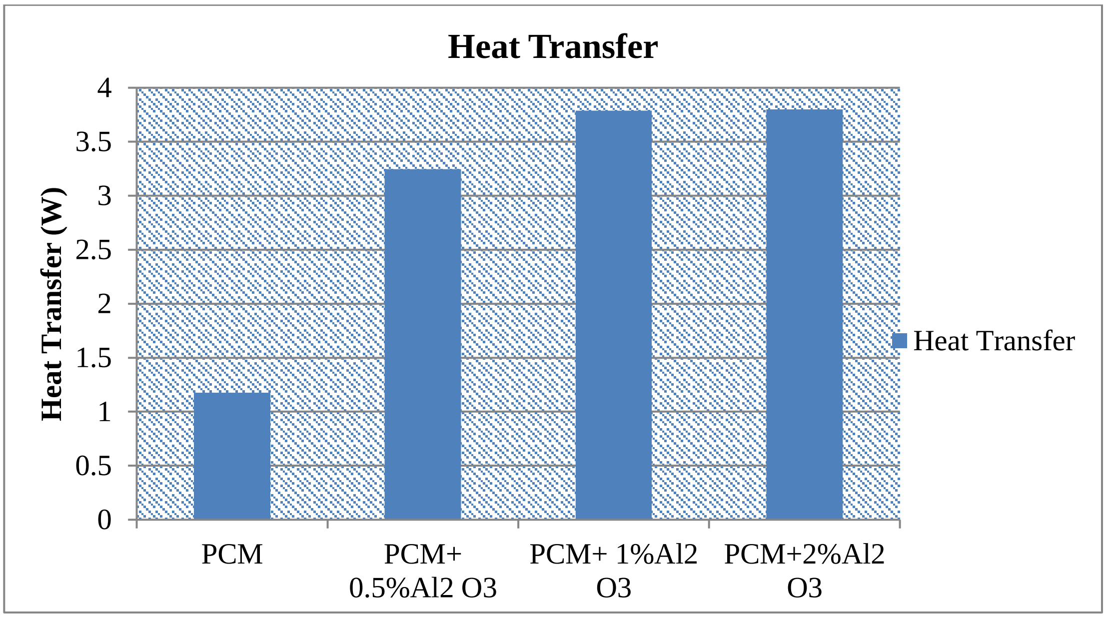

Figure 5: Total heat transfer rate in different percentage of Nano Particle

4.3. Temperature Distribution of Material

There is a 313K inlet temperature and a 0.33m/s velocity in the HTF system. The graphic depicts the temperature distribution after the completion of the study in 2560s. The greatest temperature, displayed in red, is 313 degrees Kelvin, while the lowest temperature, represented in blue, is 284.8 degrees Kelvin.

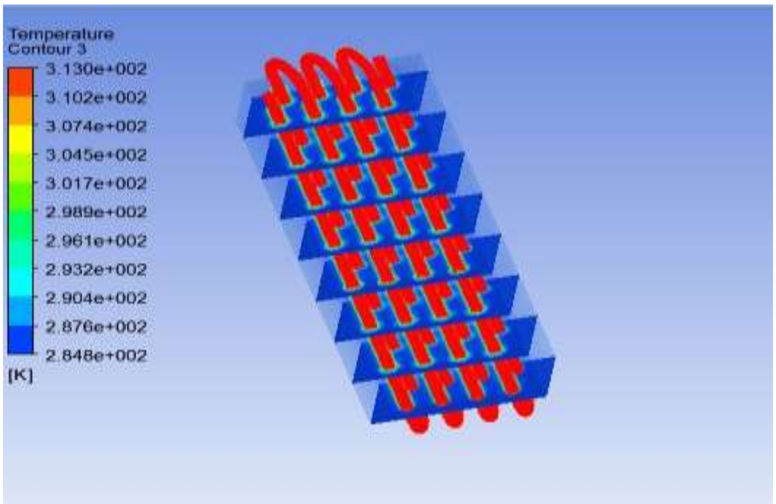

Figure 6: Temperature distribution PCM materials

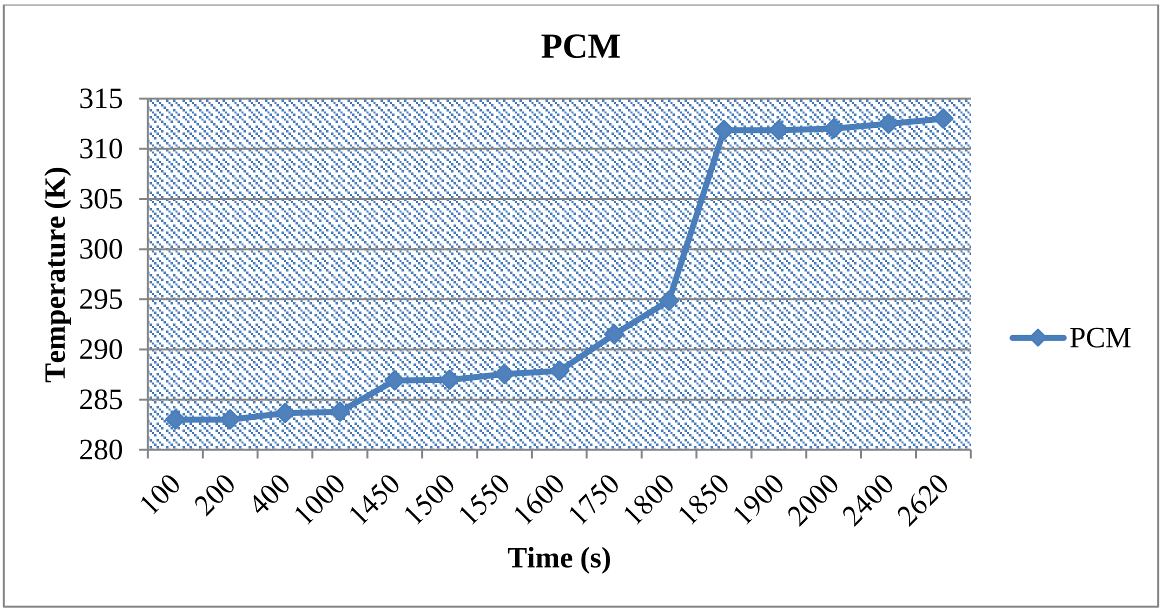

Figure 7: Graph showing steadiness in temperature rise on PCM material

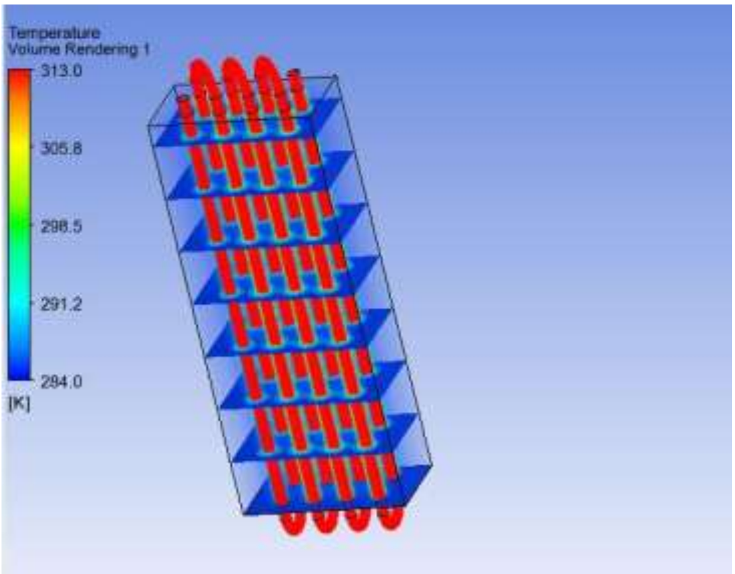

Figure 8: Temperature distribution PCM+0.5% Al_2O_3 materials

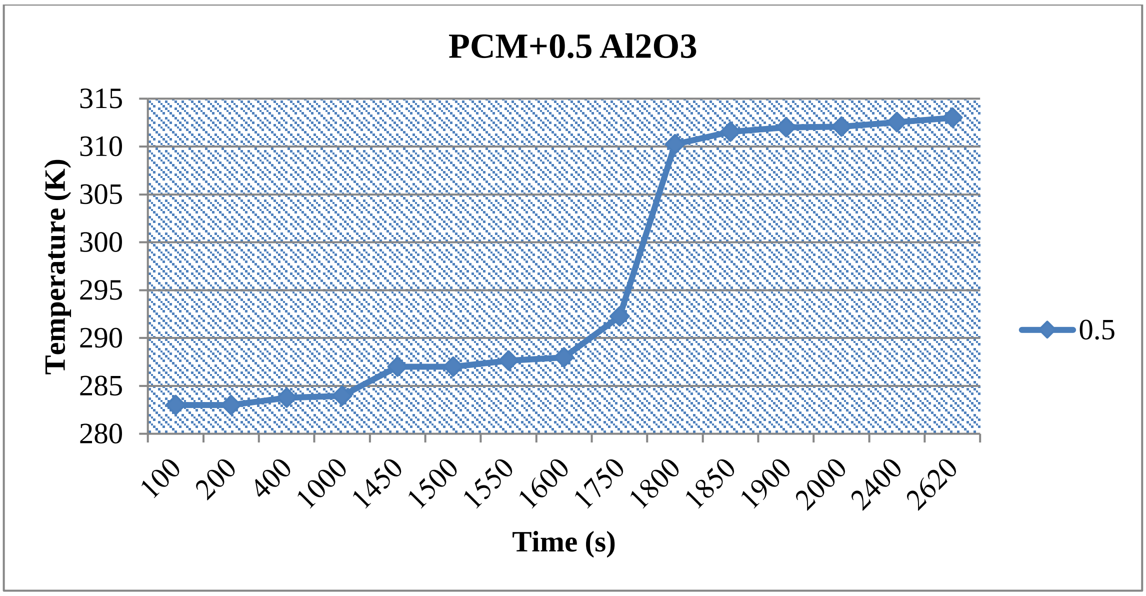

Figure 9: Graph showing steadiness in temperature rise on PCM+2% Al_2O_3 material

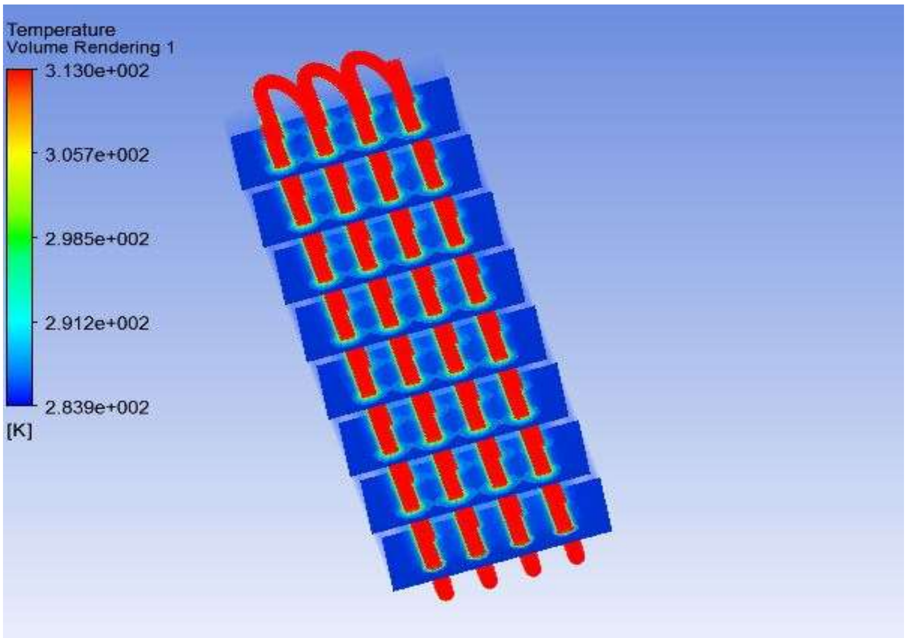

Figure 10: Temperature distribution PCM+1% Al_2O_3 materials

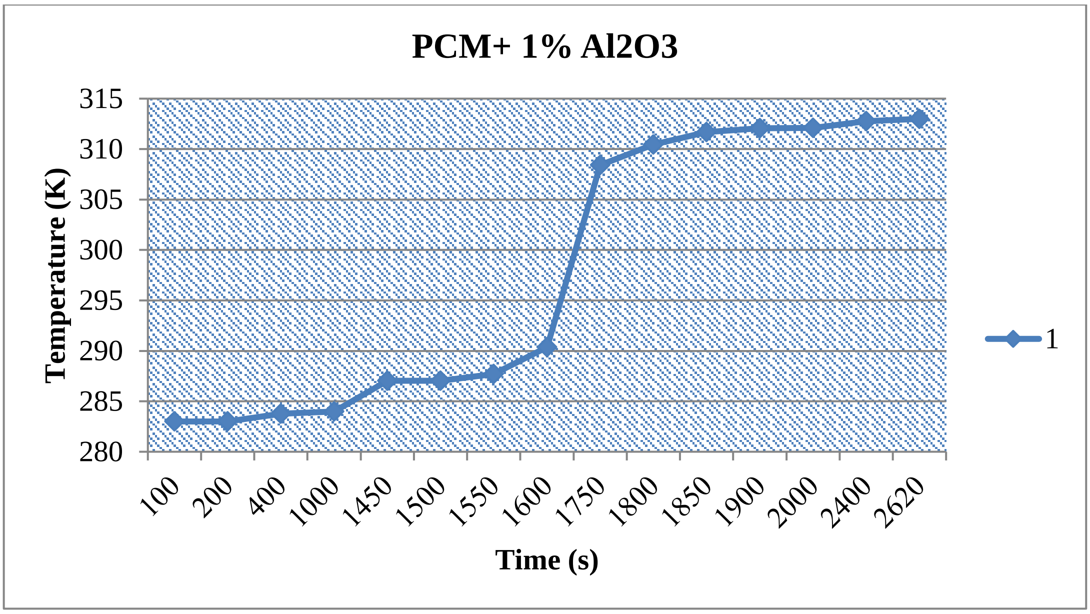

Figure 11: Graph showing steadiness in temperature rise on PCM+1% Al_2O_3 material

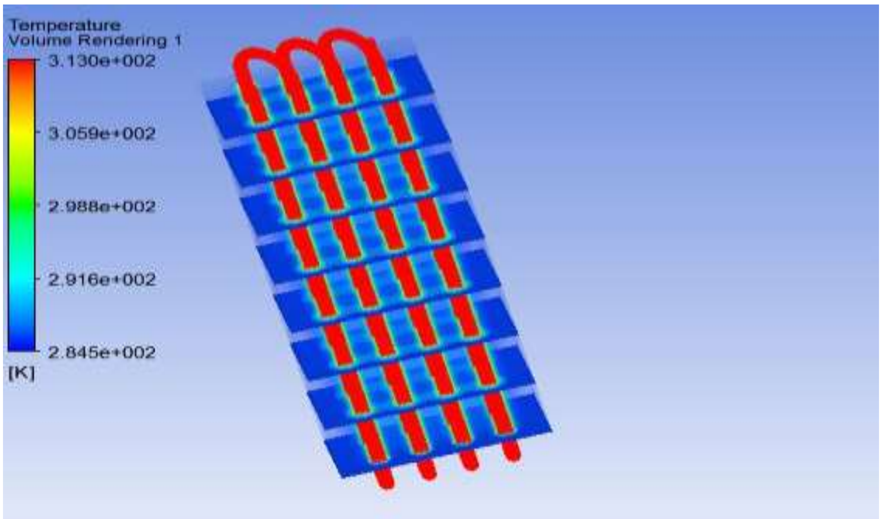

Figure 12: Temperature distribution PCM+2% Al_2O_3 materials

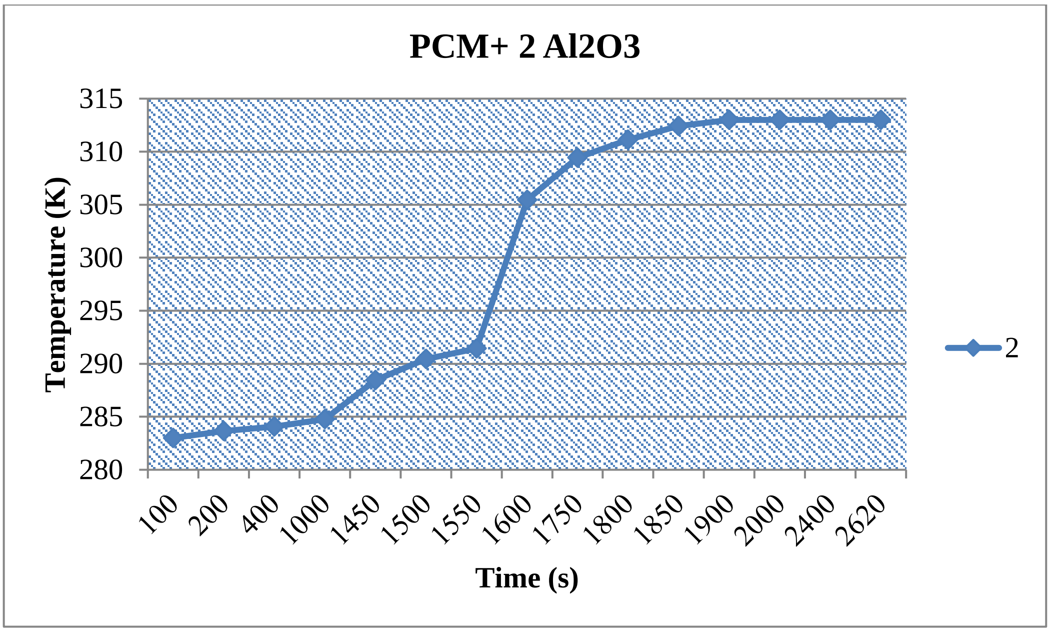

Figure 13: Graph showing steadiness in temperature rise on PCM+2% Al_2O_3 material

4.4. Discussion

- PCM material containing Nano particles has been discovered to improve the heat exchanger's performance.
- When a little number of Nano particles was added to the phase change material, the PCM's heat absorption capacity rose.

- In order to make comparisons between various percent values, the findings demonstrate how the whole system behaves when different percent of Nano particles mixed with PCM material are used.
- Using the data, we can figure out what Nano particle percentage should be used in the PCM material combination for best outcomes.
- It is possible to compare the heat exchangers with basic PCM and PCM with nanoparticles.

5. CONCLUSION

The complete CFD test was carried out satisfactorily and the desired result was reached. As a consequence of the findings, we can say the following:

- For each example, the PCM material was combined with varying percentages of the Nano particle Al_2O_3, such as 0.5, 1, or 2 percentages.
- It has been shown that the mass fraction increases as the proportion of PCM material increases.
- It has also been shown that the total heat transmission from intake to exit rises when Nano particles are added in varying percentages.
- The mass fraction of PCM material is 0.08868, whereas the mass fraction of AL_2O_3 nanoparticle mix with PCM in 0.5, 1, and 2 percentages is 0.09623, 0.09925, and 0.13165, respectively.
- Total heat transmission of PCM is 1.17W, whereas the total heat transfer of AL_2O_3 nanoparticle mix with PCM in 0.5, 1, and 2 percentages is 3.24, 3.78, and 3.8 W correspondingly.
- Temperature increases in PCM heat exchangers when AL_2O_3 nanoparticles are mixed with it in 0.5, 1, or 2 percent solutions take place in the 1800s, 1750s, and 1600s (roughly) before they reach their maximum output temperature.
- The blend of 2% PCM material yielded the highest mass fraction value. How does one choose the ideal combination of ingredients to use in the whole setup?
- It was also discovered that the temperature increase was much quicker when no Nano particle was supplied. The temperature rose steadily when Nano particles were put to PCM material.

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