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NUMERICAL ANALYSIS OF THE PARAFFIN MELTING PROCESS IN A SQUARE CAVITY WITH INCREASE GRADUALLY OF HOT WALL TEMPERATURE

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Abstract -- *Paraffin as a heat storage material has many advantages but also has drawbacks, namely low thermal conductivity so that the melting time becomes long. Efforts have been made to accelerate the melting time, including by increasing a surface area of the hot wall, or also by changing the geometry. In this study was carried out by changing the temperature of the hot wall from uniform to increase gradually, uniform hot wall temperature was 330 K, increased gradually hot wall temperature was 324 K, 327 K, 330 K, 333 K, dan 336 K. Paraffin used has specifications according to reference. They have performed numerically used ANSYS software. They are using three models, namely model-A, model-B, and model-C. The study aimed to obtain liquid-solid interface contours, changes in temperature at measurement points, and changes in the liquid fraction. The results of model validation show similarities to previous studies. The results show that the melting time in the model-A is the fastest, followed by model-B and model-C.*

Keywords: *Paraffin; Heat storage; Melting time; Temperature; Increase gradually*

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INTRODUCTION

When paraffin changes the phase from solid to liquid, it absorbs more heat when compared to the temperature rises in the same phase. So, storing heat in the form of latent heat is the right choice, this is because the latent heat of paraffin is 176 kJ / kg and the specific heat is 2.9 kJ / kg-K (liquid) and 2.7 kJ / kg-K (solid) [1]. In addition, paraffin also has many advantages over other materials. Paraffin is predictable, safe, less expensive, reliable and non-corrosive [2]. So the use of paraffin as heat storage has been widely applied, including drying food products [3], in drying agricultural products [4], at solar-powered thermo-electric generators [5], at hot water supply [6], and on the passive solar water desalination system [7].

However, paraffin also has its disadvantages, namely its low thermal conductivity [8], this results in a longer melting time so that decreases overall performance. Several studies have been carried out to accelerate the melting time. One way to do this is to increase the area of the hot wall, including installing fins on the tube [8], attaching longitudinal or radial fins [9]. In addition, there is also another way to accelerate the time of melting without adding a surface area of the hot wall, that is by changing the shape of the model of tube-and-shell into a nozzle-and-shell [10], the results show that melting time in the nozzle-and-shell model is 15.3% faster than the tube-and-shell model. Other research was carried out by changing the shape of the tube-and-shell into combine-and-shell [11]. The result showed that the melting time in the combine-and-shell model was 40% faster than the tube-and-shell model.

Numerical research to see the paraffin melting process in two-dimensional containers has also been done, with various forms of containers and various variations of hot walls, including using a square enclosure with heating on the vertical side or heating on the horizontal side, the results show that the melting rate of paraffin in heating from the vertical side is much higher than that of heating from the horizontal side [12]. Paraffin melting process in a square cavity with two heat source-sink pairs also done, the results show that the different arrangements of two heat-sink pairs produce different liquid fractions [13]. Numerical studies in a square cavity with the heating wall located at the different side, namely the left, top, right, and bottom also been done, the results show that the most rapid paraffin melting process occurs on heating the lower wall [14]. Numerical analysis in the process of melting paraffin in enclosure with partially active walls (Heating from right and cooling from left walls or Heating bottom and cooling from top), the results showed that faster melting is obtained if the enclosure is heated from below as compared with that in the passage right of the vertical sidewalls [15].

In this study, the process of melting paraffin on a square cavity done numerically 2D, to improve the heat transfer of natural convection, is done by changing the temperature of the hot wall. The original temperature of the hot wall is uniform along the wall, changing to the increase gradually, from a low temperature to greater temperature and vice versa. This research seeks to obtain an analysis of liquid-solid interface contour, velocity vector, temperature graph, and liquid fraction graph.

METHOD

Physical Model

The model used is square with a side length of 25 mm. There are three models, as shown in Figure 1, namely model-A, model-B, and model-C. The left wall is hot, while the other wall is adiabatic. The hot wall is divided into five sections of equal length, and each part has a certain temperature. The hot wall on the model - A has a different temperature on each part, which is 324K, 327K, 330K, 333K, and 336K respectively, from top to bottom. In the Model-B, the temperature of each part is equal to 330K, and in the model-C, the temperature of each part is 336K, 333K, 330K, 327K, and 324K respectively from top to bottom. The initial paraffin temperature is 300K. The position of temperature measurement points (T_1, T_2, and T_3) is shown in Figure 1.

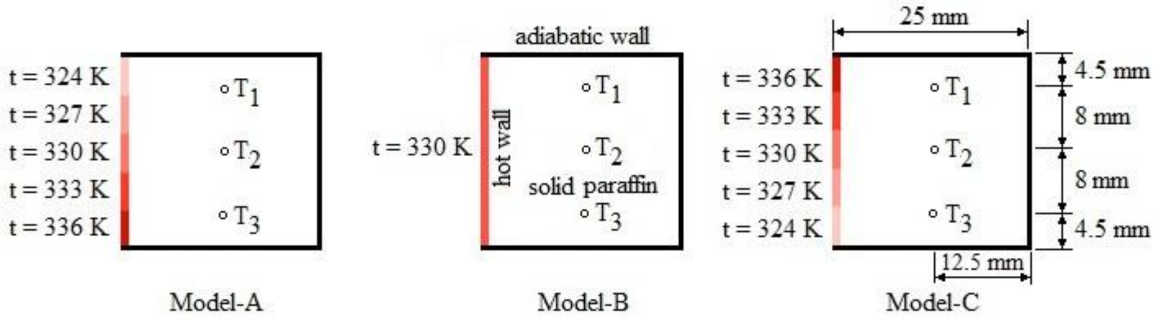

Figure 1. Models in numerical analysis

In this numerical analysis, the following assumptions are used:

1. A liquid paraffin stream is laminar
2. The physical condition of paraffin depends on the temperature
3. Volume changes in the melting process are ignored
4. Solid paraffin stays in position during the melting process

The properties of paraffin used for numerical analysis are shown in Table 1.

Table 1. Property paraffin [12]

Property	Value	Dimension
Viscosity	$0.001 \exp\left(-4.25+\frac{1790}{T}\right)$	Ns/m^2
Density	$\frac{750}{0.001(T-319.15)+T}$	kg/m^3
Specific heat	2890	J/kg K
Thermal conductivity	0.21 if $T < T_{solidus}$ 0.12 if $T > T_{liquidus}$	W/mK
Latent heat	173,400	J/kg
Solidus temperature	319	K
Liquidus temperature	321	K

Computational Methodology

Model making using ANSYS software in the Geometry subprogram, then meshing using the Mesh subprogram. The results obtained are exported to the Fluent subprogram.

In Fluent programs using the Solidification & Melting model, the material used is paraffin with properties as in Table 1, specifically for density property, viscosity, and thermal conductivity using User Defined Functions because this property is an equation. In Solution Methods, the scheme used is Simple, the gradient used is Least Squares Cell-Based, the pressure used is Presto, the momentum used is the First Order Upwind, and the Energy used is the First Order Upwind. To obtain temperature data is done by monitoring changes in temperature at points T_1, T_2, and T_3 during the melting process with the position as shown in Figure 1. To get liquid fraction is done by monitoring the melting process on all paraffin volumes.

Validation of Models

Validation is done by comparing the results of the Model-B numerical analysis with those reported by Arasu & Mujumdar [12] and by Ebrahimi & Dadvand [13], so in this numerical analysis boundary condition changes, namely adiabatic wall in front of hot wall was changed to cold wall with a temperature of 300K while the hot wall temperature is still 330K. The liquid-solid interface comparison results from numerical analysis with the results of previous studies shown in Figure 2.

Numerical results from both previous studies [12][13] use paraffin with an addition of 0% Al2O3, 2% Al2O3, and 5% Al2O3, showed that there was no difference between the use of paraffin with an additional 0% Al2O3 and the use of paraffin with an additional 2% Al2O3. Because they do not show liquid-solid interfaces using pure paraffin, then the validation was carried out using paraffin with an additional 2% Al2O3 as a heat storage material.

In Figure 2, the liquid-solid interface comparison is carried out at t = 1000s and t = 3000s, based on the liquid-solid interface, it can be said that there is a match between this research with those reported in [12] [13].

RESULTS AND DISCUSSION

Based on the liquid-solid interface in Figure 3, there is a difference in the melting process of the three models, at t = 100s melting process in the Model-A occurs near the hot bottom wall, in the Model-B it occurs evenly near the hot wall, while in the model-C occurs near the top hot wall. The condition can be explained because the influence of the hot wall temperature distribution is different between the three models, where the first melting paraffin is that which is close to the hot wall, which has a higher temperature. Heat transfer that occurs at the beginning of the process is conduction, and this lasts until the melting process occurs while the liquid paraffin has not moved.

The melting process will move away from the hot wall the next time. However, at the top, it is faster. The condition happens because of the difference in liquid density paraffin, which causes liquid paraffin to move up and accumulate in the upper enclosure.

The next heat transfer that occurs is convection, which is divided into two stages; heat transfer of convection from the hot wall to liquid paraffin, and heat transfer of convection from the liquid paraffin to solid paraffin.

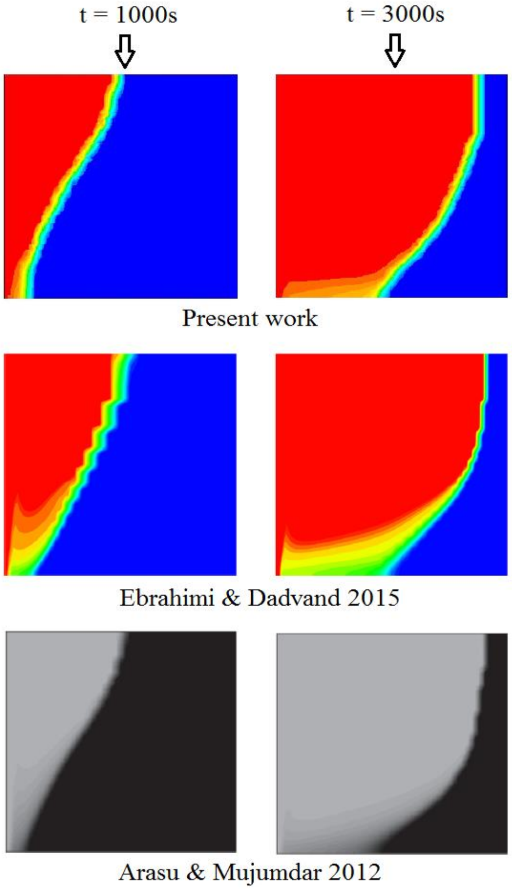

Figure *2*. Validation of liquid-solid interface

Heat transfer from liquid paraffin to solid paraffin occurs in the liquid-solid interface, this causes the temperature of the liquid paraffin to decrease and its density to increase, resulting in a downward movement of paraffin. Because the liquid paraffin moves up near the hot wall and the liquid paraffin moves down near the solid-liquid interface, the liquid paraffin circulation naturally occurs.

The speed of liquid paraffin during circulation is not the same; liquid paraffin near the hot wall has the highest speed, as shown in Figure 4. Based on the color of the velocity vector in Figure 4, shows that the speed of liquid paraffin during circulation in the model-A is greatest, and followed by successive model-B and model-C.

The last melting process occurs in the lower right, seen at t = 3500s all paraffin has turned liquid in the model-A, still leaving a small amount of solid paraffin in the model-B, and still have more solid paraffin in the model-C as shown in Figure 3. The situation shows that the melting time in the model-A is the fastest, to be followed successively by the Model-B and the Model-C.

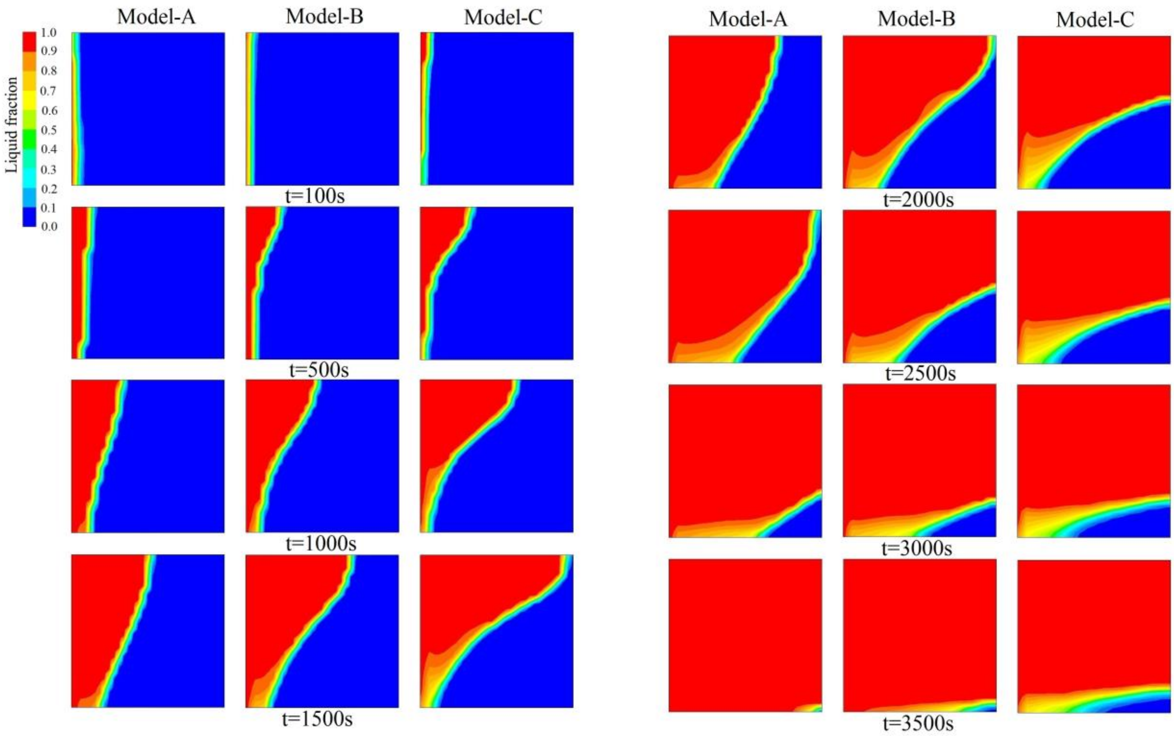

Figure 3. Comparison of Liquid-solid interface

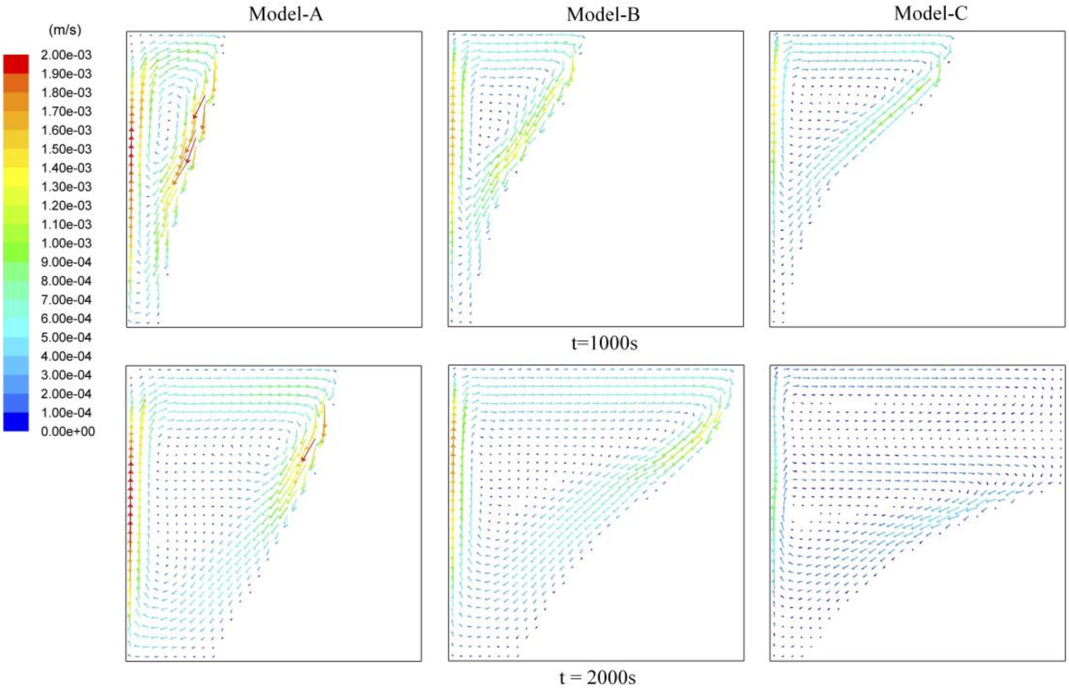

Figure 4. Comparison of the velocity vector

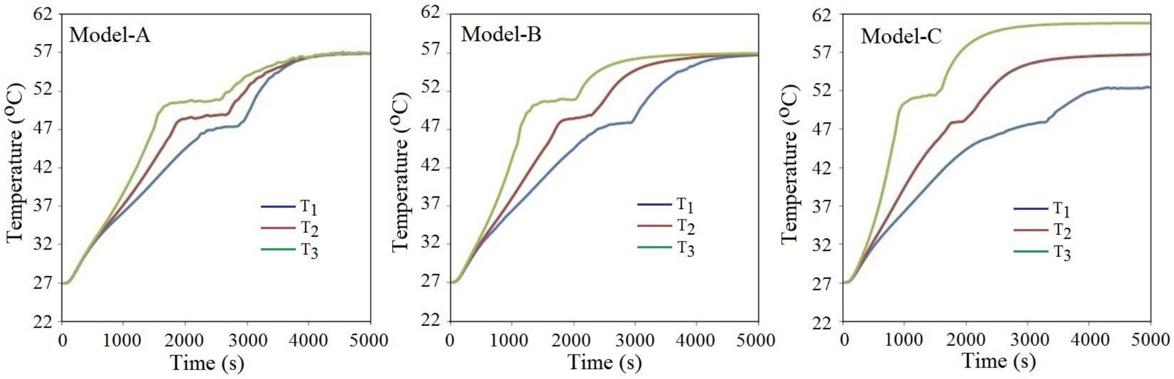

Figure 5. Comparison of temperature

Temperature changes at measurement points for all models are shown in Figure 5. At first, the same temperature increases at T_1, T_2, and T_3. Furthermore, the temperature at T_3 rises quickly, followed by T_2 and T_1, respectively. T_3 reaches the melting temperature first so that melting occurs, followed by T_2 and T_1. Differences in all three models are the time duration of the melting of T_3 to the T_1, wherein the Model-A after paraffin melting occurs on T_3 immediately followed by T_2 and T_1, in the Model-B, it takes longer and, in the model,-C the longest. At the end of the process (t = 5000s), there is a similar temperature in the model-A. The speed of liquid paraffin causes this during circulation in the Model-A is greater, so the temperature is quickly homogeneous.

The liquid fraction is the ratio between liquid paraffin to all paraffin when the value is 0 (zero), then all of the paraffin in the solid-state, when the value of 1 (one) then all has turned into liquid paraffin. Based on Figure 6, liquid fraction on all models showed the same pattern, but at the beginning of the process showed that the liquid fraction in the model-C rose faster, this showed that the paraffin melting process in the Model-C was faster than the other models, but after going on for around 2500s the opposite happens, where the liquid fraction in the Model-C becomes the slowest, this occurs until the end of the melting process. The final process shows that the paraffin melting process in the Model-A is the fastest, followed by successive Model-B and model-C. Based on the data obtained, melting in the model-A is 5.3% faster and melting in the Model-C is 26.6% slower than the Model-B.

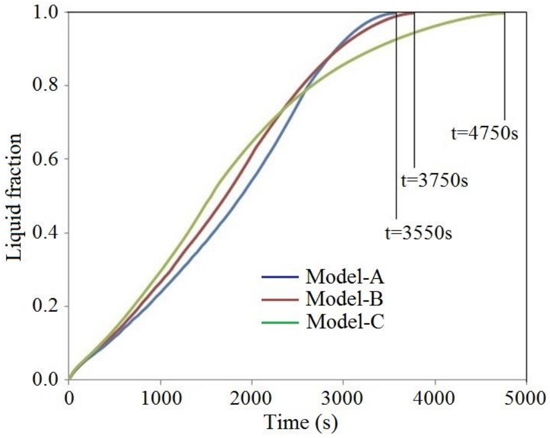

Figure 6. Comparison of the liquid fraction

CONCLUSION

At the beginning of the melting process, the heat transfer that occurs is conduction as long as the liquid paraffin has not moved, after the liquid paraffin moves, the heat transfer turns to natural convection. The melting process in the Model-A requires the least time, followed successively by the Model-B and the Model-C. The natural circulation speed of liquid paraffin in the model-A is greatest so that the liquid paraffin temperature is homogeneous faster.

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