World Academy of Science, Engineering and Technology
International Journal of Aerospace and Mechanical Engineering
Vol:6, No:8, 2012

Heat Transfer Analysis of Rectangular Channel Plate Heat Sink

Zhang Lei, Liu Min, Liu Botao

***Abstract*—**In order to improve the simulation effects of space cold black environment, this paper described a rectangular channel plate heat sink. By using fluid mechanics theory and finite element method, the internal fluid flow and heat transfer in heat sink was numerically simulated to analyze the impact of channel structural on fluid flow and heat transfer. The result showed that heat sink temperature uniformity is well, and the impact of channel structural on the heat sink temperature uniformity is not significant. The channel depth and spacing are important factors which affect the fluid flow and heat transfer in the heat sink. The two factors of heat transfer and resistance need to be considered comprehensively to determine the optimal flow structure parameters.

***Keywords*—**heat transfer, heat sink, numerical simulation

I. INTRODUCTION

HEAT sink is one kind of equipment used to simulate the cold black space environment in thermal vacuum test. The tube sheet is widely used in thermal vacuum test equipment, which enhanced heat transfer through the fins on the pipe [1-7]. Fin is the second surface of the tube to increase heat transfer area but it increases the thermal resistance which leads to reduce thermal load capacity and temperature uniformity. Plate heat sink is a new structure of heat sink which weld around the double plate and the flow channel between plates can be made into different forms as needed. In the plate heat sink, heat transfer media have direct contact with the surface of the heat sink and all the heat transfer surface are the primary surface of heat exchanger. So the plate heat sink has strong thermal load capacity and fine temperature uniformity.

This paper designed a rectangular channel plate heat sink. Using fluid mechanics theory and finite element method to simulate the heat transfer and pressure drop characteristics of the heat sink, the result about heat sink temperature distribution, the *Nu* and pressure loss in the different structural parameters were obtained. The impact of channel structural on heat sink heat transfer performance is analyzed to provide a theoretical reference for plate heat sink design.

II. SIMULATION MODEL

A. Geometric Model

Fig.1 shows the schematic of rectangular channel heat sink. The channel depth and spacing is the main factor to affect the heat transfer performance of heat sink. Thermal vacuum test equipment mostly is cylindrical structure; the actual calculation of the selected heat sink geometry model is shown in Fig. 2. Its effective size is φ1m × 1.5m. Table I gives the geometrical parameters of rectangular channel heat sink.

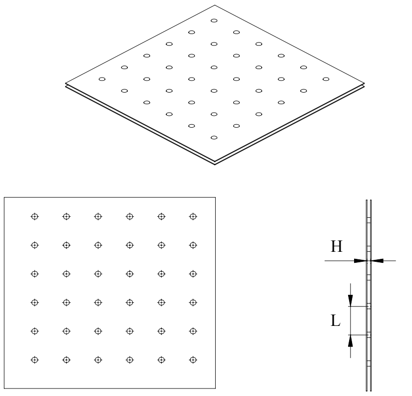


Fig. 1 Schematic diagram of rectangular channel heat sink structural unit

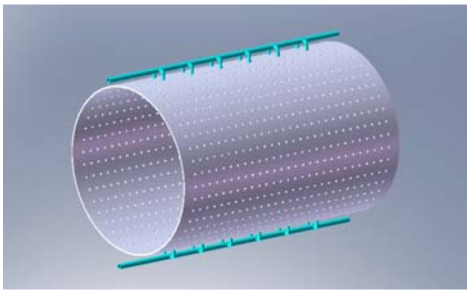


Fig. 2 Rectangular channel heat sink geometry model

TABLE I
RECTANGULAR CHANNEL HEAT SINK GEOMETRY PARAMETERS

Parameter	Spacing fixed				Depth fixed			
depth (10^{-3} m)	5	10	15	20	10			
spacing (10^{-3} m)	50				35	50	75	100

B. Control Equation

The complete mathematical description of the convective heat transfer problems including the continuity equation, momentum equation and energy conservation equations [8].

Continuity equation:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{1}$$

Where u, v, w is the component of the velocity vector in the x, y, z direction.

Momentum conservation equation in Cartesian coordinates in the i direction:

$$u\frac{\partial U_i}{\partial x}+v\frac{\partial U_i}{\partial y}+w\frac{\partial U_i}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+v\left(\frac{\partial^2 U_i}{\partial x^2}+\frac{\partial^2 U_i}{\partial y^2}+\frac{\partial^2 U_i}{\partial z^2}\right) \tag{2}$$

Where ρ is the fluid density; p is the pressure; v is the kinematic viscosity; U_i is velocity component in i direction.

Energy conservation equation:

Zhang Lei is with the Beijing Institute of Satellite Environment Engineering, Beijing, 100094 China (phone: 86-10-68746578; fax: 86-10-68746751; e-mail: zhangleibuaa@126.com).,

Liu Min is with the Beijing Institute of Satellite Environment Engineering, Beijing, 100094 China (e-mail:lemay_liu@hotmail. com).

Liu Botao is with the Beijing Institute of Satellite Environment Engineering, Beijing, 100094 China (e-mail: 1649406153@qq. com).

$$u\frac{\partial t}{\partial x}+v\frac{\partial t}{\partial y}+w\frac{\partial t}{\partial z}=a\left(\frac{\partial^2 t}{\partial x^2}+\frac{\partial^2 t}{\partial y^2}+\frac{\partial^2 t}{\partial z^2}\right) \tag{3}$$

Where a is the thermal diffusivity.

When using the above control equation to describe the turbulent flow, u, p, t is the instantaneous value. RNG $k-\varepsilon$ model was employed to simulate turbulent [9]:

$$\frac{\partial}{\partial \tau}(\rho k)+\frac{\partial}{\partial x_i}(\rho k U_i)=\frac{\partial}{\partial x_i}\left(\alpha_k \mu_{eff}\frac{\partial k}{\partial x_i}\right)+G_k-\rho\varepsilon+S_k \tag{4}$$

$$\frac{\partial}{\partial \tau}(\rho \varepsilon)+\frac{\partial}{\partial x_i}(\rho \varepsilon U_i)=\frac{\partial}{\partial x_i}\left(\alpha_\varepsilon \mu_{eff}\frac{\partial \varepsilon}{\partial x_i}\right)+G_{1\varepsilon}G_k\frac{\varepsilon}{k}-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}-R_\varepsilon+S_\varepsilon \tag{5}$$

Where G_k is the turbulent kinetic energy generated by the average speed; $G_{1\varepsilon}, G_{2\varepsilon}$ is the model constants, 1.42 and 1.68; $\alpha_k, \alpha_\varepsilon$ is the Turbulent Prandtl number of k equation and ε equation; S_k, S_ε is defined according to the specific conditions.

III. NUMERICAL SIMULATION OF FLOW AND HEAT TRANSFER WITHIN THE HEAT SINK PLATE

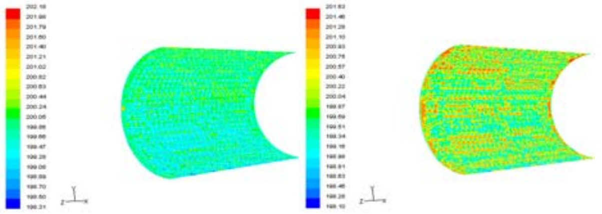
This paper studied the impact of flow channel structure parameters on the heat sink internal fluid flow and heat transfer in steady state conditions. We selected only half of the cylinder to do simulation because the cylindrical heat sink structure is symmetrical. The boundary conditions of inlets and outlets were respectively set as speed inlet, freely flow outlet, and those of the wall were set as constant heat flux.

According to the characteristics of the heat sink, unstructured grid generation was adopted in mesh generation. Mathematical calculation adopted turbulence model of RNG $k-\varepsilon$ and second-order upwind scheme; while coupling numeration of velocity field and tress was based on Simple. The solution convergence criterion was the relative residual $R \le 1\times 10^{-5}$.

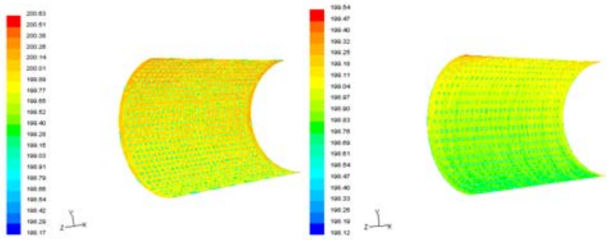
IV. RESULTS AND ANALYSIS

A. The Impact of Flow Channel Depth on Heat Sink Temperature Uniformity

Fig. 3 shows the heat sink temperature distribution of different depth.



(a) depth =0.02m (b) depth =0.015m



(c) depth =0.01m (d) depth =0.005m

Fig. 3 Heat sink temperature distribution of different depth

It can be seen from Fig. 3, the heat sink temperature uniformity is very well in different flow channel depth, and the impact of flow channel depth on the heat sink temperature uniformity is not significant. The reason is that small cylinders distributed in heat sink and these cylinders can play the spoiler's role. Different depths plate heat sink has the same number of small cylindrical, so they have the similar temperature uniformity.

B. The Impact of Flow Channel Depth on the Heat Transfer and Flow Resistance

Fig. 4 gives the curve of *Nu* with the flow channel depth, and Fig. 5 give the curve of ⊿ *P* with the flow channel depth.

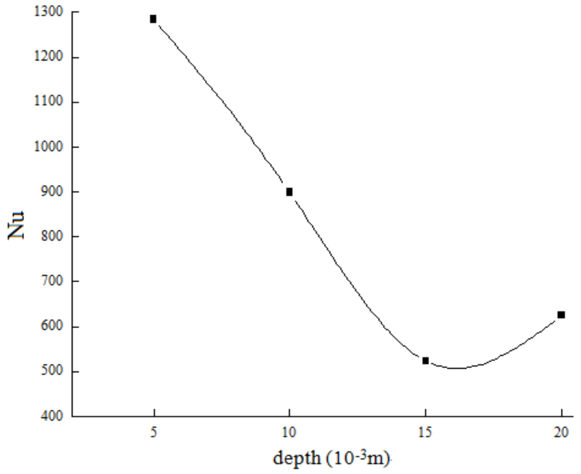


Fig. 4 The curve of *Nu* with the flow channel depth

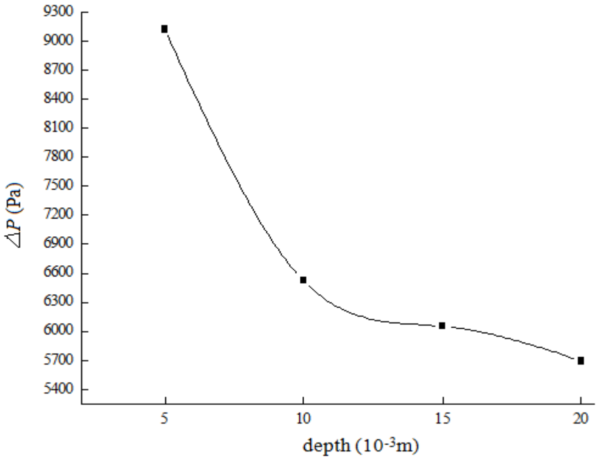


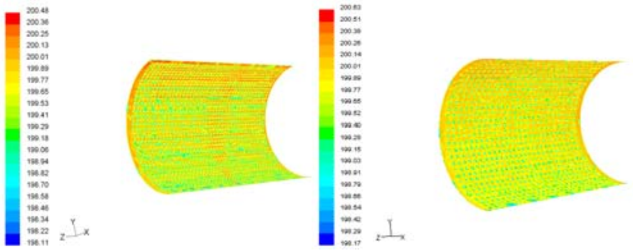
Fig. 5 The curve of ⊿ *P* with the flow channel depth

The factors that affect the heat transfer performance of heat sink are the internal fluid velocity and the action of cylinder on disturbance. When the flow channel depth increases from 0.005m to 0.015m, the fluid velocity is dominant factor. With the fluid velocity decreasing, the Nu reduced and the heat transfer effect deteriorates. When the flow channel depth increases by 0.015m to 0.02m, the dominant factor is the effect of the cylindrical size on disturbance. With cylindrical size increasing to enhance disturbance, the Nu is larger and heat transfer is strengthened.

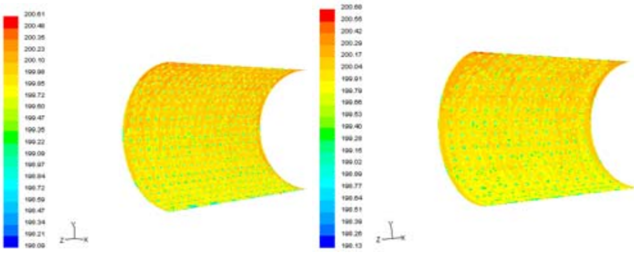
Taken the actual work of plate heat sink into account, the smaller the flow channel depth is, the greater the tendency to foul it has. If the flow channel depth is too small, it may cause the deposition of dirt within the heat sink. In addition, the smaller the flow channel depth is, the greater the flow pressure loss. Therefore, a reasonable depth of flow should be about 0.01m.

C. The Impact of Flow Channel Spacing on Heat Sink Temperature Uniformity

Fig. 6 shows the heat sink temperature distribution in different spacing.



(a) spacing=0.035m (b) spacing=0.05m



(c) spacing=0.075m (d) spacing=0.1m

Fig. 6 Heat sink temperature distribution

It can be seen from Fig. 6, the heat sink temperature uniformity is very well in different flow channel spacing, and the impact of the flow channel spacing on the heat sink temperature uniformity is not significant.

With the increase in spacing, the number of small cylindrical in heat sink reduces and the disturbance weakens. However, due to the small cylinder distributing evenly in different flow channel spacing, which making the heat sink temperature distribution is not affected by the difference of flow channel spacing.

D. The Impact of Flow Channel Spacing on the Heat Transfer and Flow Resistance

Fig. 7 gives the curve of Nu with the flow channel spacing, and Fig. 8 give the curve of ΔP with the flow channel spacing.

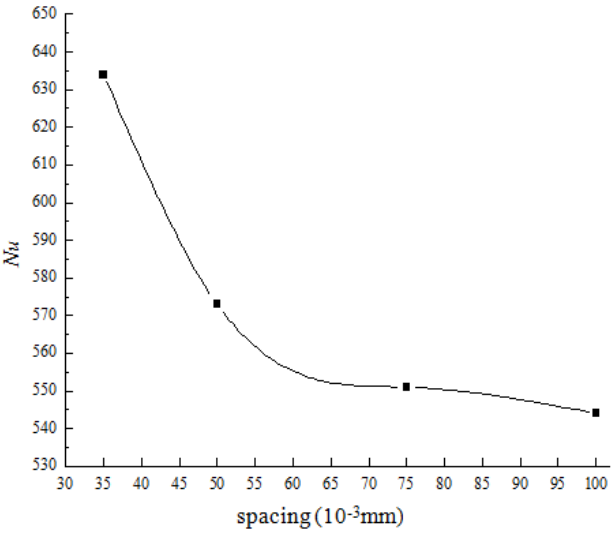


Fig. 7 The curve of Nu with the flow channel spacing

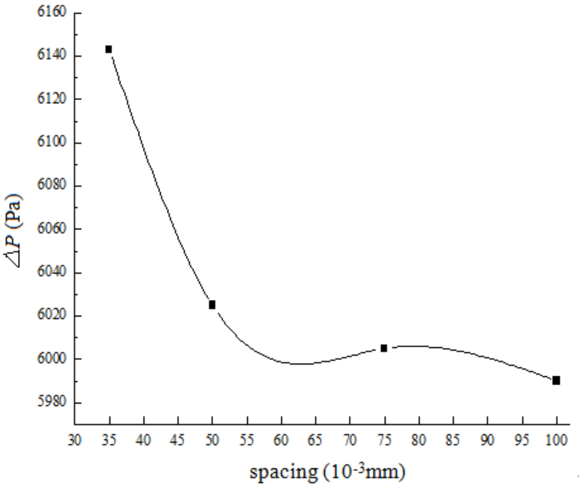


Fig. 8 The curve of ΔP with the flow channel spacing

It can be seen from Fig. 7 and Fig. 8, when the flow channel spacing decreases from 0.1mm to 0.05mm, Nu and ΔP increased, but change slightly. When the flow channel spacing decreases from 0.05m to 0.35m, Nu and ΔP are significantly increased. This is because with the decrease of the flow channel spacing, the number of small cylindrical in heat sink increase and disturbance enhance, thereby the efficiency of the convective heat transfer between the fluid and heat sink is strengthened. With the number of small cylinder to a certain extent, secondary reflux will produce. As the result, the heat transfer between the fluid and heat sink is strengthened and the flow resistance is larger. It can be seen from the above analysis, heat transfer and resistance should be comprehensive considered to determine the optimal flow channel spacing. This is the same conclusion with the literature [10].

V. CONCLUSION

Based on the rectangular channel heat sink simulation calculation and the analysis of result, we get the following conclusions:

1) Rectangular channel heat sink has excellent temperature uniformity, and the impact of flow channel structural parameters on heat sink temperature uniformity is not significant;
2) The flow channel depth and spacing are important factors which affect the fluid flow and heat transfer in the heat sink. And the reasonable choice of structural parameters can improve the heat transfer performance of heat sink;
3) During the design of plate heat sink, we need to consider comprehensively heat transfer and flow resistance to determine the optimal flow channel structure parameters.

REFERENCES

[1] Yu Tao, Liu Min, and Zou Dingzhong, “Thermal uniformity analysis for heat sink of space simulator,” *Chinese Space Science and technology*, no. 6, pp. 37-41,2006.

[2] Yang Jianbin, Zhang Wenrui, Bai Shu, et al, “Technology development in ZM4300 space environment test facility,” *Vacuum & Cryogenics*, vol. 16, no. 1, pp. 25-29, 2010.

[3] Liu Botao, Ru Xiaoqin, Zhang Liwei, et al, “Development of KM3B space simulator,” *Spacecraft Environment Engineering* , vol. 23, no. 4, pp. 232-235, 2006.

[4] R. N. Watson, G. F. Proulx, “A new thermal vacuum facility for Hughes space and communications at El Segundo California,” in *Proc. 20th Space Simulation Conference the Changing Testing Paradigm*, 1998, pp. 113–130.

[5] Guee-Won Moon, Hyokjin Cho, “Shroud System Design for A Large Thermal Vacuum Chamber,” in *Proc. 49th Annual Technical Meeting and Exposition of the Institute of Environmental Science and Technology*, 2003, pp. 479-484.

[6] P. Govindan, M. Satyanarayana, Deviprasad Karnik, “Design and performance of φ0.6m thermal vacuum chamber,” in *Proc. 18th International Cryogenic Engineering Conference*, 2000, pp. 679-682

[7] R. N. Watson, “A new thermal vacuum facility at the Martin Marietta Waterton Plant,” in *Proc. 17th Space Simulation Conference*, 1992, pp.32-37

[8] Tao Wenquan, *Numerical heat transfer technology.* The Publishing Company Xi'an Jiaotong University, 1998.

[9] V. Yakhot, S. A. Orzag, “Renormalization group analysis of turbulence: basic theory,” *J Scient Compute,* vol.1, pp.3-11, 1996.

[10] Ji Changfa, Wang Yueyong, and Liu Xiaobing, “Analysis on heat transfer enhancement effect of dimpled plates,” *Journal of Xi’an University of Science and Technology*, vol. 30, no. 3, pp. 330-335, 2010.

Zhang lei, Born in Handan, China, 1983 and get the Ph.D. degree from Beijing University of Aeronautics and Astronautics in 2010. He is now working in Beijing Institute of Satellite Environment Engineering. The current and previous research interest is the heat transfer characteristics of high performance heat sink.

Liu Min, Born in Liaoning, China, 1970 and get the Master's degree from Beijing Information Science & Technology University in 2008. She is now working in Beijing Institute of Satellite Environment Engineering as a professor. The current and previous research interest is the heat sink design.

Liu Botao, Born in Heilongjiang, China, 1966 and get the Master's degree from Beijing University of Aeronautics and Astronautics in 2006. He is now working in Beijing Institute of Satellite Environment Engineering as a professor. The current and previous research interest is the vacuum thermal environment simulation technology

Open Science Index, Aerospace and Mechanical Engineering Vol:6, No:8, 2012 publications.waset.org/5516.pdf