Heat Transfer Performance of a Rotating Phase Change Material (PCM) based Thermal Energy Storage (TES)

By

Yasmin Alia binti Hasbollah

16871

Dissertation submitted in partial fulfillment of the requirements for the Bachelor of Engineering (Hons) (Mechanical)

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UniversitiTeknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak DarulRidzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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in partial fulfillment of the requirement for the
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(MECHANICAL)

Approved by,

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(DR. JUNDIKA CANDRA KURNIA)

UNIVERITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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YASMIN ALIA BINTI HASBOLLAH

ABSTRACT

The objective of this project is to investigate the heat transfer performance of a rotating phase change material (PCM) based thermal energy storage (TES). Paraffin wax are used as the phase change material in a horizontal cylindrical acrylic capsule while water bath as the heat transfer fluid passing through the paraffin wax in a copper tube. During charging process, the solid paraffin wax start to melt and the latent heat released being stored. The heat transferred during the natural convection only occurred at the top section of the horizontal cylindrical capsule causing it to limit the amount of heat transfer stored. By proposing to rotate the horizontal cylindrical capsule, the idea is to spread the heat transfer uniformly to the top and bottom of the cylindrical capsule. There are two objectives of this study; to develop a computational model of heat transfer in a phase change material (PCM) based thermal energy storage (TES) and to investigate and evaluate the heat transfer performance of a rotating PCM-TES design. The models for PCM-TES is developed, validated and then utilized to evaluate the key parameters that affect the heat transfer performance. The numerical predictions achieved relatively good agreement with experimental counterpart obtained from literature of the previous study. It is found that heat transfer performance of rotating thermal energy storage is better than static thermal energy storage.

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INTRODUCTION

1.1 Background

The developments of energy storage are widely gaining the acknowledgement around the world nowadays. Researcher are doing research on varies type of energy storage such as mechanical, thermal, electrochemical, hydrogen, power to gas and many more. For this project, the author is focusing only on the latent heat thermal energy storage (LHTES) that are using the commercial paraffin wax as the phase change material. As the Earth is getting older day by day, humans need to come out with an alternative for energy resource that will help them to survive in case the resource finish. Hence, solar energy is presently one of the most promising renewable energy resources. Every day, the Earth receives an enormous amount of solar energy approximately 0.2 Terawatts [1], which is more than 10000 times the present energy consumption of the world.

Even though, the energy is abundantly available, it cannot be used cost-effectively unless it is collected at the right place, stored at the right temperature and used at the right time. The advantages of the latent heat thermal energy storage is its ability to store large amount of heat at minimum temperature increase hence reducing the heat lost to the environment. Unfortunately, for every situation, they have their own drawbacks as it is not an ideal situation. The latent heat thermal energy storage has low at transfer process especially during discharging because conduction process that taking over. Natural convection that taking over the process caused the heat transfer to occurred only at the top part of the capsule. This will limit the amount of heat transfer stored in the capsule. This bring to the project where it will evaluate the heat transfer performance of a rotating phase change material (PCM) based thermal energy storage (TES) design by using a computational modeling. Theoretically, by rotating the cylindrical capsule, the heat transfer will spread to the bottom part of the capsule uniformly.

1.2 Problem Statement

Latent heat can store large amount of thermal energy, but there is drawbacks where the heat transfer process are taking very slow causing the phase change material to melts non-uniformly. This project addresses the heat transfer process in latent heat thermal energy storage with the aim to improve heat transfer process. In order to improve heat transfer performance across the thermal energy storage, a rotating PCM-TES design is proposed.

1.3 Objectives

The objectives of this study are:

1) To develop a computational model for heat transfer in a phase change material (PCM) based thermal energy storage (TES)
2) To investigate and evaluate the performance of a rotating PCM-TES

1.4 Scope of Studies

The scopes of study are as following:

1) The phase change material use in the study is paraffin wax
2) Heat transfer fluid for this study is water
3) The simulation only focus on the laminar flow
4) The study focus on temperature of 298 K to 305 K

CHAPTER 2

LITERATURE REVIEW

2.1 Thermal energy storage

A thermal energy storage (TES) is a storing technology that undergo a heating and cooling process of phase change material (PCM) which the energy will be stored for later used as a heating or cooling application and power generation [2]. In order to reduce the amount of carbon dioxide and fossil fuel dependency, thermal energy storage is one of the best solutions [3].Storing a thermal energy can be divided into two techniques, sensible heat storage and latent heat storage.

As per stated by Regin [4], the heat is applied to the medium (state A) hence causing the solid medium to be experiencing sensible heating (A-B state). At state B-C, the crystalline structure will change into another structure. Basically, during this phase, the volume differences are small than the solid-liquid phase so thus the latent heat, Sharma et al [5]. As the heating proceed, the sensible heating occurs at the C-D state and after some times, the state change from solid to liquid (D-E state). During this process, the solid-liquid phase will start to distance itself from the heat transfer surface. As stated by Velraj et al [6], the molten medium start to grow at the surface, it will create a resistance hence decreasing the heat flux of the state. However, [3] finds that at this state, the phase change is more reliable for the use of thermal energy storage. The sensible heating will repeat itself at E-F and G-

H state. At F-G state, the liquid change into gaseous have even smaller volume changes and latent heat value than the solid-solid state.

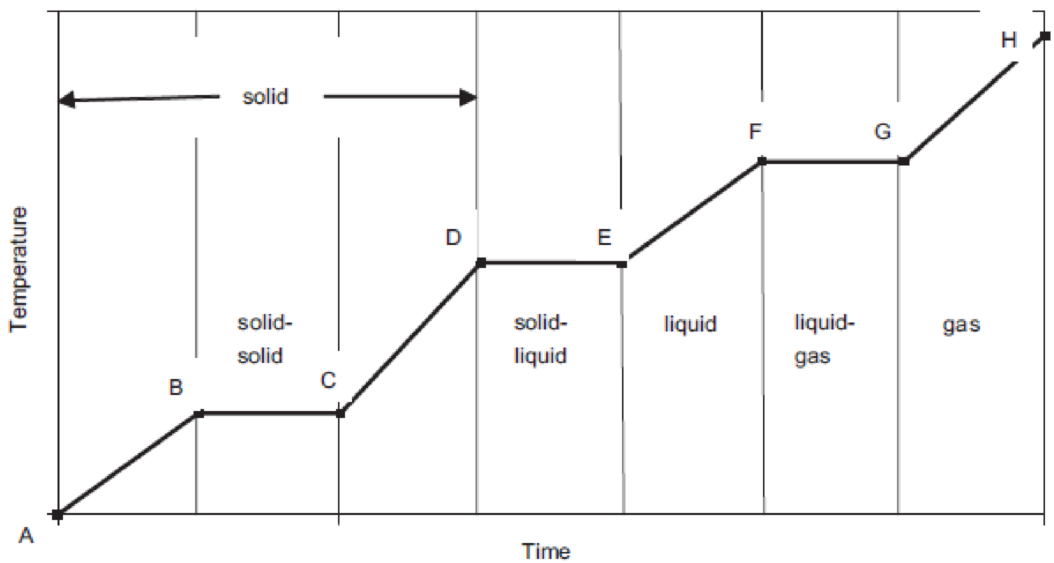


Figure 1: Transition diagram (Regin et al, 2008)

Sensible heat storage working principle is based on the increase of the temperature of the storage medium [7]. Sensible heat storage will put to use the melting and solidification process of the medium. Most of the time, the sensible heat depends on the temperature difference, amount of storage material and the heat capacities [3]. The mostly used storage medium for sensible heat storage are water as it is the cheapest and of abundance supply factor but for temperature that exceed 100℃, the use of molten salts, oil and liquid metal are more preferable.

Whereas, latent heat storage are storing the energy while the material start to change from one phase to another. The energy transfer usually occurs during solid to liquid and liquid to solid phase. During this phase, the temperature is constant. It is more preferable to store latent heat rather than the sensible heat as the latent heat has higher storing capacity than the sensible heat [3]. The reason behind the large storage capacity is because of the small change of volume at a specific range of temperature. A latent heat thermal energy storage (LHTES) must have the three basic components; a heat storage substance that go a transition phase of solid-liquid-solid, a container for holding the storage medium and heat exchanging surface that transfer the heat from the fluid to the phase change material.

For years, researchers are finding ways to enhance the performance of phase change material based thermal energy storage. Buddhi et al [8] evaluated the effect of different shapes of thermal storage devices would have different storage capacity. There are several ways to enhance the heat transfer, such as using fins, mixing metal that contains high thermal conductivity metal with the phase change material, disperse high thermal conductivity particles with a phase change material and microencapsulated of phase change material. Bellan et al [9] investigated the effect of capsule size on the performance of the thermal energy storage system. The research is done numerically and from the research, it can be conclude that the melting and solidification time increase as the size of the capsule increases. Kurnia et al [10] have studied on the design of heat transfer performance of a novel phase change material where they conclude that in order to gain the highest heat transfer rate, a novel festoon design are proposed. Wu et al [11] focused on hydrated salts that impregnated with expanded graphite composite which later coated with paraffin wax. The result from this research not only reduces the subcooling but also increases the thermal conductivity of the hydrated salts. The effect of charging and discharging periods of water in a latent heat storage unit was experimentaly investigated by Ezan et al [12]. The result indicate that the inlet temperature plays an important role in determining the amount of rejected energy. Hence determining the most suitable inlet temperature will help in increasing the heat transfer performance of thermal energy storage.

To ensure the storage materials to have long term stability, the materials properties have to be stable and no corrosion happen between the phase change material and the container. Thermal stability is the repeating process of heating and cooling [13]. Thermal cycling are required to test if there will be a migration of phase change material during a thermal exposure that will affect the thermal properties of phase change material. Hasnain[7] have confirmed that paraffin’s thermal properties will not change when the paraffin in contact with metal. This can be supported by a study done by Anant et al [14] on thermal cycling test of a few selected inorganic and organic phase change material such as paraffin wax, di-sodium tetraborate, ferric nitrate, sodium hydroxide and erythritol and a few more. It reaches to the conclusion that all the inorganic phase change materials studied cannot b use for latent heat thermal energy storage. Whereas, paraffin wax and erythritol shows a good thermal reliability in term of latent heat fusion, melting temperature and thermal cycling.

In thermal energy storage, natural convection and conduction are two main heat transfer process that occurs throughout the charging and discharging process. At the beginning, conduction plays the role in transferring the heat from the heat transfer fluid to the wall of the copper tube, once the heat reached the copper tube, natural convection will take over hence making it the main process during the discharging process. From the working principle of natural convection where the hotter fluid will moves upwards making the cool fluid will move to the bottom of the capsule. Tao et al [15] go deeper into the effect of natural convection on the performance of salts in a horizontal tube. He prove that the natural convection cause the heat to moves upwards making the interface of solid liquid to be non-uniform. Hence, to improve the latent heat storage performances, adding an appropriate size of fin are recommended. In his study, Liu et al [16] who do an experimental study of heat transfer between phase change materials in a horizontal cylindrical latent heat energy storage system. Copper tubes attached with fins are placed inside of horizontal cylindrical storage to let the heat transfer fluid to pass through. The fins are positions at 45° from each other where he conclude that fins at the lower parts of the cylindrical are slower in term of the temperature increase. It also delays in melting time. This statement are supported by Sun et al [17] where she studied on enhancing the heat transfer during the phase transition processes of solid-liquid phase change materials. The results show that natural convection will reduce the time required to absorb the latent heat during melting process.

2.2 Phase Change Material

There are a several number of phase change material with wide range of temperature in the industry nowadays. Phase change material are actually a material that being use as a medium to generate heat. Researchers had discovered several possible phase change material that can be used for energy solving problems such as organic, inorganic and eutectic materials.

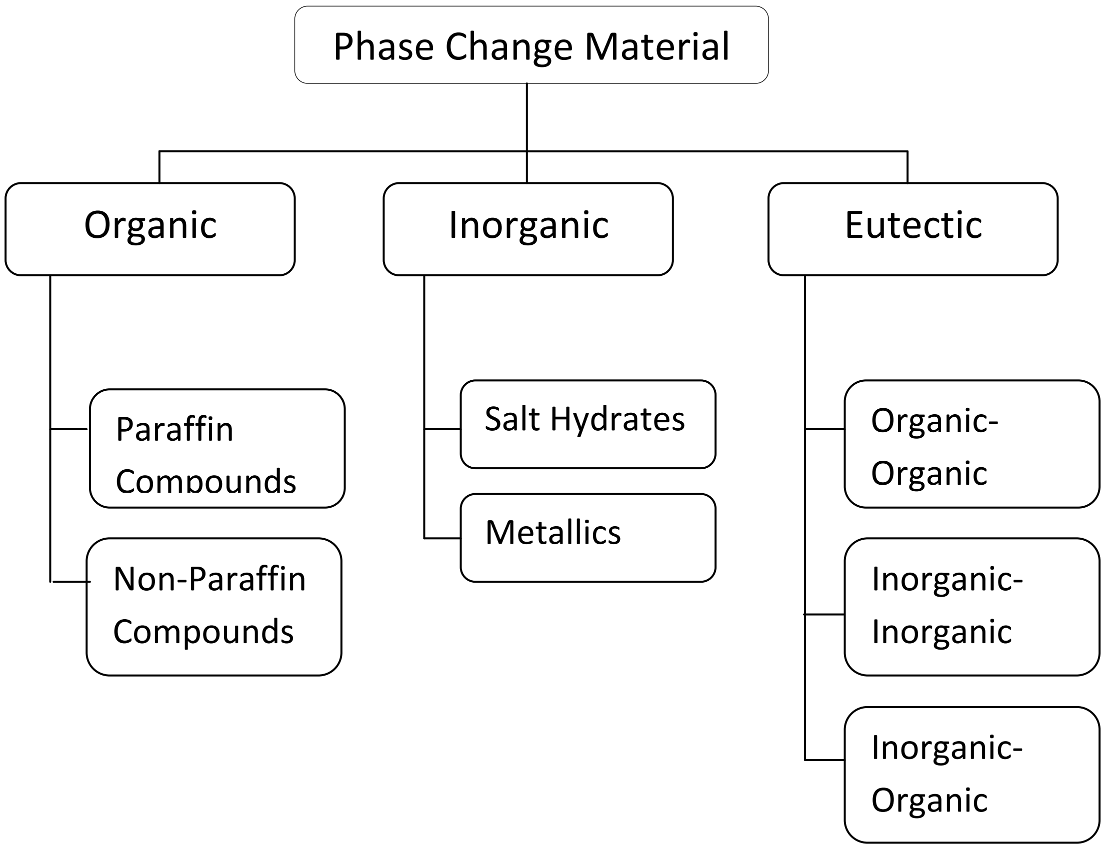


Figure 2: Classifications of phase change material

Most of the phase change material categories listed in Figure 2 have meet it owns melting temperature in the operating range but it does not fulfill the requirement to be a storage medium. In order to meet the requirement, the materials need to have a good system design. Melting temperature is the main thing that needs to take into consideration as materials that have melting temperature below 15℃ is mostly used for air conditioning cooling. Materials that have melting temperature above 90℃ are specifically used for refrigeration absorption. Meanwhile, materials that have melting temperature between 15℃ and 90℃are for solar heating and load level applications.

2.2.1 Paraffin compound as phase change material

Scientifically, paraffin wax is a long chain oh alkanes CH_3-(CH_2)-CH_3 [3]. Paraffin wax have a lot of advantages, this include the chemically inert, stable and no phase segregation factors [7, 13]. In term of it thermal stability, paraffin wax are well known for its stability even after several numbers of cycle. Unfortunately, there are cons for every pros. Paraffin wax are well known for its low thermal conductivity, not compatible with plastic and moderately flammable. [3] Adding conductive fillers in a thermal energy storage filled with paraffin wax will help to increase the thermal conductivity. Pure paraffin is expensive hence using commercial paraffin will be one of the alternatives to overcome this problem. With the presence of high amount of hydrocarbon mixtures in commercial paraffin wax, this brings to a wide range of melting temperature rather than a specific melting temperature [7]. As per mentioned by A. Sharma et al [5], the melting temperature will increase as the number of carbon atoms increases. The properties of commercial paraffin wax vary as it depends on the manufacturer. A few researchers have come out with different value of melting temperature and latent heat fusion [5, 13]. This statement can be supported through the following summarization of the data collected from varies of research papers regarding paraffin wax:

Table 1: Latent heat of fusion by different manufacturer

Phase Change Material	Melting Temperature(˚C)	Latent Heat of Fusion (kJ/kg)
Paraffin [3]	51	166
Paraffin [8]	44	167
	53	200
Paraffin A [10]	55	102
Paraffin B [10]	62	110

The reasons behind the differences of latent heat of fusion at different melting temperature are caused by the presence of impurities in the commercial paraffin wax that being used by different researchers [7].

CHAPTER 3

METHODOLOGY

3.1 CFD modeling

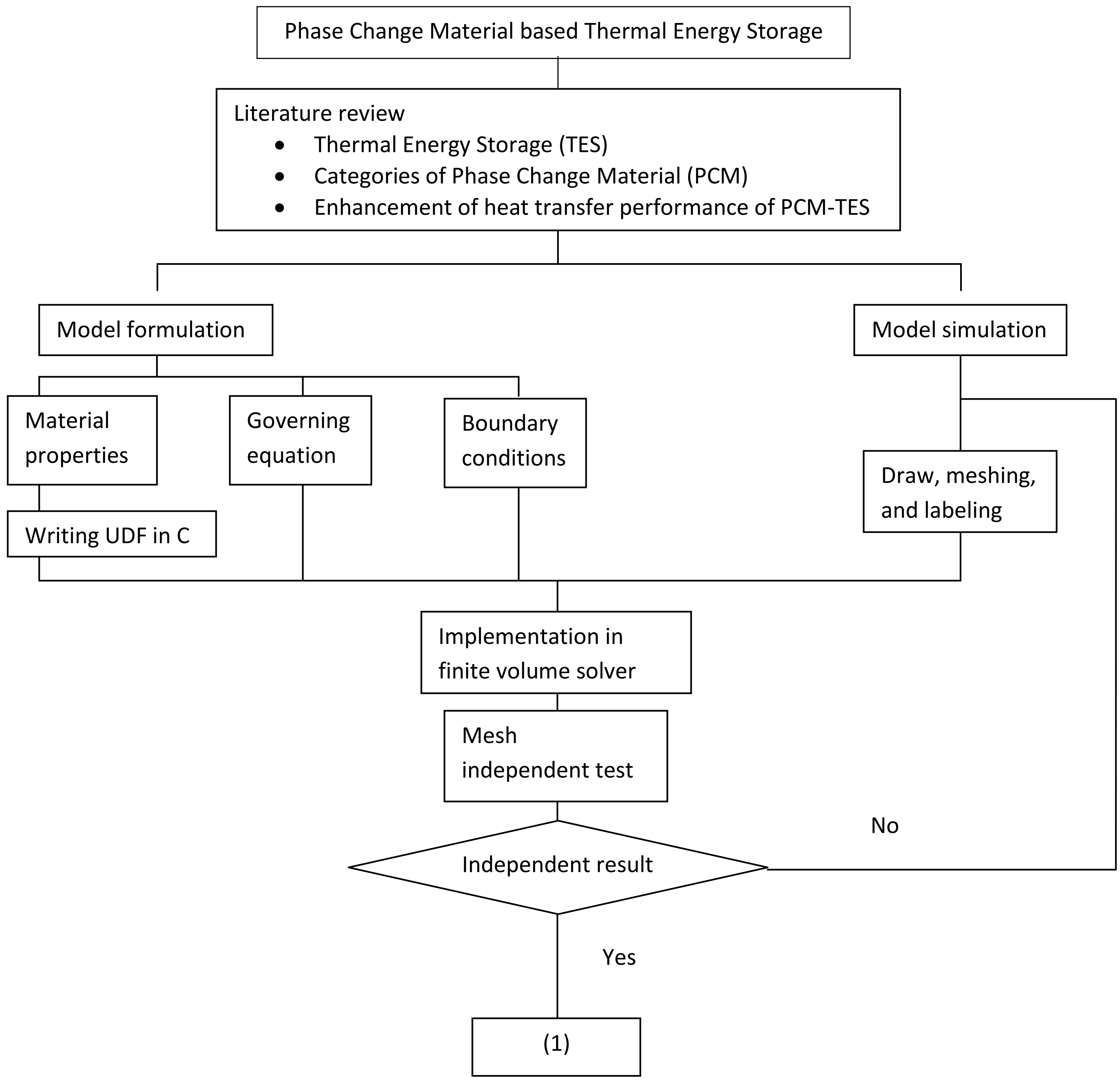
The study is divided into two parts, model formulation and model simulation. Both of the parts are later combined in the Fluent 15.0. By using Fluent 15.0 to run the simulation, the heat transfer performance of phase change material based thermal energy storage can be evaluate through the result of liquid fraction and temperature gradient.

The model formulation is to determine the material properties, governing equation and boundary conditions of the tube model. The properties are determined by referring to several number of research paper. All the properties are then used in writing the user-defined function (UDF) in the C++ languages.

The model is first being drawn and mesh by using GAMBIT. A fine mesh is used as this is to obtain the most accurate simulation result. After meshing is done, the tube is then being label according to the type of state and their surface. For example, solid, fluid, copper tube, heat transfer fluid and many more.

The model is basically a thermal energy storage tube containing paraffin wax which acts as the phase change material. A copper tube flowing the heat transfer fluid; water, will pass through the thermal energy storage. As the water pass through, the heat will start to transfer to the paraffin wax and cause it to start melting. Throughout the process, the heat transfer performances are observed at z = 50 cm and z = 90 cm. The model is validated using an experimental study of a research done by Lacroix.

The process flow of this study is basically based on following:



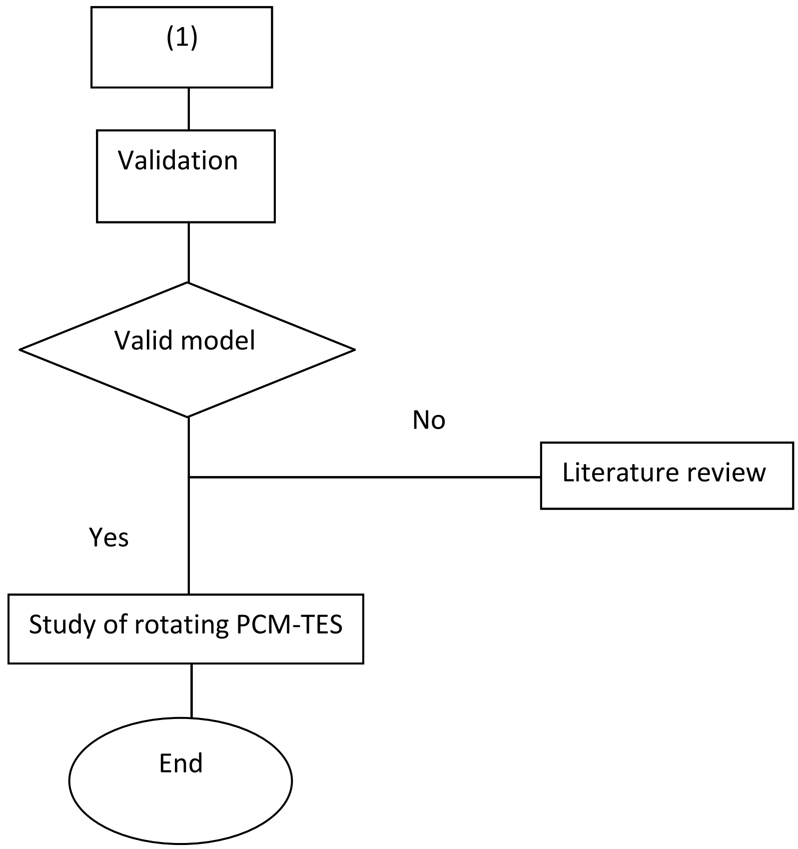


Figure 3: Project flow

A few tubes are created with each having different total number of mesh. Each of the tube are run for simulation for 36000 time steps. At the end of the simulation, all of the result will be compared with the existing result from Lacroix's research paper.

Table 2: Mesh independent test

Tube	**Tangential**	**Radial**	**Axial**	**Total number of mesh**
Tube base	100	60	100	306600
Tube 1	60	60	100	164700
Tube 2	60	60	80	131760
Tube 3	120	60	100	390300
Tube 4	120	30	100	74900

The most accurate result will be selected to be use in the study of rotational PCM-TES. Time for completion of simulation also will be considered as time constraint issues. The total number of mesh for each tube is set as Table 2.

Two different rotational speeds are applied to the tube; 2 rpm and 0.5 rpm. Both result of heat transfer are compared with the simulation result for the tube that are not being applied any rotational speed. The simulation will run roughly five to eight days to complete.

The following is the gantt chart use in the research.

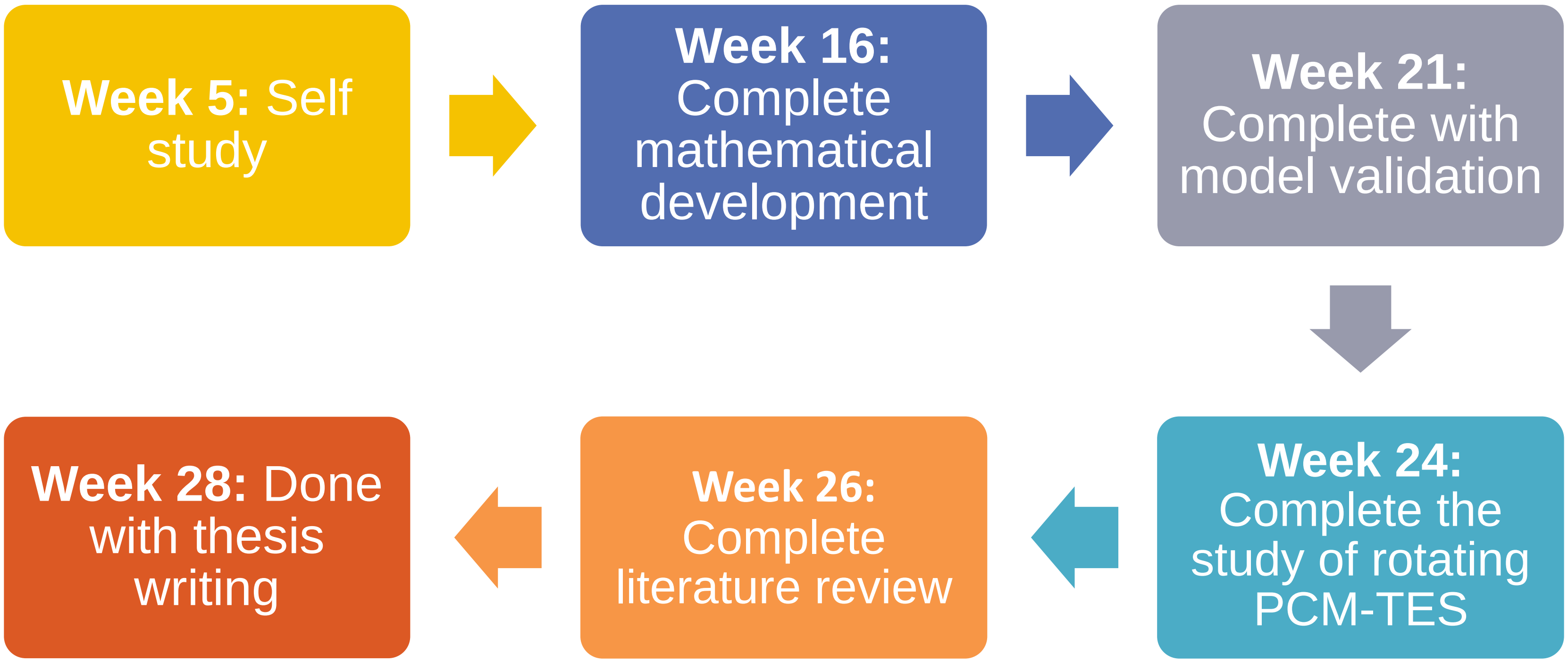


Figure 4: Key Milestones

Throughout the research, the time specified for each activity is referring as following:

Table 3: Gantt chart

NO.	ACTIVITIES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	SEMESTER BREAK	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	Literature Review	■	■	■	■	■	■	■	■	■	■	■	♥				■	■	■	■	■	■	■	■	■	■	■	♥		
2	Model Development													■	■		■	ϟ												
3	Model Validation																		■	■	■	■	★							
4	Study of Rotating PCM-TES																							■	■	■	■	▲		
5	Progress Report						■								■								■			■		■		
6	Thesis Writing																								■	■	■	■	■	☼

♥ Complete literature review

ϟ Complete model development

★ Complete model validation

▲ Complete the study of rotating PCM-TES

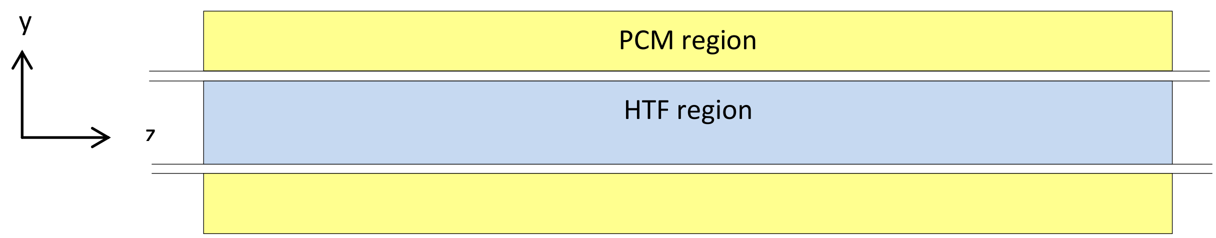
● Complete the study of parameters

☼ Complete thesis writing

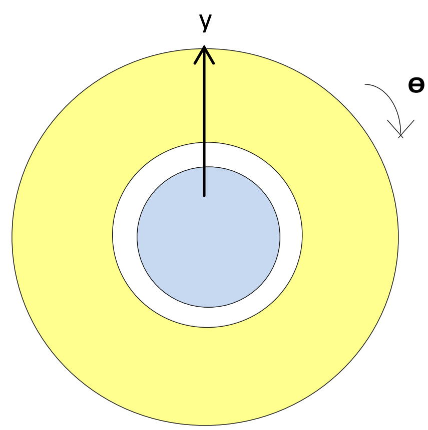
3.2 Model description

3.2.1 Physical model

For this research, the model will involve acrylic tube as the outer capsule to hold the paraffin wax and a copper tube passing through both of them where the heat transfer fluid (in this case, water) pass through. The physical model for the research is as per shown below in Figure 4.



a) Front view



b) Side view

Figure 5: Schematic of the model

The dimension of the model and the thermophysical properties of the paraffin wax are summarized in the Table 3 and Table 4, respectively.

Table 4: Model dimension

Parameter	Dimension (meter, m)
Diameter acrylic tube, D_{ac}	0.0258
Copper tube outer diameter, D_o	0.0158
Copper tube inner diameter, D_i	0.0127
Length	1.00

Table 5: Thermophysical of paraffin wax

Fusion temperature	**300.7K**
Latent heat of fusion	243.5 $kJ.kg^{-1}$
Thermal conductivities	
Liquid (at 313K)	0.148 $W.m^{-1}.K^{-1}$
Solid (at 298K)	0.358 $W.m^{-1}.K^{-1}$
Thermal diffusivities	
Liquid (at 313K)	8.64×10^{-8} $m^2.s^{-1}$
Solid (at 298K)	2.14×10^{-7} $m^2.s^{-1}$
Kinematic viscosity	
Liquid (at 313K)	4.013×10^{-6} $m^2 s^{-1}$
Thermal expansion coefficient	9.0×10^{-4} K^{-1}

3.3 Governing equation

3.3.1 Heat Transfer Fluid

Both fluid flow and convective heat transfer will be taken into consideration in the heat transfer fluid.

$$\frac{\partial \rho_w}{\partial t} + \nabla \cdot (\rho_w \mathrm{u}) = 0$$

$$\frac{\partial (\rho_w u)}{\partial t} + \nabla \cdot (\rho_w u \otimes u) = -\nabla p + \nabla \cdot [\mu_w (\nabla u + (\nabla u)^T)]$$

$$\frac{\partial}{\partial t}\left(\rho_w c_{p,w} T\right) + \nabla \cdot \left(\rho_w c_{p,w} u T\right) = \nabla \cdot (k_w \nabla T)$$

whereρ_w is density fluid, u is the velocity of the fluid, p is the pressure, μ_w is the fluid dynamic viscosity, $c_{p,w}$ is the specific heat of fluid and T is the temperature. The inlet velocity is set to be constant at all time.

3.3.2 Storage for Phase Change Material

The conservation of mass, momentum and energy include the fluid flow, heat transfer and the phase change processes.

$$\frac{\partial \rho_{pcm}}{\partial t} + \nabla \cdot (\rho_{pcm} u) = 0$$

$$\frac{\partial \rho_{pcm}}{\partial t} + \nabla \cdot (\rho_{pcm} u \otimes u) = \nabla \cdot \sigma + \rho_{pcm} g + S_{mom}$$

$$\sigma = -pl + \nabla \cdot [\mu_{pcm}(\nabla u + (\nabla u)^T)]$$

$$\frac{\partial}{\partial t}(\rho_{pcm} H_{pcm}) + \nabla \cdot (\rho_{pcm} u H_{pcm}) = \nabla \cdot (k_{pcm} \nabla T)$$

Where $\rho_{pcm}$is the density for the phase is change material and μ_{pcm} is the dynamic viscosity of the phase change material. For the enthalpy porosity formulation, it is represented by the S_{mom} for the enthalpy in term of momentum equation whereas; the enthalpy in term of energy equation is represented by H_{pcm} in the above equation.

3.3.3 Constitutive Relations

For the thermophysical properties of the water, the polynomial functions of temperature are used.

The density of water, ρ_w

$$\rho_w = -3.570 \times 10^{-3} T^2 + 1.88T + 753.2$$

Water viscosity, μ_w

$$\mu_w = (2.591 \times 10^{-5}) \times \left(10^{\frac{238.3}{T-143.2}}\right)$$

Thermal conductivity of water, k_w

$$k_w = -8.354 \times 10^{-6} T^2 + 6.53 \times 10^{-3} T - 0.5981$$

For the specific heat of water,$c_{p,w}$ it will consider constant at 4200 kJ/kg K^{-1}

Since this paper will be using paraffin wax, the density of paraffin wax is given by

$$\rho_{pcm} = \frac{750}{0.001(T - 319.15) + 1}$$

The thermal conductivity of the phase change material can be estimated as

$$k_{pcm} = \begin{cases} k_{pcm}^{(s)}, & if\ T < T_{solidius} \\ k_{pcm}^{(l)}, & if T > T_{liquidius} \end{cases}$$

where solid phase and liquid phase are represented by (s) and (l), respectively.

To defined the viscosity of the phase change material,μ_{pcm} the following equation can be use

$$\mu_{pcm} = 0.001 exp\left(-4.25 + \frac{1790}{T}\right)$$

At previous equations, the enthalpy in term of energy equation, H_{pcm} and in term of momentum energy, S_{mom}have been introduced. Hence, H_{pcm} can be defined by

$$H_{pcm} = h_{pcm} + \Delta H_{pcm}$$

whereh_{pcm} is the sensible heat and is defined by

$$h_{pcm} = h_{pcm}^{ref} + \int_{T_{ref}}^{T} c_{p,pcm}\, dT$$

where$c_{p,pcm}$ is the specific heat of the phase change material. To calculate the latent heat of the phase change material, the following equation is used

$$\Delta H_{pcm} = \beta L$$

Where L is the latent heat of phase change material and β is the melted mass fraction of phase change material which is given by

$$\beta = \begin{cases} 0 & if\ T < T_{solidius} \\ \dfrac{T - T_{solidius}}{T_{liquidius} - T_{solidius}} & if\ T_{solidius} < T < T_{liquidius} \\ 1 & if\ T > T_{liquidius} \end{cases}$$

Since the partially solidified region (mushy region) is considered as porous medium, each of the cells is set to equal to the liquid fraction in cell. For a fully solidified region, the porosity is equal to zero. Approximately, the enthalpy in term of momentum equation is defined by

$$S_{mom} = \frac{(1-\beta)^2}{(\beta^3 + 0.001)} Hu$$

where H is known as the mushy zone constant.

3.3.4 Boundary and Initial Conditions

The boundary conditions are as follow:

a) At inlet,

for charging; $u=U^{in}$, $T=T^{max}$,

b) At outlet,

for pressure; $p=p^{out}$

for stream-wise gradient of temperature; $n \cdot (k_w \nabla T) = 0$

c) At wall,

No slip; u = 0,

No heat flux; $n \cdot (k\nabla T) = 0$.

d) At interface between the heat transfer fluid and the phase change material,

No slip; u = 0,

Coupled temperature; $T_{itf}^{+} = T_{itf}^{-}$

The initial conditions are given by

a) During charging,

at t = 0, $T = T^{min}$ and u = 0

where T^{min} is the ambient temperature.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Model validation

The finite volume method (FVM) is used to simplify the governing equations. Throughout the simulation, SIMPLE pressure- velocity coupling methods are use since it gives a stable result than the order method even if the model is experiencing transient state. Since at the middle of the copper tube are having unstructured meshes, the best way to minimize the problem is by using Green-Gauss Node Based for the gradient.

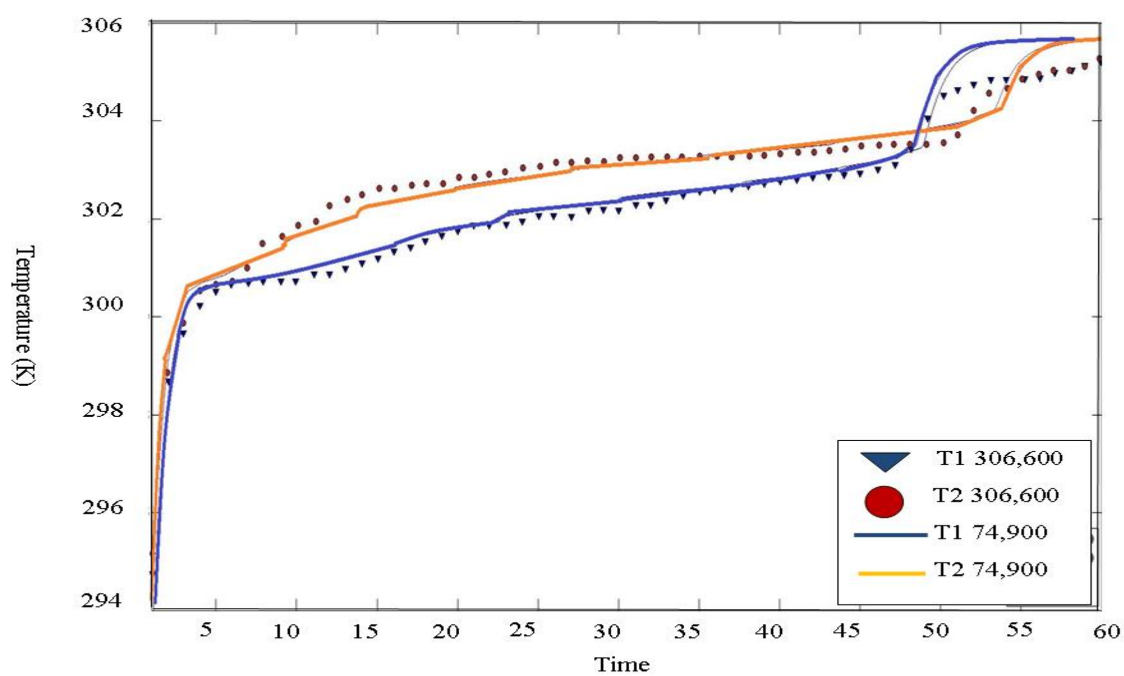


Figure 6: Comparison between Lacroix's and tube 4

minimize the time consume for each simulation to be done. This model tube will be used throughout the entire simulation. As shown in the Figure 6, the physical model and simulation code in the previous research paper are correct and reliable.

4.2 Effect of tube orientation

The study focus on two different tubes orientation where the temperature gradient and the liquid fraction of the paraffin wax are observed. From the observation on the temperature gradient, the inner part of the copper tube shows the highest where basically carrying the heat transfers fluid. The heat transfer fluid is supply from the bath water where it is maintain at 306K. As the region move further from the copper tube, the temperature decreases. Figure 7 show the temperature gradients throughout the z-direction of the tube. Nearest to the end of the tube, the highest temperature region starts to become smaller because of the presence of heat loss.

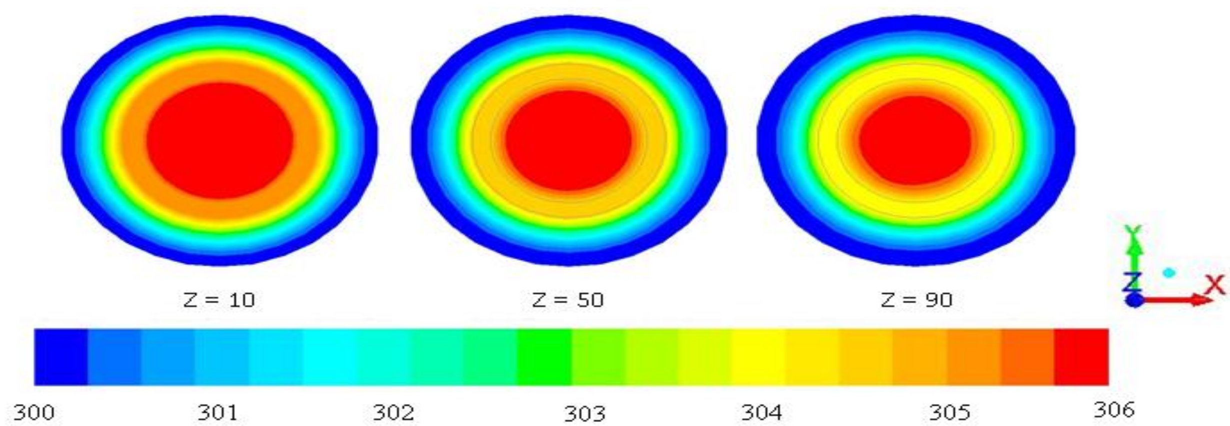


Figure 7: Effect of vertical orientation on the temperature gradient

In term of liquid fraction of the paraffin wax, the region shows concentric distributions as in Figure 8 where there is no natural convection process occur as the process is fully heat conduction. On the z direction of the tube, the temperature of the paraffin wax is constant for each of the cross section.

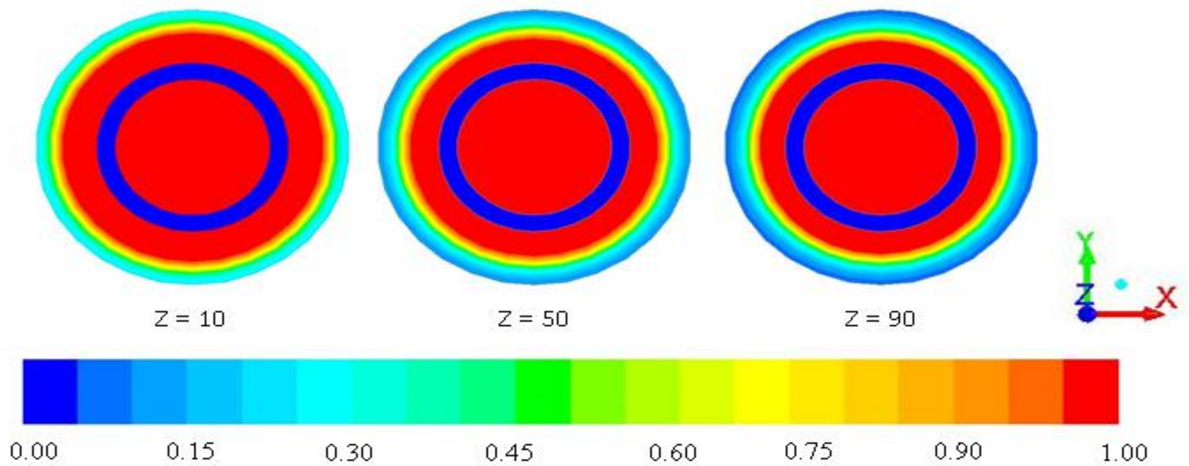


Figure 8: Effect of vertical orientation on liquid fraction

The tube later observed when it is vertically oriented. At this point of view, the natural convection is fully considered. The principle of the natural convection itself has explained that the less dense fluid will rise upward hence this can be confirmed through Figure 9 as the temperature gradient of the tube is cooler at the bottom of the tube. Paraffin wax surrounding the copper tube receives the heat from it and causing it to move to the top of the tube. The denser fluid will move to the bottom of the tube. The temperature at the top of the tube also shows higher that the bottom side of the tube. As per mentioned earlier, there will be heat loss throughout the z-direction of the tube. This caused the heat transfer to be limited.

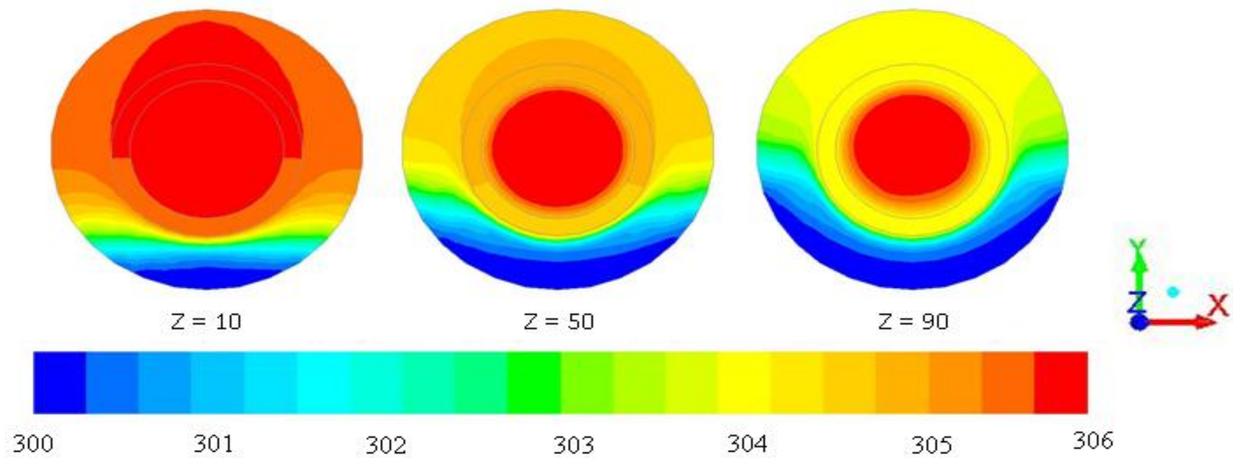


Figure 9: Effect of horizontal orientation on the temperature distribution

Figure 10 are obviously showing the liquid fraction of the paraffin wax in a horizontal tube. The paraffin wax start to melts at the top of the tube and leaving the bottom side to maintain as a solid paraffin wax. The region with liquid fraction equal to 1 become smaller as the length of the tube increase. When the paraffin wax is in the transition phase from solid to liquid, it will release latent heat. Hence, by having a limited region of melted paraffin wax, the amount of latent heat also become limited. In order to increase the heat transfer performance from the fluid to the paraffin wax, a rotating phase change material based thermal energy storage is proposed.

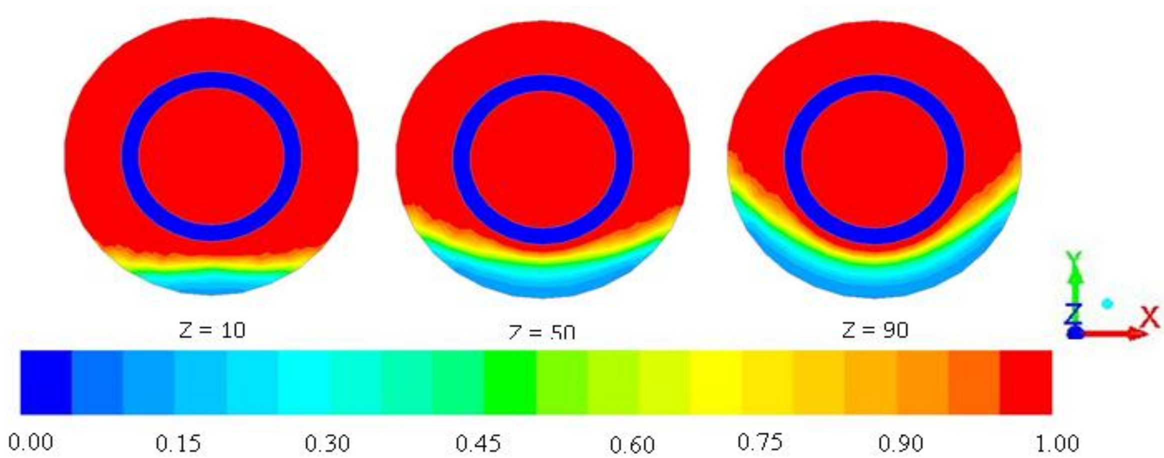


Figure 10: Effect of horizontal orientation on the liquid fraction

4.3 Effect of rotational speed

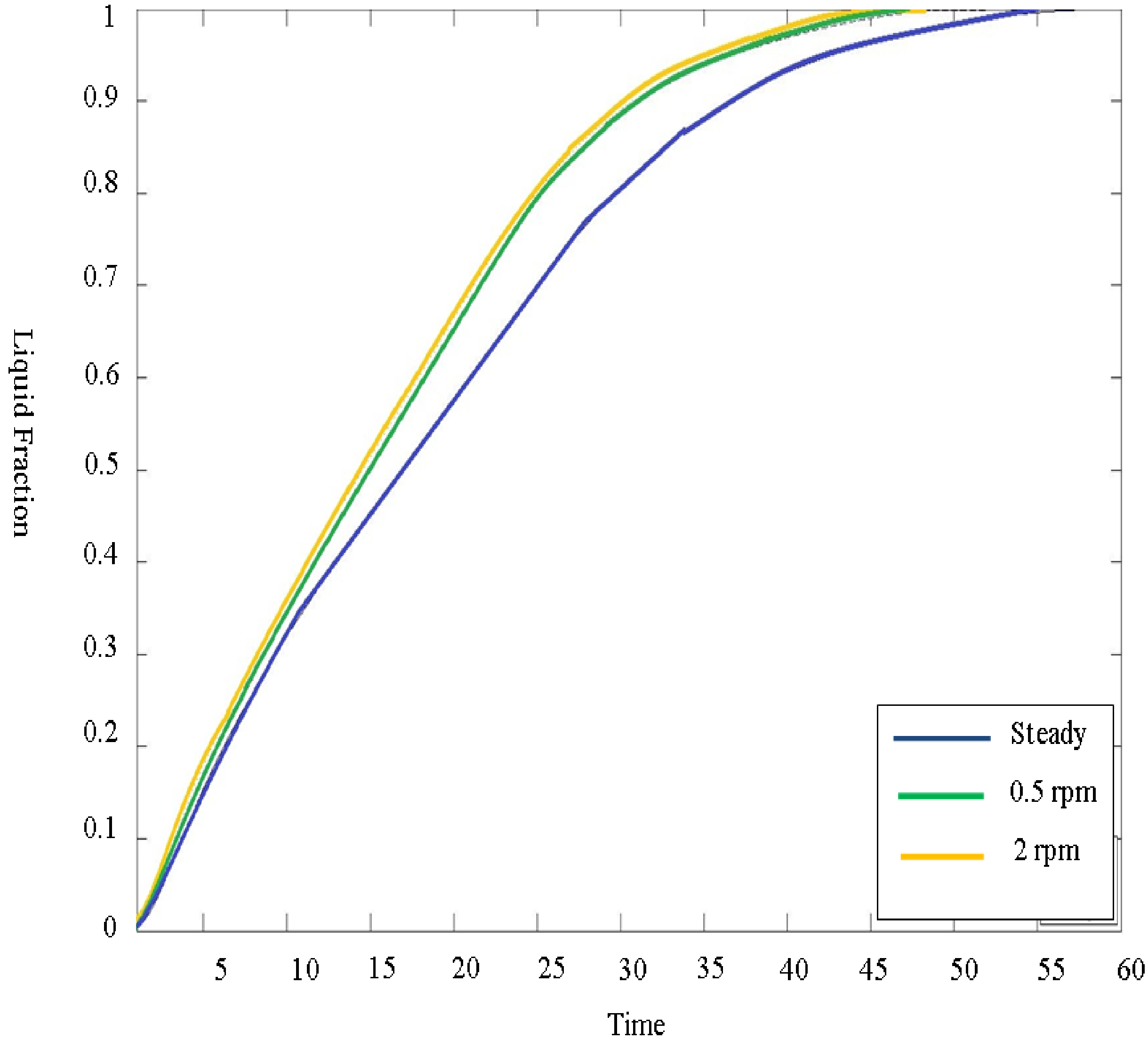


Figure 11: Performance of tube with different rotational speed applied

Rotational speeds are then applied on the horizontal oriented tube. The rotational speeds are set as the variables in order to observe the heat transfer performance in the tube. Figure 11 is comparing the effect of rotational speed on the liquid fraction in the tube. It can be observed that as the rotational speed increases, the paraffin wax start to melt uniformly. The result shows a small different in the liquid fraction between a tube that being applied 2 rpm rotational speed and 0.5 rpm. Half rotation per minute is applied at the tube first to observe the effect of rotation on the heat transfer performance. The temperature distribution shows a good result where the temperature range starts at 302K to 306 K whereas, in term of liquid fraction distribution, there is a small improvement in the liquid fraction region.

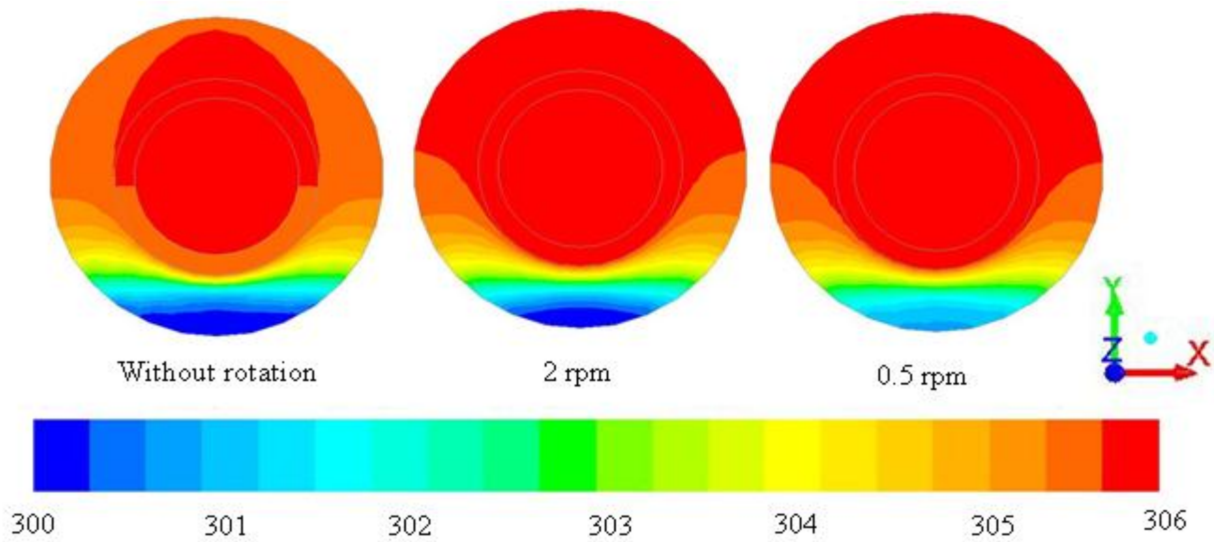


Figure 12: Effect of rotational speed on the temperature distribution

The tube is further observed when 2 rpm of rotational speed is applied to the tube. The temperature distribution shows a slight different compared to the tube that being applied 0.5 rpm. The temperature range starts at 301 K to 306 K. In other hand, the liquid fraction shows an improvement where the highest temperature concurring the phase change material regions. This can be agreed since rotating act as a forced convection where it can increase the heat transfer performance.

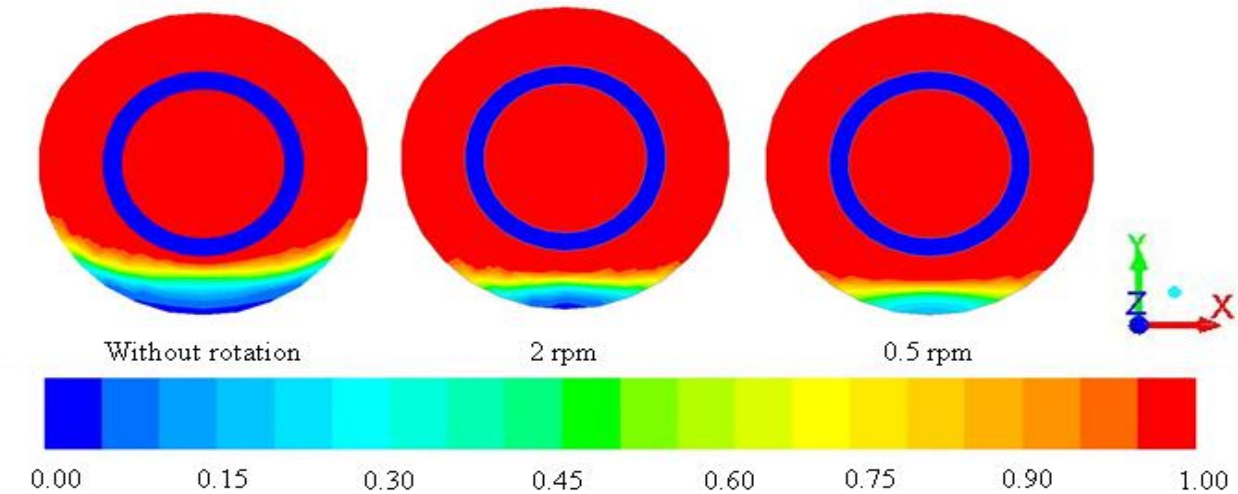


Figure 13: Effect of rotational speed on the liquid fraction

CHAPTER 5

CONCLUSION & RECOMMENDATION

At the end of the study, computational models for heat transfer in a phase change material based thermal energy storage are developed by using GAMBIT. It is later being simulated by using Fluent 15.0 by using user-defined function (UDF). Mesh independent tests are done on five different tubes with different total number of mesh. By comparing the base tube with all the other tubes, it is conclude that throughout the study, tube 4 with a total number of meshes equal to 74900 will be use.

The orientation of the tube gives a significant effect on the melting of paraffin wax. While positioning the tube vertically, the temperature gradient shows at uniform in z-direction. The temperature of paraffin wax that are near to the heat transfer fluid are higher and decreases as it moves further from the heat transfer fluid. In term of liquid fraction of the paraffin wax, the paraffin wax totally at the region near to the heat transfer fluid. When the tube is in horizontal oriented, the effect of natural convection can be seen clearly where only the upper side of the tube experiencing the melting of paraffin wax. Whereas, the bottom of the tube still in the solid phase. This can lead to a limited amount of heat transfer from the heat transfer fluid to the paraffin wax.

The study later, step into another stage where it needs to study and evaluate a rotating phase change material based thermal energy storage. In this study, a few rotational speed are observed; 0.5 rpm and 2 rpm. The 2 rpm are the fastest among the two, the impact that it gives on the melting of the paraffin wax is big when compared to the steady PCM-TES tube without applying a rotation. If the rotation speed is compared to each other, the 2 rpm tube still the highest among them even the difference is small. This fit the theory of melting ice in a cup of coffee as by stirring the ice will help in cooling the coffee faster. In this case, rotating the PCM-TES will helps in spreading the heat uniformly and causing the paraffin wax to melts faster and wider.

5.1 Recommendation

A few recommendation need to take into accounts for the improvement of the study. The study need to be further investigate if the inlet temperature and velocity affects the heat transfer performance of the phase change material based thermal energy storage. There is a number of researches done that results in the effects of inlet temperature and velocity on the heat transfer performance. Hence by considering this into the research will helps in gaining a more concrete result. The study also needs to continue if the tube can handle thermal cycle. Thermal cycle can change the result as it will change the properties of the material after it undergoes several cycle of charging and discharging process. Another suggestion is on the usage of different phase change material. Hydrated salt and microencapsulated phase change material are suggested as it has shown an impressive result in term of their heat transfer performance. Since adding a fins or using a novel festoon can enhance the heat transfer performance, the next study should also focus on this aspect. These recommendations are hopes to be look into as the study bring a significant impact in the thermal energy storage world.

In the study, the flow of heat transfer fluid will focus only on laminar flow where this mean that it will not take into consideration if the flow of the heat transfer fluid change into turbulence. The main medium of the phase change material will later focus on paraffin wax as it is the cheapest and the most promising phase change material. The study should be focusing the temperature change between 298K and 305K only.

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