ENHANCING THE PERFORMANCE OF SPIRAL TUBES HEAT EXCHANGER USING PCM WITH NANO PARTICLES (Al_2O_3)

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A B S T R A C T
The current rapid economic growth, demands for energy are progressively increasing. Conservation of energy has attracted the huge number of researchers due to the rapid decrease in non-renewable resources. That's why Thermal energy storage is one of the most effective way of saving waste heat energy from the vast field of heat exchanger results in saving fossil fuels and thus make the system cost effective. There a use of phase change material has an effective and capability to thermal energy storage because of the high latent heat storage capacity at small temperature intervals. This research is study in effect of heat transfer rate of spiral tube heat exchanger when PCM is used as energy storage medium. In this study, the PCM is mixed with nano particles such as Al2O3 in order to enhance the performance of the spiral wired tube heat exchanger. Complete study carried out analytically using simulation tools and software to get the results.
Keyword: Phase Change Material, Nano Fluid, Nano Material, CFD, ANSYS,

1. INTRODUCTION

Heat exchanger is a system used for the heating and cooling of the equipment's. It is used to transfer heat from one system to another. One will understand their usage that any method involves cooling, heating, condensation, boiling or evaporation would force a device for this purpose. Process fluids, sometimes heated or cooled before the method or endure a physical change. Completely different heat exchangers are named in step with their application.

Nomenclature

ρ Density
C_p Specific heat capacity
K Thermal Conductivity
n_p Nano Particles
n_f Nano fluid
b_f Base Fluid

1.1. Phase Change Material (PCM)

Phase change materials (PCMs) are extensively used for the purpose of storing heat energy and for heat transfer. PCM material has the capability to store a huge amount of heat energy and without changes its temperature it changes phase. By changing its phase it transfer heat to the ambient temperature fall on it. Thus, the PCM material has a capability to change its phase and absorb or release heat nearby at a constant temperature. If the thermal conductivity of PCM material is low, which is below 0.5 W/ (mK), it will affects the heat transfer enhancement of the heat exchanger system. Hence in order to manage low thermal conductivity of phase change material, new techniques have to be applied.

1.2. Nano Particles

Nanofluids are the type of fluids which contains nanoparticles (size below 100 nm), are the innovative technique of increasing heat transfer capacity of any conventional fluids. In this technology, Nano particles science and thermal engineering meets. Nanofluids a formed by adding Nano sized particles, these particles have a great thermal heat transfer capability and this solution is used on the place of conventional fluid. The nanoparticles always have great thermal performance as compared to their base fluids. This solution of base fluid and nanoparticle is expected to improve the thermal conductivity of the solution conjointly. Hence there is need of morestudy of nanoparticles and Nano fluids in order to utilized there properties at the best. Benefits of nanofluids are includes, removing heat, heat transfer, etc.

2. LITERATURE REVIEW

(Mahdi et al., 2019) As the discontinues availability of solar and wind energy, there is a need of better thermal energy storage system. The application of Phase change material in Triplex-tube heat exchanger (TTHX) has been found to very efficient for the thermal energy storage system. There already a various studies going on the extend fins, metals etc. But there is a much focused is needed on the improved technology of thermal energy storage. Practically, a system runs on the storage and recovery or charging of heat simultaneously. In this study the performance of TTHX is improved by adding a novel fins SCD conditions were studied. Numerical study is done to investigate the performance with different fin geometry.

(Solano et al., 2018) In a present study, the heat transfer between fluid, tube and a PCM material is investigated. The heat transfer fluid inlet and outlet boundary conditions are connected with the solar collector, which provides the thermal energy to the fluid. This provides the model with a sensible approach that enables for quantifying the result of a given solar irradiance curve on the capability of thermal energy storage. The lower latent thermal storage sensed in winter conditions (peak irradiance of 500 W/m2 and nine hours of solar light) with a typical shell and tube instrumentation may be overcome with the use of rectangular finned tube. A rise of the heat transfer surface to PCM volume magnitude relation of 5.7 times yields a 2.2-fold augmentation of thermal energy storage.

(Al Siyabi et al., 2018)small-scale phase change material (PCM)-based conductor will regulate the temperature of electrical devices because of high latent-heat capability. 3 totally different heat sinks are examined to review the consequences of PCM combination, arrangement of PCMs in multiple-PCM conductor, PCM thickness, melting temperature and intensity of heat supply on the thermal behavior of heat sink. Results are obtained for the temperature distribution across the heat sink and therefore the PCM melting profile. Results shows that (i) PCM combination RT50–RT55 will increase the thermal regulation amount and additionally reduces the heat sink temperature at the top of the operation, (ii) the RT58–RT47 arrangement slightly reduces the most temperature as compared to RT47–RT58, (iii) As PCM thickness will increase from 30 millimeter to 60 millimeter, the thermal-regulation-period will increase by 50 min, (iv) as the PCM melting temperature will increase, the thermal-regulation-period and therefore the conductor temperature increase and (v) The thermal-regulation-period decreases because the power rating will increase from 1 to 2 W.

(Samui, 2018) constant efforts to minimize the energy load by using phase change materials (PCM). The development of PCM has reached a stage where the applications can be planned with desirable properties. Together with development of PCM strategies one parallel area is slowly growing, which is the use of PCM and its Nano composites for tapping solar energy in addition to the existing photovoltaic solar cells. There are some efforts to commercialize the technologies. More and more efforts are being done to store the thermal energy by using molecular strategies. The present paper discusses some of the developments in the area of tapping light energy for generation of heat and its storage.

Constant efforts to reduce the energy load by phase change materials (PCM). The improvement of PCM has reached a stage wherever the applications may be planned with fascinating properties. Alongside development of PCM methods one parallel space is slowly growing, that is that the use of PCM and its Nano composites for sound alternative energy additionally to the present photovoltaic solar cells. There are some efforts to commercialize the technologies. More and more efforts square measure being done to store the thermal energy by using molecular methods. The current paper discusses a number of the developments within the space of sound light-weight energy for generation of heat and its storage.

(Duan et al., 2017) Solar energy is clean and property however intermittent in nature. Economical storage of solar thermal energy is essential for its wider applications. This paper presents design and analysis on a thermal energy storage unit using phase change material (PCM). A prototype of PCM device with a turbinate coil tube was designed and fictitious for solar thermal energy storage, and was tested on solar thermal experimental equipment. This paper discusses the look ideas, choice of materials, yet as heat transfer analysis with the CFD tool Ansys Fluent.

(Fu, Wen and Zhang, 2017) totally different porosities of Al wire meshes (10PPI, 14PPI, 20PPI) and 3 totally different diameters of Al wires were accustomed fabricate heat exchangers by connecting Al tubes to extend the heat transfer area. A twin wire-arc thermal spraying system will generate a dense, high strength Al coating to attach wires and Al tube. Titled and clamped connections between the wire mesh and tube were applied to get an economical device. The heat transfer characteristics for plain tube, 3 sprayed tube-wire and 6 sprayed wire-meshes (SPW) heat exchangers were through an experiment tested. Also, device surface temperatures were measured utilizing infrared camera. Ideal fin model was applied once validation utilizing data of sprayed tube-wire heat exchangers. The tube recess temperature ranged from a hundred 100 to 200°C and therefore the structure air rate was from 2 to 20 m/s.

(Ushak et al., 2016) inorganic phase change materials (PCM) are terribly rarely microencapsulated, thus this study aims to contribute to filling this analysis gap. Bischofite, a by-product from the non-metallic trade known as having smart potential to be used as inorganic PCM, was microencapsulated by means that of a fluidized bed technique with acrylic as chemical compound and chloroform as solvent, once compatibility studies of each many solvents and a number of other polymers. The formation of bischofite and pure $MgCl_2.6H_2O$ microcapsules was investigated and analyzed. Results showed associate degree potency in microencapsulation of 95% might be achieved once using a 2 min of fluidization time and a 2 kg/h of atomization flow. The ultimate microcapsules had wonderful melting temperatures and H compared to the initial PCM, 104.6oC and 95 J/g for bischofite, and 95.3 and 118.3 for $MgCl_2.6H_2O$.

(Sharma et al., 2016) presents a unique experimental analysis of phase change materials (PCM) to increase performance of low-concentration BICPV system via thermal regulation. Previous studies have primarily targeted on temporal and special studies of PCM temperature inside the BIPV systems however this work additionally discusses the result of PCM on electrical parameters of the BICPV systems. Because of the inadequacy of the sooner reported model, a replacement analytical model is projected and enforced with the in-house controlled experiments. Paraffin based mostly RT42 was used inside associate degree in-house designed and fictitious PCM containment. An enclosed experiment was performed using extremely collimated continuous light at 1000 Wm? 2. Results show a rise in relative electrical potency by 7.7% with PCM incorporation. A mean reduction in module centre temperature by 3.8°C was recorded within the BICPV–PCM integrated system as compared to the naturally airy system while not PCM.

3. OBJECTIVE

The objectives of this work are:

- Setup the CFD modeling of heat transfer during the melting phase change of material.
- Validation of model by comparing the results with previous study data.
- Heat transfer enhancement in order to provide guidelines to the design of heat exchanger.
- To study the performance when Nano fluid is mixed with PCM material.
- In present study aluminum oxide (Al_2O_3) is used as nanoparticle.
- Complete simulation is carried out on Ansys CFD simulation.
- Calculation of result based on mixture of PCM material with different percentage of Nano particle and comparing the result.

4. METHODOLOGY

- Collecting information and data related to the PCM material based heat exchanger.
- Manually calculation of mixing ratio of PCM material and nanofluid is done.
- The proposed model is designed in CATIA V5 as per the reference in the base paper.
- Then after converting the CATIA V5 File is converted in .step format and the file is imported in ANSYS Fluent work bench.

- Further name selections are assigned to the different parts.
- Meshing is done on the 3D model.
- Boundary conditions are applied on the model according to the selected base paper.
- Properties of materials are assigned.
- Results are calculated and comparison is done on different cases.

4.1. Mathematical model

In the design of a heat exchanger, the requirement of the geometry of the heat exchanger and material properties are important. For the structural requirement and physical shape of the exchanger different strength considerations and physical shape of the heat exchanger are inevitable. In addition to that empirical relations and other factors based on experiments are also used in a designing. Apart from analytical methods, graphical solutions are also useful in many aspects of design. First, draw the boundary of PCM Material container according to given design parameter using software CatiaV5 as shown in figure 1.

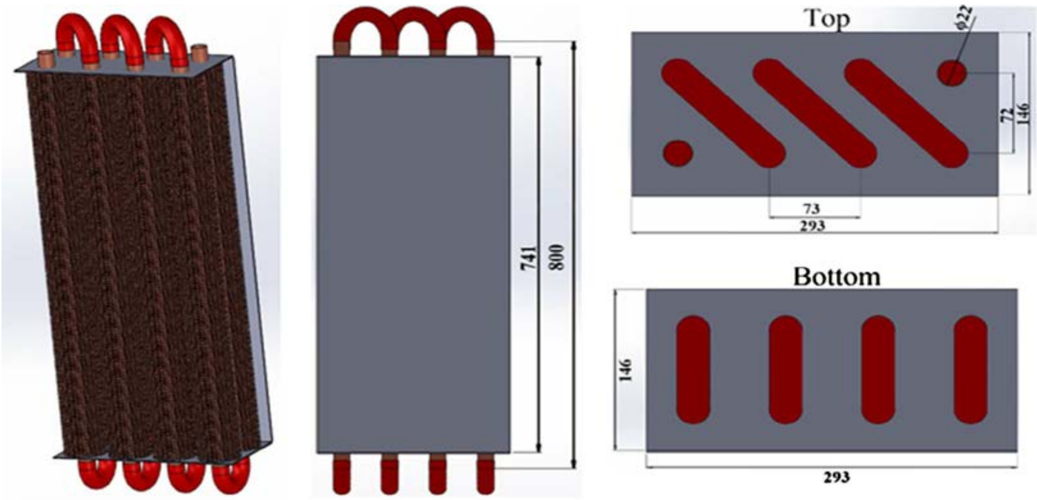


Fig. 1 - Model of Heat Exchanger

4.2. Boundary condition

The standard k-ε turbulence model with standard wall functions is applied. The multiphase function is enabled and “Volume of Fluid” model is selected with implicit volume of fraction parameters and pull velocity enabled. The PISO scheme is used for pressure-velocity coupling. The spatial discretization settings for pressure, momentum, volume of fraction and energy are PRESTO, first order unwinds, and compressive and second order unwinds respectively. The under relaxation value factors for pressure, density, momentum, energy, and liquid fraction are 0.3, 1, 0.7, 1 and 0.9 respectively. The predetermined convergences of energy and velocity are 10−4 and 10−3 respectively.

For the initial conditions of charging process, the PCM and HTF temperatures are set to 10 °C and 40 °C respectively and PCM is in solid state. As to the boundary conditions of the CFD model, the type of “Velocity-inlet” is used for the HTF at the PCM HX inlet. The inlet HTF flow velocity is determined from the inlet volumetric flow rate and inlet inner pipe diameter.

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

4.3. Material Property

Three different type of material is used in study the one is solid material which is copper and second one is Phase change material which is A16 and last one is Nanoparticle which is aluminium oxide (Al_2O_3). The material physical property is shown in table.

Table 2 - PCM Material Property

	A16
Congealing temperature ^{0}C	17-15
Melting temperature ^{0}C	15-17
Flash Point ^{0}C	>250
Density of solid (Kg/m^3)	830
Density of Liquid (Kg/m^3)	800
Specific Heat (J/KgK)	2.3-2.37
Thermal Conductivity (W/m.K)	0.16

4.4. Preparation of Nanofluid

The following equations were used to obtain the thermos physical properties of the nano-enhanced PCM:

Density

$$\rho_{nf} = (1-\emptyset)\rho_{bf} + \emptyset\rho_{np} \quad (1)$$

Specific Heat

$$(C_p)_{nf} = (1-\emptyset)(C_p)_{bf} + \emptyset(C_p)_{np} \quad (2)$$

Thermal conductivity

$$K_{nf} = \frac{K_{np} + 2K_{nf} - 2\emptyset(K_{bf} - K_{np})}{K_{np} + 2K_{nf} + \emptyset(K_{bf} - K_{np})} \quad (3)$$

Where

np –Nano Particles

nf – Nano fluid

bf – Base Fluid

Table 3 - Property of Nanofluid in different mass frachtion

Parameter	**% Mass Fraction of Al_2O_3**		
	0.5%	**1%**	**2%**
Density(Kg/m^3)	815.4	830.8	861.6
Specific Heat (J/KgK)	2292.365	2284.73	2269.49
Thermal Conductivity (W/m.K)	1.015	1.030	1.06

4.5. Meshing

Then, this model is imported to analysis software Ansys and the name selection is done for the inlet and outlet parts, and mesh is generated, as shown in figure 2 using quadrilateral meshing in PCM material and tetrahedron meshing in pipe and water. The number of nodes is 5073908 and number of element is 4796407.

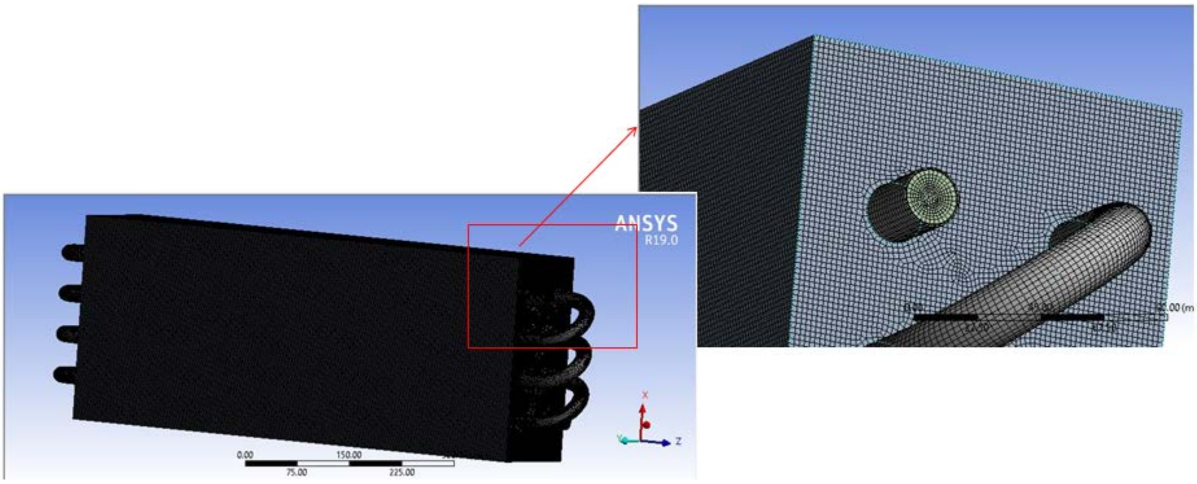


Fig. 2 - Meshing of Heat exchanger

5. RESULT

As a result, the melting of the PCM has been observed, at initial condition the PCM was solidified in the room temperature. With respect to the low HTF inlet velocity of 0.33m/s, and turbulence model in consider. The simulations provided detailed phase distributions as the following figures.

5.1. Mass Fraction of Different Material

The value of mass fraction is under the range of 0-1. The range of 0 indicates the material is solid state and 1 indicates that material is liquid state. The red color indicates that the material is liquid state and blue color indicates that the material is solid stage. Results are found in terms of contours, tables, snaps and Bar Chart.

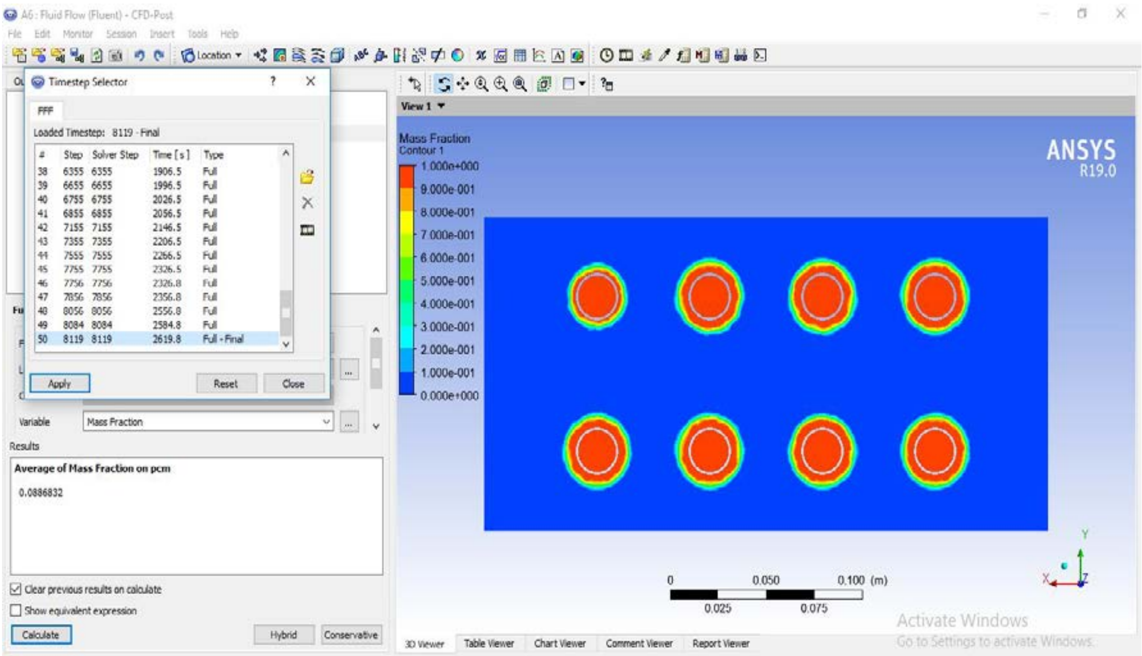


Fig. 3 - Mass Fraction Contour of only PCM

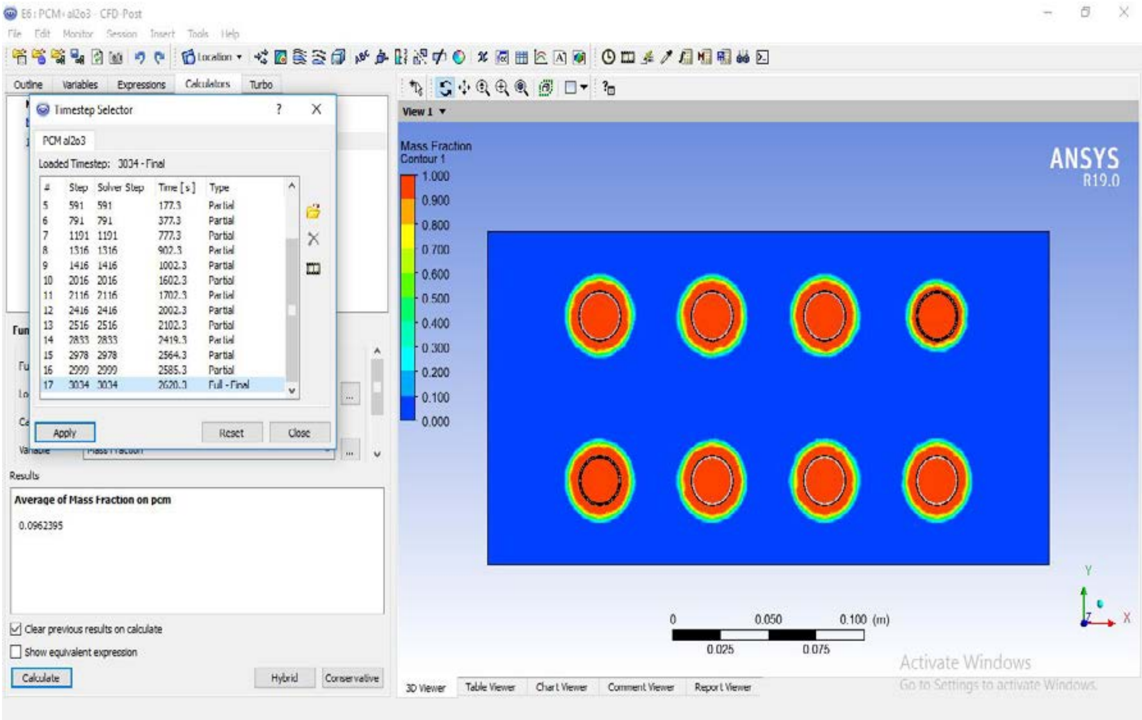


Fig. 4 - Mass Fraction Contour of PCM + 0.5%Al_2O_3

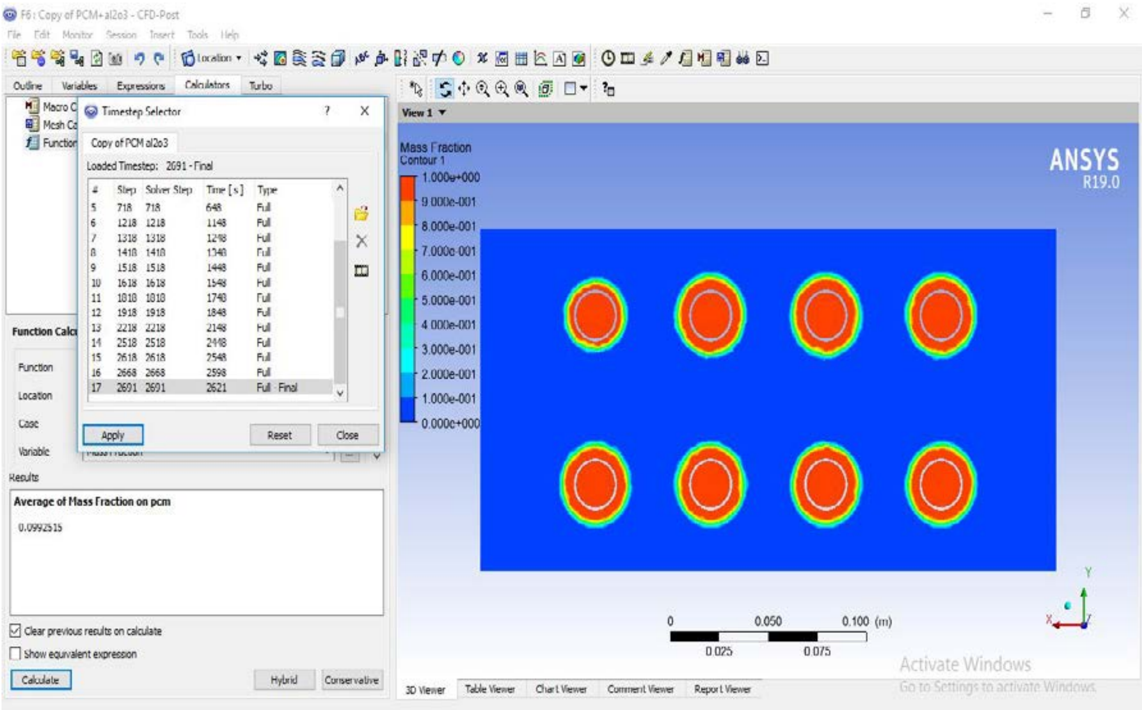


Fig. 5 - Mass Fraction Contour of PCM + 1%Al_2O_3

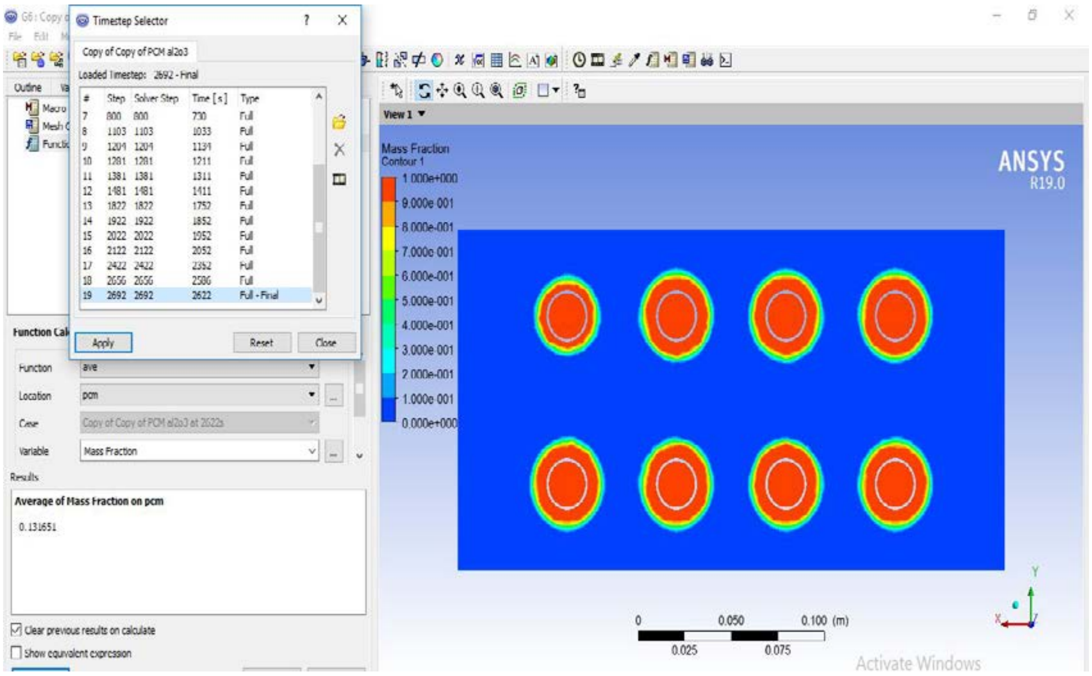
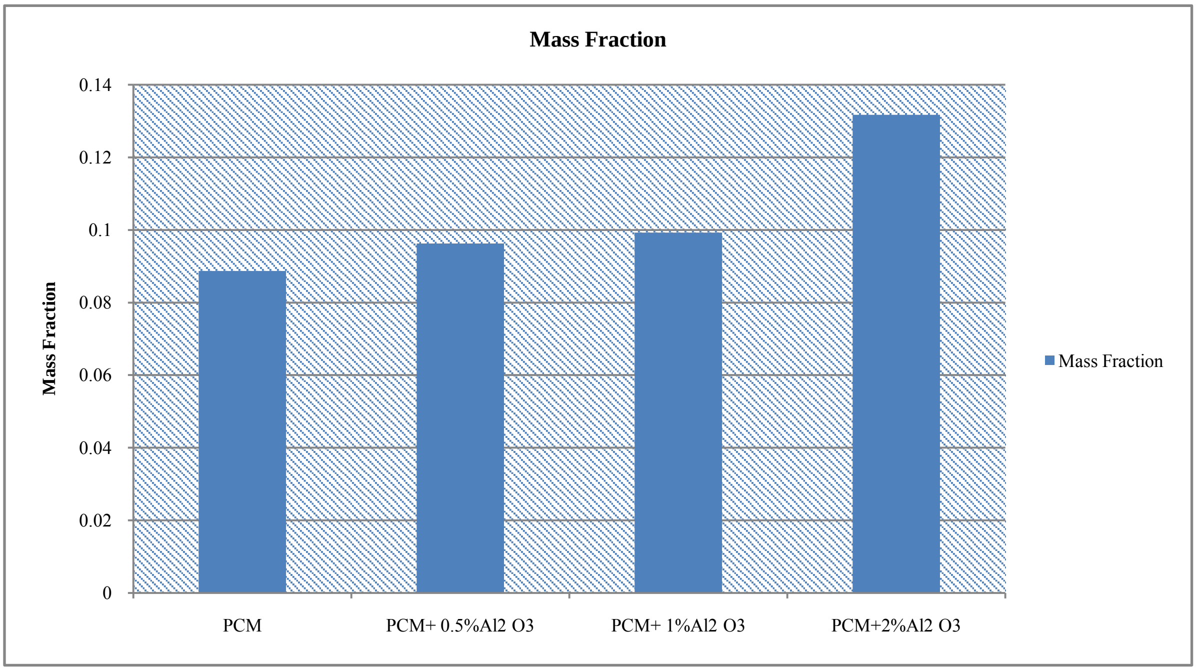


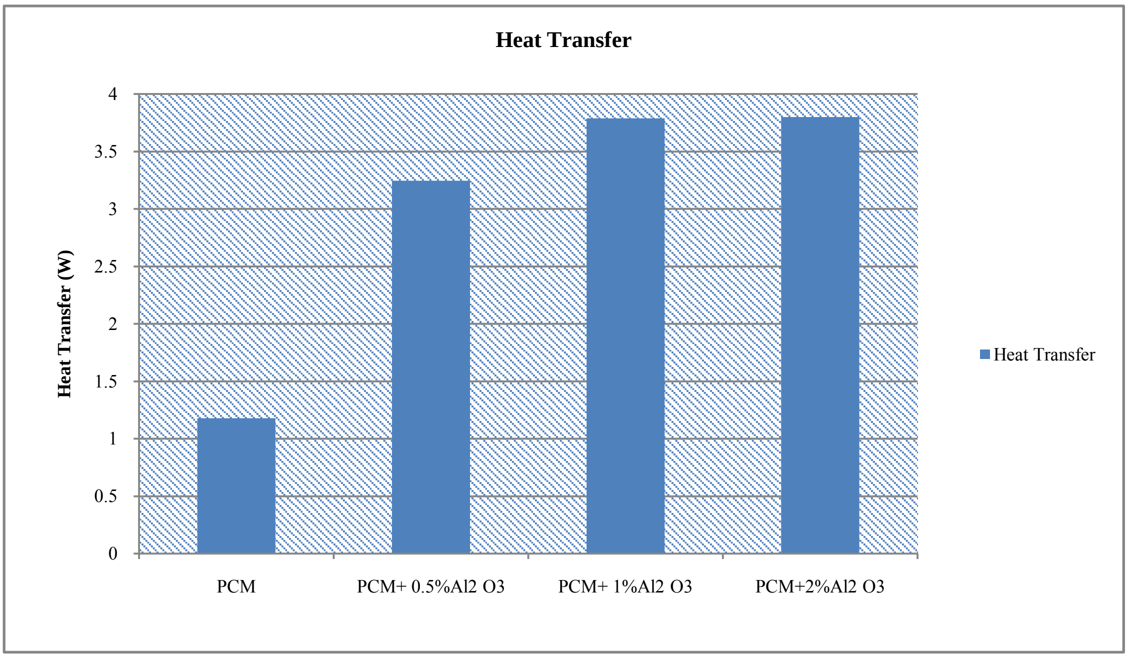
Fig. 6 - Mass Fraction Contour of PCM + 2%Al_2O_3

Table 4 - Average mass fractions table in different percentage of nano particles

Material	**Time (s)**	**Mass Fraction**
PCM	2620	0.08868
PCM+ 0.5%Al_2 O_3	2620	0.09623
PCM+ 1%Al_2 O_3	2620	0.09925
PCM+ 2%Al_2 O_3	2620	0.13165
Material	**Time (s)**	**Mass Fraction**



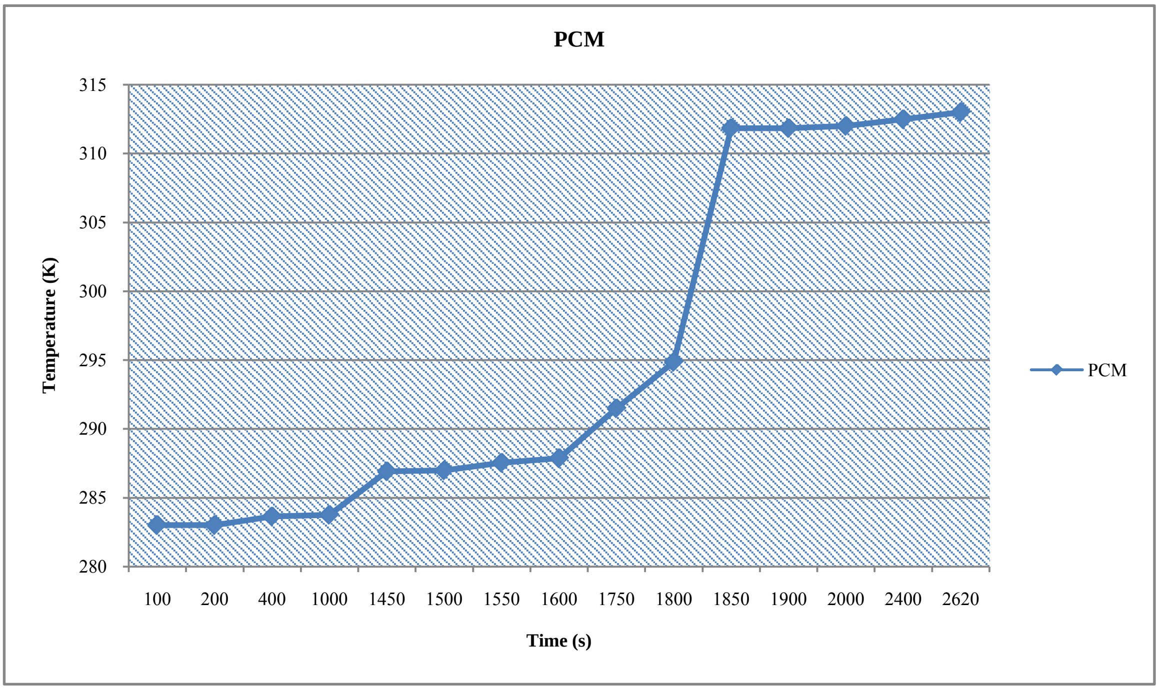
Graph 1 Average of mass fraction Graph



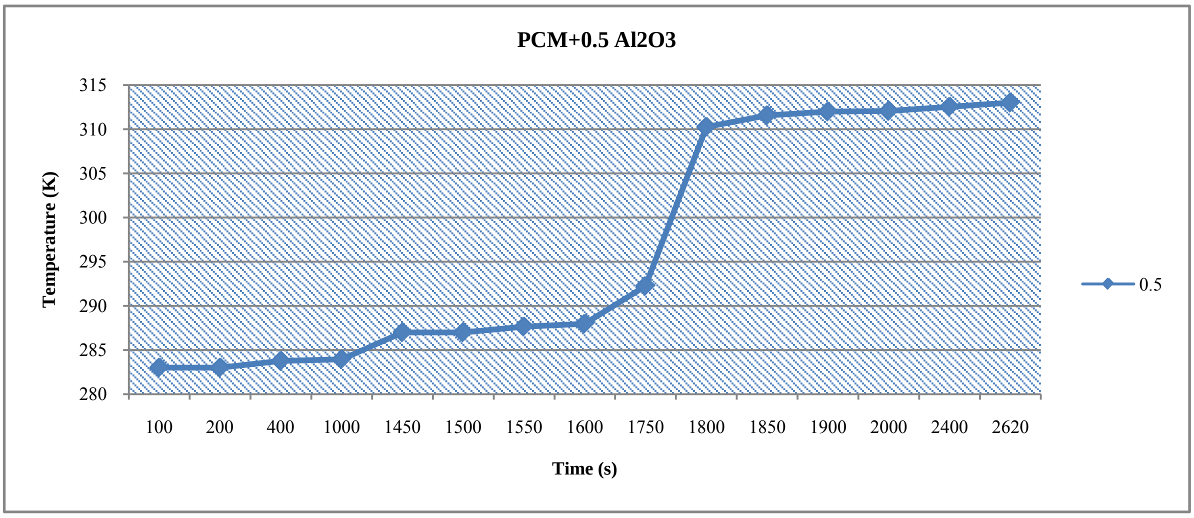
Graph 2 Total heat transfer rate in different percentage of Nano Particles.

5.2. Temperature Distribution of Material

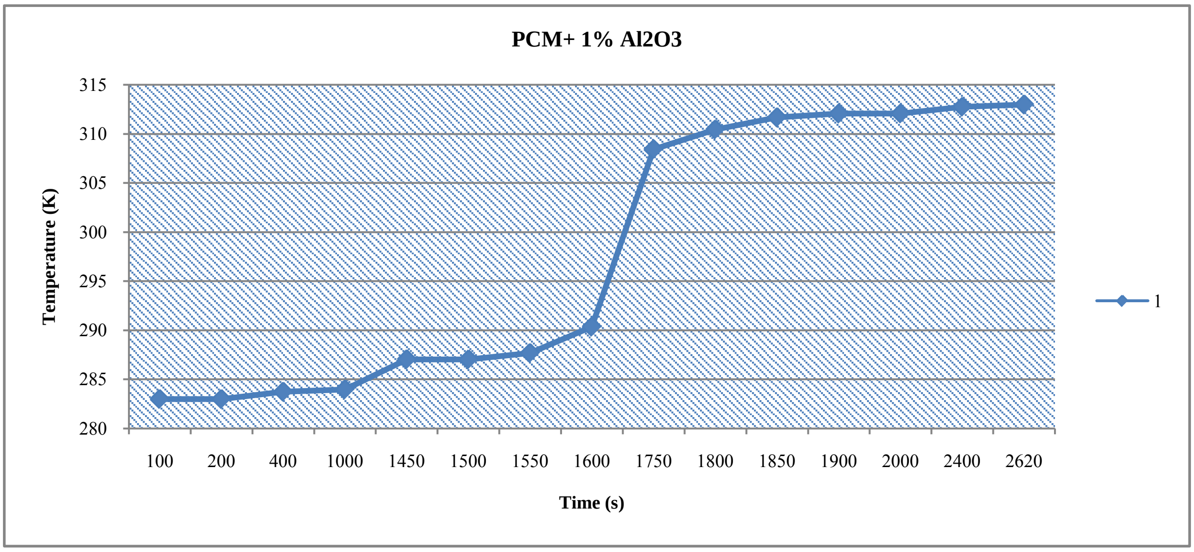
In inlet temperature of HTF is 313K and velocity is 0.33m/s. after run the analysis in 2560s the temperature distribution is shown in figure. The red counter is shown the maximum temperature which is 313K and blue contour show minimum temperature which is 284.8K.



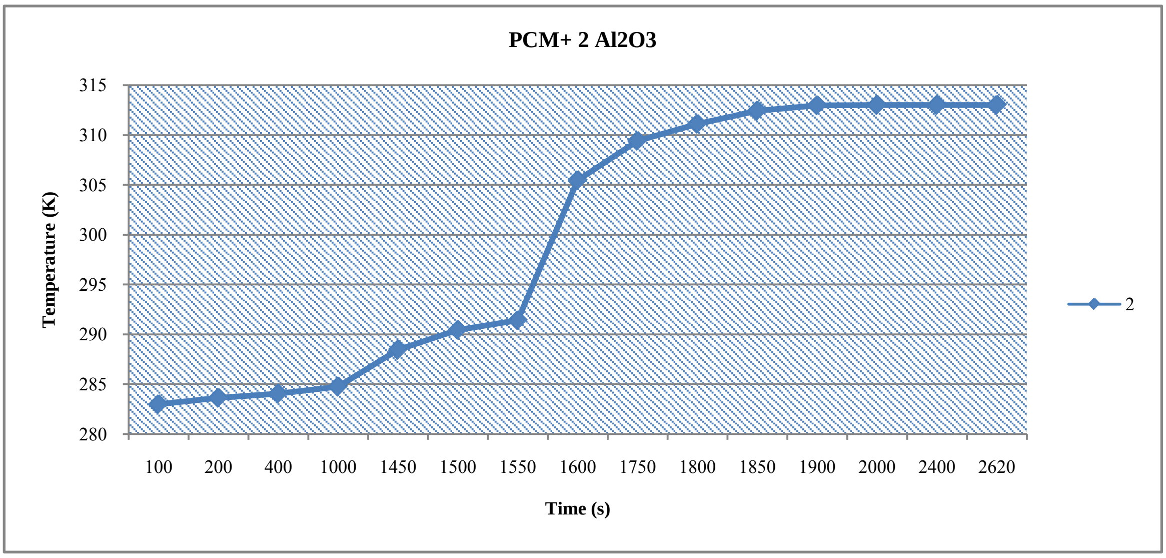
Graph 3 Graph showing steadiness in temperature rise on PCM material



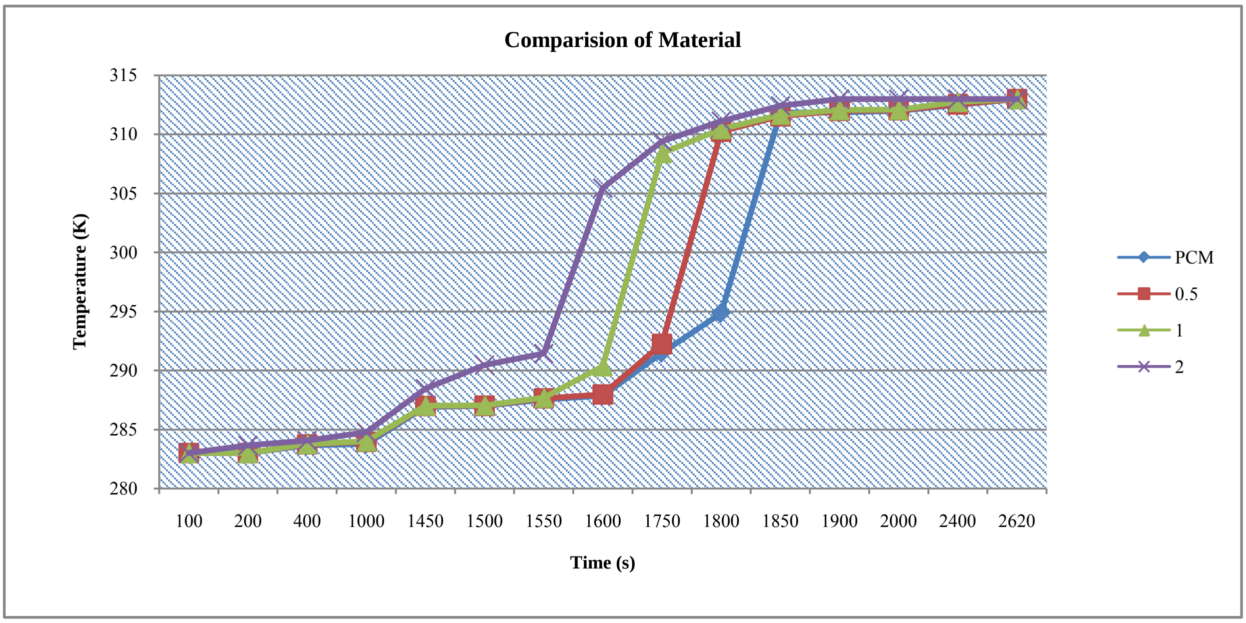
Graph 4 Graph showing steadiness in temperature rise on PCM+2% Al_2O_3 material



Graph 5 Graph showing steadiness in temperature rise on PCM+1% Al_2O_3 material



Graph 6 Graph showing steadiness in temperature rise on PCM+2% Al_2O_3 material



Graph 7 Comparative graph PCM and different parentage of nanoparticle

6. DISCUSSION

- It is found that the PCM material with Nano particle increase the performance of heat exchanger.
- It is found that the capacity of the heat absorption of PCM increased on mixing small amount of Nano particles in the phase change material.
- The results show the behavior of the complete system on different percent of Nano particles mixed with PCM material based on which comparison can be carried out with respect to different percent values.
- The results help in identifying the most optimum configuration percent of Nano particle required in the mixture with PCM material.

A comparison of heat exchanger with simple PCM and PCM with Nano particle can be evaluated

7. CONCLUSION

The entire tests were successfully performed on CFD simulation and the required result where obtained. from the result following conclusion are drawn:

- PCM material was mixed with different percentage such as 0.5, 1, 2 percentages with the nano particle Al_2O_3 and values for mass fraction is calculated for each case.
- It is found that the value of mass fraction increase with respect to increment in the percentage of PCM material.
- It is also found that the value for total heat transfer increases of inlet to outlet on addition of nano particles in different percentage.
- The maximum value for mass fraction was found in the mixture of 2% with PCM material. This shows the best configuration of mixture required in the complete setup.
- It was also found that when no nanoparticles were added the rise in temperature was considerably faster. And when nano particle where added with PCM material the rise in temperature became steady.

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