Optimization of the Fin Heat Pipe for Ventilating and Air Conditioning with a Genetic Algorithm

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Abstract: This paper illustrates that use of a heat pipe as a heat-reclaiming device can significantly influence the air-conditioning system. It analyzes the heat transfer model of the uniform annular fin heat pipe under the condition of air conditioning. It establishes functions of the fin structure parameters such as height，spacing and thickness of the fin when the volume of fin is the smallest under unit temperature difference and unit quantity of heat. It uses a genetic algorithm to optimize the model of the uniform annular fin heat pipe. The calculation result shows that the method of genetic algorithm is effective.

Key words: heat pipe; air conditioning system; fin structure

1 INTRODUCTION

With the improvement of the living standards of working, the new wind capacity of the air-conditioning system is often insufficient, and it leads to indoor air quality (AIQ) badly and arouses the so-called sick building syndrome (SBS). So the researches on new systems and new equipments must be compatible with the three major themes of thermal comfort, indoor air quality and energy conservation, and it is urgent. At the same time, the energy consumption about air-conditioning of buildings continues to increase and the new wind energy accounts for 4%~12% of the buildings total energy consumption [1]. A heat recovery system for air-conditioning systems will be of important practical significance.

Heat pipe can achieve high efficiency of heat transfer, and it needn't add a driving force. Its some characteristics as following: a small transmission difference in temperature, the scope of application of temperature is wide, and fine control of the liquid identity in pipe. So it is in the use of energy recovery widely [2-3].

In air conditioning systems carbon steel -water heat pipes often are used, and we often adopt passive method in order to enhance the thermal performance of the heat pipe, such as installing annular fin heat pipe or rectangle fin in heat pipe light pipe called fin heat pipe.

The application condition of heat pipe in air conditioning is different with that of in industry energy conservation. For the former, the temperature difference is no more than 15 in summer or 30 in winter [4]. So the physics parameters of air are similar to the constant.

This paper will analyze heat model of annular fin heat pipe, establish object function on the condition of air conditioning, and uses genetic algorithm to optimize fin's structure.

2 ANNULAR FIN HEAT PIPE HEAT TRANSFER MODEL

2.1 The Basic Assumptions

Annular fin heat pipe is shown in Figure 1, where fin high is H; fin thick, t; and fin space, s. To facilitate to analyze the annular fin heat pipe, the assumptions as following:

The heat conduction is homogeneous, and heat conduction coefficient along the fin high's direction is constant. It is thermal insulation at the fin end and ignores the sending and receiving radiation heat transfer.

Heat pipe's partition plate is at the midpoint, and fin structure parameters of the heat pipe evaporation segment and condensation segment are consistent, neglecting of the length of insulation segment.

Heat bare pipe and its internal structure parameters are looked as given value. Axial direction heat conduction of pipe wall heat can be omitted.

The temperature difference of air is small, and heat transfer is at the dry condition. The movement viscosity coefficient of air is $15\times10^{-6}\mathrm{m}^2/\mathrm{s}$ and heat conduction coefficient is $2.6\times10^{-2}\ \mathrm{W}/\left(\mathrm{m}\cdot{}^{\circ}\mathrm{C}\right)$, and Pr is 0.7 approximately, respectively.

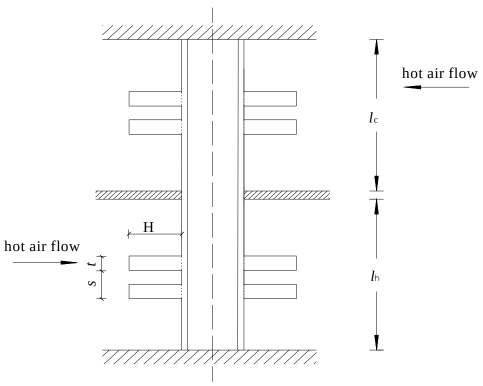

Fig.1 Schematic of annular fin heat pipe heat transfer model

2.2 Annular Fin Heat Pipe Heat Transfer Model

2.2.1 The heat resistance of stable work condition

In the stable work situation, taking no account of the heat resistance of dirt, the quantity of heat transfer of simple root heat pipe is [5]

$$Q=\frac{1}{R}\Delta T_{\mathrm{m}} \quad (1)$$

where Q is the heat transfer quantity of heat pipe; R is the heat transfer resistance of heat pipe; ΔT_{m} is the logarithm average temperature difference of cold and hot air flows.

The heat transfer resistance of heat pipe includes the convection heat resistance R_c, R_h of cold and heat air flows, wall axial conduction heat resistance R_{wc}, R_{wh}, evaporation and refrigeration heat resistance R_{ei}, R_{ci}. That is

$$R=R_h+R_{wh}+R_{ei}+R_{ci}+R_{wc}+R_c \quad (2)$$

$$R_h=\frac{1}{h_h A_h \eta_h} \quad (3)$$

$$R_{wh}=\frac{1}{2\pi\lambda_w l_h}\ln\left(\frac{d_o}{d_i}\right) \quad (4)$$

$$R_{ei}=\frac{1}{h_{ei} A_{hi}} \quad (5)$$

$$R_{ci}=\frac{1}{h_{ci} A_{ci}} \quad (6)$$

$$R_{wc}=\frac{1}{2\pi\lambda_w l_c}\ln\left(\frac{d_o}{d_i}\right) \quad (7)$$

$$R_c=\frac{1}{h_c A_c \eta_c} \quad (8)$$

where A_h and A_c are hot side and cool side pipe outer surface area (including fin area); A_{hi} and A_{ci} are inner surface area hot side and cool side pipe; h_h and h_c are surface heat transfer coefficient based on A_h and A_c; h_{hi} and h_{ci} are evaporation and condensation heat transfer coefficient factor; η_h and η_c are fin wall overall efficiency of hot side and cool sided; λ_w is heat conduction coefficient of pipe wall; l_h and l_c are length of hot side and cool side; d_o and d_i are outer diameter and inner diameter of heat pipe bare pipe.

2.2.2 Overall Efficiency Of Fin And Surface Heat

Transfer Coefficient

When using appropriate equivalent length, the solution of calculating fin efficiency in equal cross-section rectangle fin can be applied to annular fin [6], and equivalent length is

$$H_{eq} = H\left[1 + 0.35\ln\left(1 + \frac{2H}{d_o}\right)\right] \quad (9)$$

And annular fin efficient of heat pipe is respectively

$$\eta_{fh} = \frac{th\left(\sqrt{\frac{2h_h}{\lambda_f t}}H\left(1 + 0.35\ln\frac{d_o + 2H}{d_o}\right)\right)}{\sqrt{\frac{2h_h}{\lambda_f t}}H\left(1 + 0.35\ln\frac{d_o + 2H}{d_o}\right)} \quad (10)$$

$$\eta_{fc} = \frac{th\left(\sqrt{\frac{2h_c}{\lambda_f t}}H\left(1 + 0.35\ln\frac{d_o + 2H}{d_o}\right)\right)}{\sqrt{\frac{2h_c}{\lambda_f t}}H\left(1 + 0.35\ln\frac{d_o + 2H}{d_o}\right)} \quad (11)$$

where λ_f is fin heat conduction coefficient.

By the formula (10), (11), we get fin overall efficient of heat pipe heat side and cold side is respectively

$$\eta_h = \frac{A_r + \eta_{fh} A_f}{A_r + A_f} \quad (12)$$

$$\eta_c = \frac{A_r + \eta_{fc} A_f}{A_r + A_f} \quad (13)$$

$$A_h = A_c = A_r + A_f \quad (14)$$

where A_r and A_f are bare pipe area and fin surface area of one heat pipe, respectively.

Surface heat transfer coefficients of hot side and cold side are [2,7]

$$h_h = h_{hb}\left[1 - 0.217\left(\frac{H}{s-t}\right)^{0.469}\right] \quad (15)$$

$$h_c = h_{cb}\left[1 - 0.217\left(\frac{H}{s-t}\right)^{0.469}\right] \quad (16)$$

$$h_{hb} = 0.1370\frac{\lambda}{d_o}\left(\mathrm{Re}_h\right)^{0.6388}\mathrm{Pr}_h^{1/3} \quad (17)$$

$$h_{cb} = 0.1370\frac{\lambda}{d_o}\left(\mathrm{Re}_c\right)^{0.6388}\mathrm{Pr}_c^{1/3} \quad (18)$$

$$\mathrm{Re}_h = \frac{u_h d_o}{\nu} \quad (19)$$

$$\mathrm{Re}_c = \frac{u_c d_o}{\nu} \quad (20)$$

where h_{hb} and h_{cb} are surface heat transfer coefficient that are based on A_h and A_c without fin; λ is heat conduction coefficient of air; Re_h and Re_c are Re number of hot and cool flow; Pr_h and Pr_c are Pr number of hot and cool flow; u_h and u_c are velocity of hot and cool flow.

Therefore, the total heat resistance of one heat pipe is

$$R = \frac{1}{A_h}\left(\frac{1}{h_h\eta_h} + \frac{1}{h_c\eta_c}\right) + \left[\frac{1}{2\pi\lambda_w l_h}\ln\left(\frac{d_o}{d_i}\right) + \frac{1}{h_{ei}A_{hi}} + \frac{1}{h_{ci}A_{ci}} + \frac{1}{2\pi\lambda_w l_c}\ln\left(\frac{d_o}{d_i}\right)\right] \quad (21)$$

According to the basic assumption, heat resistance R_{wh} , R_{wc} , R_{ei} and R_{ci} may be considered as invariable in the condition of the air conditioning for the specific heat pipe., Through abundant experimentation, in various normal condition, for carbon steel-water heat pipe, the h_{ei} , h_{ci} of heat pipe are equal to 5180 $\mathrm{W}/\left(\mathrm{m}^2 \cdot {}^{\circ}\mathrm{C}\right)$ [2]. By the formula (15) ~ (21), the overall resistance of heat pipe will be only the function of fin structure parameters, which are H, s and t when the velocities of hot and cool flow are constant.

3 THE FOUNDATION OF OPTIMIZATION MODEL

3.1 Objective Function

The cost of fin heat pipe is higher than bare heat pipe. When satisfying the heat transfer quantity, we try to lower material weight so far as possible for making fin heat pipe get to high efficiency and saving the quantity of consuming material. So the least fin volume of heat pipe at unit temperature difference and unit heat-transfer quantity is selected as object function, namely Φ, that is

$$\Phi = V / \left(Q / \Delta t_m\right) = V \cdot R \tag{21}$$

$$V = \left(H^2 + H \cdot d_o\right) \frac{\left(l_c + l_h\right) \cdot t}{s} \tag{22}$$

From the previous analysis, we know that when the velocity of flow of hot and cool air flow is presented, object function can be expressed as

$$\Phi = \Phi\left(H, s, t\right) \tag{23}$$

And H, s, t are the decision-making variables of the optimization questions.

3.2 Constraint Condition

In the optimization design, we need to restrict some design variables. In the paper, fin structural parameters are bound by the conditions as following [2, 7]:

$$0.02 \geq H \geq 0.0032$$
$$0.002 \geq t \geq 0.00013$$
$$s - t \geq 0.0014$$
$$s \leq 0.02$$

3.3 nonlinear optimization and genetic algorithms

The formula (23) is a highly nonlinear optimization problem, and that using the existing methods such as gradient laws and simplicity form laws to solute is very difficult and sometimes impossible. But the genetic algorithm that is a developed problems solution strategy and random calculation model of simulated natural biological evolution which uses selection, crossover and mutation, so that the winners are kept down and losers are eliminated, ultimately it can find optimal or near-optimal solutions. Biggest advantage of genetic algorithm is a direct function as a search for objective information without derivative value of an objective function and the some other ancillary information, particularly for highly nonlinear optimization problems more showing strong adaptability [9-11].

This optimization problem is the overall minimum question of seeking object function, and object function always greater than zero, in order to ensure the function of non-negative degrees, the conversion methods between objective function and sufficiency function should be [9]

$$F = \begin{cases} \Phi & \text{constraint condition meeted} \\ \mathrm{D} & \text{constraint condition not meeted} \end{cases} \tag{24}$$

where Φ is the objective function and D is estimated value. D is greater than or equal to an arbitrary group of rational decision-making variables to calculate the value of the objective function, to ensure normal genetic algorithm running, which determines the size of the search space and the size of the solution space. Optimization criteria of genetic algorithm generally are based on different issues. Here the optimization criteria are that generation exceeds scheduled value. If arriving at a genetic termination generation, computation is terminated.

4 SOLUTIONS

4.1 Parameters Choice of Genetic Algorithm

The paper adopts genetic algorithm toolbox of mathematical software MATLAB to optimize simplified annular fin heat pipe mode for fin structural parameters.

Optimized target is a carbon steel -water heat pipe, and fin material is carbon steel. The attended mode of fin and shell of pipe is high-frequency welding. Its parameters are as follows: bare pipe external diameter d_o is 0.032m, heat pipe inner diameter d_i is 0.027m, the length of evaporation and condensation sections are 1m respectively, and the velocities of flow of the hot and cool air flow are respectively 3m/s and 2m/s.

According to the more ideal calculation time and calculation precision, operating parameters in the procedure were selected as following: group size M is 50, Crossover-probability P_c is 0.8, methods of cross-Scattered, mutation probability P_m is 0.001, mutation method is Gaussian method, Termination generation T is 300, and the parameter D is 2.0 which could be selected after repeated software operation testing.

4.2 Optimization Results

The optimization results are presented in figure 2, the best adaptation degree (Best fitness) is 0.8246, the average degree is 0.33108, terminate generations algebra is 3000. The best value for the individual are (H, s, t) = (0.0199, 0.0027, 0.00013), the optimal solutions is Q =0.8246.

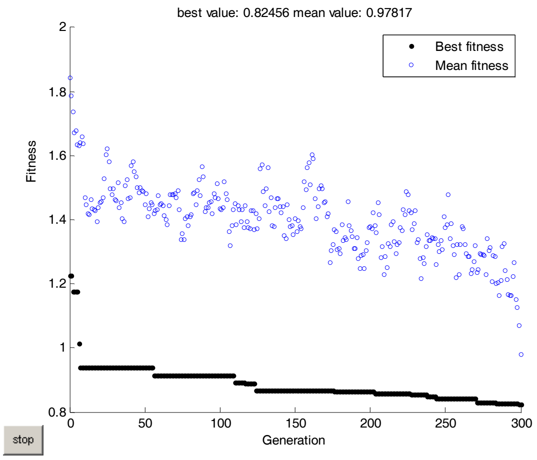

Fig.2 The evolutionary process of genetic algorithm

Table 1 is the comparison of optimization design parameters and before optimization. As can be seen from Table 1, under unit difference in temperature and unit heat-transfer quantity, the smallest value of round fin heat pipe fin volume is target function Φ, which is much smaller than the value that was not optimized.

Tab. 1 Optimization results

parameters	Optimization results	Data before Optimization
H	0.0199	0.015
s	0.0027	0.0052
t	0.0013	0.0012
Φ	0.8246	1.8474

5 CONCLUSIONS

Aiming at fin structure parameters of annular heat pipe at air conditioning system we put forward optimization scheme of genetic algorithm for its excellent global optimization capability and can reduce the risk of local extremum, especially adaptability for nonlinear problems. The results indicate the effectiveness of this method.

REFERENCES:

[1] Zhao Yang, Zhiguang Wu. Research of heat pipe heat recovery equipment in air conditioning systems. Energy research and utilization, 2004 (3): 14-16.

[2] Jun Zhuang, Hong Zhang. Heat pipe and its engineering applications. Beijing: Chemical Industry Press, 2000.

[3] Mingcong Jin, Yuanguo Chen. Heat pipes and heat pipe interchanger. Chongqing: Chongqing University Press, 1990.

[4] Qinghai Luo, Guangfa Tang and Guangcai Gong.The application of Heat pipe technology in ventilation air-conditioning energy-efficient. Gas and heat, 2003 (6): 27-31.

[5] Tinghan Li, Chengsheng Hua. Heat pipe design and application. Beijing : Chemical Industry Press, 1987.

[6] Enze Zhang, Yingtian Chi. Performance and numerical simulation of the surface cooling exchanger. Energy research and utilization, 2001,17 (4) : 232-238.

[7] Zhongqi Chen. Heat transfer special topics. Beijing: Higher Education Press, 1989.

[8] Xiaoping Wang, Liming Cao. Genetic algorithm[M]. Xi'an: Xi'an Jiaotong University Press, 2002.

[9] Chaudhuri P， Diwekar U. An automated approach for the optimal design of heat transfer [J]. Int Eng Chem Res， 1997， 36:3685-3693.

[10] Queipo N， Devarakonda R. Genetic algorithms for thermoscience research: application to the optimized cooling of electric components [J].Int J Heat mass transfer，1994，37(6):893-908