

# Research on Optimization Model of Heat Exchange Fin Structure in Energy Storage System

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**Abstract:** Aiming at the thermodynamic problem of heat transfer fin in heat storage system, the solidification and melting model and thermodynamic conventional model are established by using simulation software, thermodynamic image processing and other methods. MATLAB, COMSOL and other software are used to program the optimal rectangular fin spacing Angle and the optimal heat exchange fin structure. Firstly, based on the reason that the simulation software can simulate the heat transfer process of phase change material (PCM) in the actual process to the greatest extent, the plane modeling and thermodynamic equation method are used to analyze the distance Angle of the rectangular fin, and the melting solidification model is established, and the optimal solution is obtained. Finally, combined with the analytic hierarchy model and TOPSIS method, the triangular fin structure and rectangular fin structure were compared from three levels, namely, the heat sink area, temperature rise time and PCM maintenance time of different shapes. And create a heat transfer rate of return to more favorably analyze the data and visually present the comparative results.

**Keywords:** COMSOL; Solidification and Melting Model; Hierarchical Analysis; Simulation Experiment.

## 1. Background Introduction

Energy is the foundation for the growth of human society and the foundation for the growth of human society and technological progress. In order to improve the rapid heat transfer ability of the heat storage system, the important problems of optimizing the system structure design and parameters are studied. The implementation of efficient energy storage technology can store energy in thermal storage materials, which can release the stored energy when the external energy consuming equipment is insufficient [1]. The invention of phase change materials (PCM) made latent heat storage (LHTE) possible. However, due to the poor thermal conductivity of most phase change materials, the heat storage and release rates of LHTE significantly deteriorate, thus severely limiting its practical application. Therefore, the problem is to expand the heat transfer area by installing fins on the outer tube wall, so as to improve the heat transfer rate. This method is widely regarded as a direct and effective way to improve the heat transfer efficiency of phase change materials, thus expanding the application field of LHTE and making a great contribution to the development of renewable energy.

## 2. Text

### 2.1. Establishment of Model

#### 2.1.1. Mathematical Model

According to the solution idea of problem I above, in the establishment of phase change heat storage tank, each parameter of rectangular fin is divided according to variable and immutable in accordance with the requirements, so as to save the operation time, compare and analyze with different interval angles, judge the optimal interval Angle by changing the interval Angle of rectangular fin, and use simulation software to solve. Substitute the specific parameters given by the question, and solve the second question.

In order to reduce experimental errors, our team used COMSOL and SIMDROID respectively to establish thermal models, integrated the modeling data of three kinds of software, adopted variance method and average method to reduce experimental errors [2].

the hypothesis, the energy conservation equation in the melting process is as

$$d_{iv(U)} = 0 \quad (1)$$

Continuity equation:

$$\frac{\partial \rho v}{\partial t} + d_{iv(\rho v U)} = d_{iv(\eta \text{grad} u)} - \frac{\partial p}{\partial x} + S_v \quad (2)$$

Momentum equation:

$$\frac{\partial \rho h}{\partial t} + d_{iv(\rho h U)} = d_{iv(k \text{grad} T)} \quad (3)$$

$$S_b = \rho k (T - T_r) g \quad (4)$$

$$S_i = A_m = \frac{(1-\lambda)^2}{\lambda^3 + \varepsilon} \cdot i \quad (5)$$

The numerical description of the fluid fraction

$$\lambda = \frac{\Delta H}{L} = \begin{cases} 0, T < T \\ \frac{(T-T_s)}{T_l-T_s}, T_s \leq T \leq T \\ 1, T_l < T \end{cases} \quad (6)$$

$$\frac{1-\lambda}{r^3+0.001} A_{mush} \vec{v} = -\nabla \cdot P + = -\nabla \cdot P + \mu \nabla^2 \vec{v} \cdot \frac{\partial}{\partial t} (\rho_h c T) + \rho_h g \quad (7)$$

Among them,

$$h = h_r + \int_{T_r}^T c_p dT \quad (8)$$

$$= -\nabla \cdot P + \mu \nabla^2 \vec{v} + \rho \vec{v} \beta (T - T_{ref}) + \vec{s} \cdot \vec{s} \quad (9)$$

$$\Delta H = \gamma L \quad (10)$$

Total heat storage:

$$Q = \rho V_{PCM} (T_{ave} - T_0) + \rho V_{PCM} \gamma L \quad (11)$$

Average heat storage rate:

$$\varphi = \frac{Q}{t} \quad (12)$$

#### 2.1.2. Mathematical Model

In order to analyze the relationship between the spacing Angle of rectangular fins and the improvement of heat storage

efficiency, a simulation APP was created by using the thermodynamic model in Simdroid software. This model is an important method to solve this kind of thermodynamic analysis problem [3]. Considering sensible thermal conductivity in question 1, the thermodynamic model has two important categorical variables: the shape size of the fin and the density of the phase change material.

Simulation software is used to test whether there is a relationship between the two variables, fin shape size and PCM density, so as to accurately determine the influence of fin shape size and PCM density on the energy storage system, so as to deduce the appropriate fin spacing Angle. Firstly, construct a three-dimensional model (as shown in Figure 1):

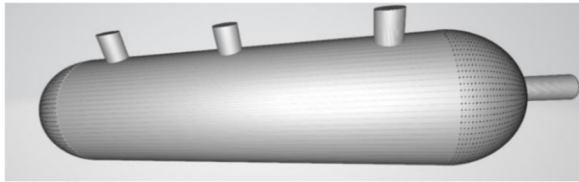


Fig 1. 3D front view of the heat storage tube

Second, simulation software is used to simulate the preliminary model (as shown in Figure 2).

After qualitative and quantitative treatment of the phase change material PCM, our team substituted the relevant heat transfer equations, digitized the model, and demonstrated it powerfully with visualized simulation process diagrams. In order to get the preliminary conclusion, the author chooses a

variety of simulation software for simulation test, and calculates the results. We use variance method and mean method to reduce the error of simulation experiment.

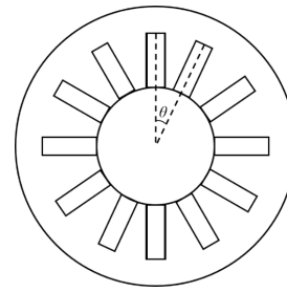


Fig 2. Preliminary model of rectangular fin structure Then by modifying the rectangular fin spacing Angle

## 2.2. Analytical Process 1

Solution setup: Based on solidification and melting modelenthal method, the material phase transition process of was substituted into the energy equation and thermodynamic model, and the simulation experiment was conducted in the simulation software.

From many numerical simulation experiments, angles 30, 45, 60, 75 and 90 were selected as typical data to show the simulation experiment results. First, the numerical table of experimental data was derived (see Table 1).

Table 1. Preliminary experimental data table

Time (min)	30, Temperature (K)	45, Temperature (K)	60, Temperature (K)	75, Temperature (K)	90, Temperature (K)
0	293.0191495	293.1489436	293.1499395	293.1499412	293.1499813
1	298.3812571	296.352664	298.3715744	300.3826514	297.9763307
2	294.4076229	296.3398436	298.93291	301.5494618	296.0021372
3	294.0550725	294.3948772	294.3525186	293.0155324	294.1620698
4	292.9805295	312.5983469	296.4889376	300.6934702	300.4084185
5	317.244721	306.9993848	292.9990291	293.150027	299.970602

Based on the data value table, our team drew a thermal curve (see the figure 3) using different colors to distinguish, to make full use of visual effects to improve the integrity of the problem. From the figure, we can see that the efficiency increases with the reduction of the Angle of the rectangular fin, but when the Angle is less than 30, we can see that the efficiency does not improve significantly, but decreases. Therefore, our team believes that when the rectangular fin spacing Angle is 30 degrees, the heat transfer efficiency of the heat storage system is the best. Through simulation and verification of other simulation software, the heat transfer efficiency is better when the rectangular fin is roughly 30 degrees, that is, in the heat transfer system, the heat dissipation efficiency of twelve rectangular fins is high.

In order to further explore the time, it takes the rectangular heat transfer fin to increase the temperature of phase change material (PCM) from 293K to 333K, our team used simulation software to conduct physical simulation, recorded the temperature and heat distribution of phase change material (PCM) at regular intervals through the interval recording method, and drew the corresponding thermal distribution diagram (see Figure 4). It can be seen from the figure that the

temperature rise of phase change material at different moments takes 73.6 S to reach 333K.

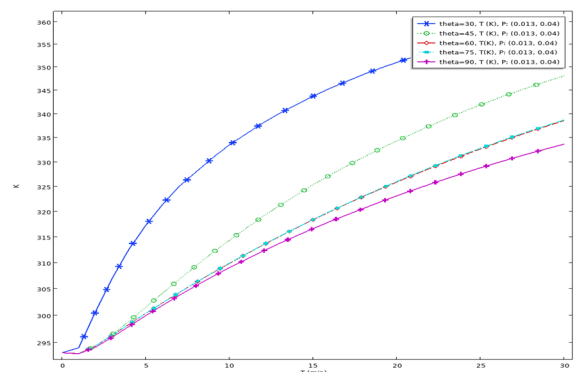


Fig 3. Heat transfer efficiency of heat storage system with different angles

## 2.3. Analytical Process 2

The effect on PCM's heating rate was also investigated by optimizing the size and distribution of the triangular fins, as shown in the diagram given below. Solving Procedure 2 also required a comparison of the advantages and disadvantages of

the heat transfer efficiency of the triangular fins with the heat transfer efficiency of the rectangular fins in problem 1. the preliminary model is simulated by simulation software (as shown in Figure 5)

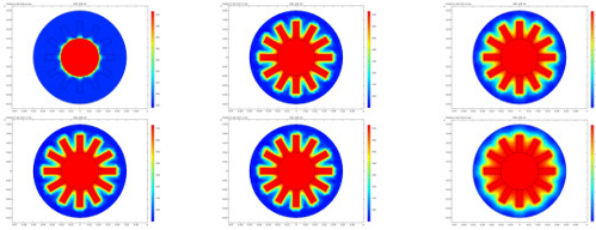


Fig 4. Thermal profile of rectangular fin

Note: Blue represents different values. Blue represents 362K in the last picture

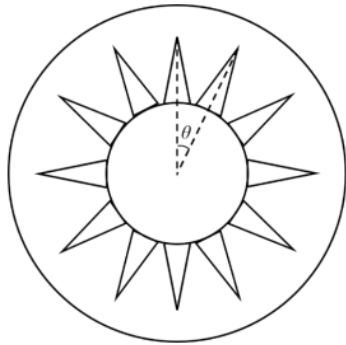


Fig 5. Triangular fin structure

We used a similar approach to Solving Procedure 1 to model with enthalpy-porosity and LTR methods. The heat transfer rate and temperature values were compared to determine if fin shape and size affect the heat transfer rate. In order to evaluate the heat transfer efficiency, it is important not to pursue a fast heat transfer rate but also to achieve a high "payback" rate [4]. We define high heat transfer rates and small increases in heat transfer area as two evaluation criteria for heat transfer efficiency.

The principle regarding the heat exchange rate calculation

still uses the enthalpy-porosity model, similar to the first question, to simulate the melting process of PCM. This model divides the phase change region into a multivacancy region and defines the ratio of the liquid fraction of the PCM as the porosity. The fraction allows the representation of the PCM's solid-liquid mix during the melting process and, again, the changing state.

We have used various methods, such as Euler's formula and Runge Kutter's method, to derive similar temperature values for the temperature analysis part of the heat transfer principle. Thus, we demonstrate the accuracy of the model. We have also used simulation software represented by com-sol for simulation reduction to confirm our conclusions' accuracy further.

In order to further explore the time, it takes for the triangular heat transfer fin to increase the temperature of phase change material (PCM) from 293K to 333K, our team used simulation software to conduct physical simulation, recorded the temperature and heat distribution of phase change material (PCM) at regular intervals through the interval recording method, and drew corresponding thermal distribution diagram (see Figure 6). It can be seen from the figure that the temperature rise of phase change material at different times takes 64.5 S to reach 333K.

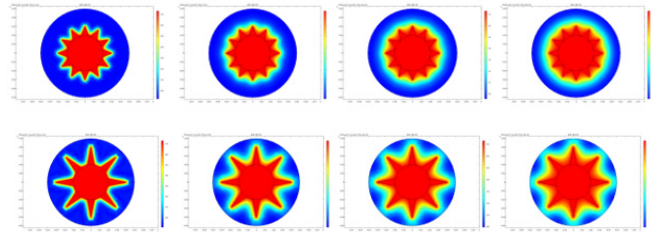


Fig 6. Thermal distribution of triangular fin

From many numerical simulation experiments, angles 30, 45, 60, 75 and 90 were selected as typical data to show the simulation experiment results. First, the numerical table of experimental data was derived (see Table 2).

Table 2. Preliminary experimental data table

Theta	t (min)	T ref (K)	T (K)
30	1	372.9999975	372.9999975
45	1	373.0000356	373.0000286
60	1	373.0000162	373.0000069
75	1	373.0000353	373.0000347
90	1	373.0000198	373.0000164

## 2.4. Analytical Process 3

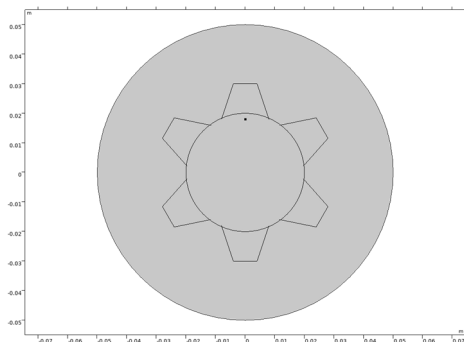


Fig 7. Tooth fin scheme design drawing

We defined the basic characteristic parameters of the trapezoidal fin as theta, upper width as w1, lower width as w2, and height as h1. By establishing a physical model and combining control variable method based on COMSOL Multiphysics software, we analyzed the relationship between fin parameters and temperature one by one (see Figure 7). Finally, the optimal relationship is determined based on the multiple regression-fitting (neural network fitting) model.

Assuming that the initial fixed value is the value of the research problem (fin length is 0.018 m, width is 0.006 m, and the interval Angle between fins is theta) (see Table 3), the characteristic sizes w1, w2 and h1 are selected as 0.002, 0.006, 0.01, 0.014, 0.018 and 0.02m, respectively. The characteristic time was 0, 1, 5, 10, 20 and 30min as the research object. (96

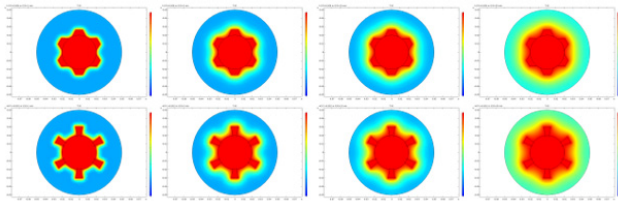
results below).

**Table 3.** Design fin analysis category table

L	0min					Theta
W1(m)	0.002	0.01	0.014	0.018	0.02	60
W2(m)	0.002	0.01	0.014	0.018	0.02	
h1(m)	0.002	0.01	0.014	0.018	0.02	
T(min	1min					
W1(m)	0.002	0.01	0.014	0.018	0.02	
W2(m)	0.002	0.01	0.014	0.018	0.02	
h1(m)	0.002	0.01	0.014	0.018	0.02	
T(min	5min					
W1(m)	0.002	0.01	0.014	0.018	0.02	
W2(m)	0.002	0.01	0.014	0.018	0.02	
h1(m)	0.002	0.01	0.014	0.018	0.02	

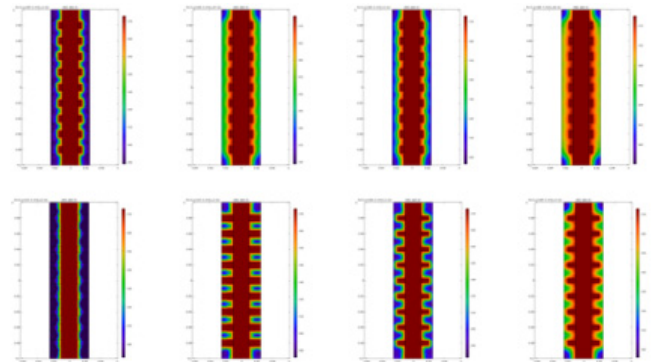
Based on COMSOL software and combined with the method of control variables, the relationship between fin parameters and temperature change was analyzed one by one. Through the interval recording method, the change of physical quantity was controlled only. The temperature and heat distribution of phase change material PCM was recorded every once in a while, and the corresponding thermodynamic distribution diagram was drawn (see Figure8).

of the previous question that the Angle of the fin has little effect on the temperature conduction and distribution, and the Angle value can be set to be fixed [5]. Therefore, by simply changing the length and width of the tooth fin, it is found that the sharpness of the fin is of great help to the heat transfer ability of PCM. The thermal distribution diagram of tubular profile structure of annular fin was drawn by AHP (as shown in Figure 9).



**Fig 8.** Tooth fin scheme design drawing

It can be analyzed from the conclusion of the previous question that the Angle of the fin has little effect on the temperature conduction and distribution, and the Angle value can be set to be fixed. Therefore, by simply changing the length and width of the tooth fin, it is found that the sharpness of the fin is of great help to the heat transfer ability of PCM.



**Fig 9.** Thermal distribution diagram of tubular profile structure

To evaluate the influence of annular fins on the optimal heat transfer capability of PCM heat storage tank. Assume that the initial fin length is 0.018 m, the width is 0.006 m, and the spacing.

Through the analysis of the tubular profile structure of Scheme 4 annular fin, the fin size analysis from different angles, combined with the fitting curve, the optimal heat transfer of PCM can be calculated as the fin width of 0.005m and length of 0.01m (see Table 4). With the increase of fin Angle, the thermal dissipation rate of CPM becomes slower and slower, and the slope of the corresponding curve gradually slows down.

Angle between the fins is theta (assuming that the fins are always perpendicular to the inner tube). Define the fin length as h1 and width as h2. it can be analyzed from the conclusion

**Table 4.** Design fin analysis category table

T	theta=30	theta=45	theta=60	theta=75	theta=90
0	293.150	293.148	293.149	294.149	295.1497
1	294.055	293.019	293.0155	292.999	292.98
2	300.693	294.351	294.394	294.407	294.162
10	333.529	314.3696	309.865	309.91	309.054

### 3. Conclusion

In the structural optimization of heat transfer fin in energy

storage system, combined with the design analysis of COMSOL above, according to the physical model and its mathematical fitting model, it is found that in limited space, changing the height size of fin or improving the sharpness of

fin has higher benefits for heat transfer. However, changing the fin width alone cannot realize the heat transfer capacity of phase change materials, and cannot objectively reflect the heat transfer advantage of phase change materials. Therefore, we finally propose scheme 1: toothed fin model. When the inner tube is evenly distributed at a 60-degree Angle and the tooth fin size is as follows: tip 0.002m, root 0.006m and height 0.02m, the heat transfer performance of phase change materials is the best, which makes great contribution to the development of renewable energy.

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