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Investigation of Nanofluid Flow Field and Conjugate Heat Transfer in a Microchannel Heat Sink with Four Different Arrangements

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ABSTRACT: In this study three dimensional fluid flow and heat transfer of Al_2O_3-water nanofluid in a triangular microchannel heat sink, consisting from seven isosceles triangular microchannels, have been investigated numerically by considering conduction in solid parts. The governing equations have been solved using finite volume method based on finite element and utilizing coupled algorithm. The objective has been investigating the effects of four inlet/outlet flow arrangements on flow field and heat transfer of Al_2O_3-water nanofluid. These arrangements consist of: inlet from the center of the north wall and outlet from the center of the south wall (I-type), inlet from the right side of the north wall and outlet from the left side of the south wall (N-type), inlet and outlet from the top and bottom parts of the west wall (D-type) and inlet from the upper part of the east wall and outlet from the bottom of the west wall (S-type). Also the effects of the Brownian motion of nanoparticles and temperature-dependent properties of the nanofluid have been considered. The results showed that increasing the nanoparticles volume fraction from 0 to 4% increases the average Nusselt number between 4.72% and 5.47, decreases thermal resistance between 1.81% and 2.34% and decreases the ratio of maximum temperature difference of heat sink substrate to heat flux between 1.28% and 1.56%. Also the results indicated that the I-type arrangement has a better heat transfer performance, lesser thermal resistance and provides more uniform temperature distribution. In this case, the I-type arrangement has higher Nusselt number between 1.69% and 18.33%, lower thermal resistance between 3.55% and 29.29%, and a smaller ratio of maximum temperature difference of heat sink substrate to heat flux between 5.23% and 36.25%, when compared with those of other arrangements. The heat sink performance characteristics have improved between 0.1% and 0.75% by considering the Brownian motion and between 1.9% and 3.9%, by considering temperature dependent properties.

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1- Introduction

Microchannels are an important part of micro-electromechanical systems, which are used for mass transfer, fuel delivery and as a heat sink for heat removal. Chain and Chen [1] studied the effect of six inlet and outlet arrangements of a microchannel heat sink with rectangular microchannels utilizing 3D numerical method. They showed that the velocity distribution inequality in the microchannels for I, N, D and S arrangements, for which the flow entered horizontally into the heat sink, was more than those of V and U arrangements, for which the flow entered vertically into the heat sink. They also showed that, according to thermal resistance, the V arrangement had the best performance. Khorasanizadeh and Sepehrnia [2] investigated the effect of four different inlet/outlet arrangements on thermal performance of a porous trapezoidal microchannel heat sink, for which water was used as the coolant. In another study, Khorasanizadeh et al. [3] studied the performance of a microchannel heat sink including triangular microchannels considering two horizontal and vertical arrangements of flow inlet/outlet utilizing water-CuO nanofluid as the coolant. They indicated that horizontal inlet/outlet arrangement is better than the vertical arrangement. They concluded that the heat sink performance, in addition to the inlet and outlet arrangement, is dependent to the microchannel geometry and the ratio of its solid part to the fluid part. They also showed that the use of CuO-water nanofluid compared to utilization of water, improved the heat sink performance about 4.6%.

In this study, the performance of a rectangular heat sink with seven isosceles triangular microchannels is investigated for four different horizontal inlet/outlet arrangements. This geometry with these arrangements has not been studied previously. Furthermore, the conduction in the solid parts of the heat sink is considered, temperature dependent properties of the Al_2O_3-water nanofluid are utilized and the effects of Brownian motion are considered.

2- Geometry

The configuration of the I-type arrangement is shown in Fig. 1. The dimension of triangular microchannel and

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trapezoidal fins are shown in Fig. 2. Three other microchannel heat sink arrangements, called D, S, and N, are shown in Fig. 3.

3- Governing Equations, Boundary Conditions and Performance Indexes

The continuity, momentum in the x, y and z directions and the energy equations in the fluid and the solid parts of the heat sink are the governing equations.

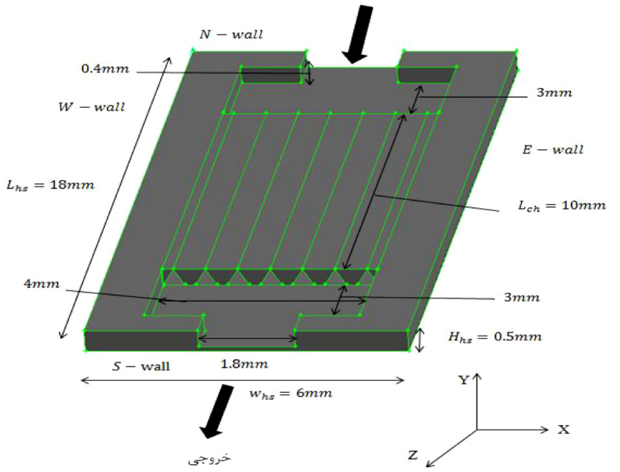

Fig. 1 Geometry of microchannel heat sink with direct inlet and outlet (I-type)

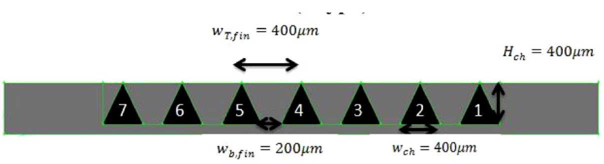

Fig. 2 Fin and microchannel dimensions

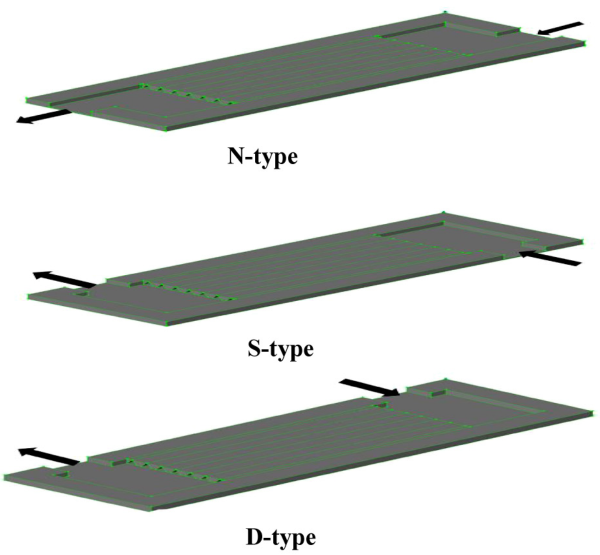

Fig. 3 The geometry showing the N, S and D-type inlet and outlet arrangements

The boundary conditions are:

$$P = P_{\text{in}}, \quad T = T_{\text{in}} = 300\ \text{K} \tag{1}$$

$$P = P_{\text{out}} = 0, \quad \frac{\partial T}{\partial z} = 0 \tag{2}$$

$$q_{\text{w}} = -k_{\text{s}} \frac{\partial T_{\text{s}}}{\partial y} \tag{3}$$

Three indexes of Nusselt number, thermal resistance and the ratio of maximum temperature difference of the heat sink substrate to the heat flux are used for evaluating the microchannel heat sink performance [4]. The average Nusselt number is defined as:

$$Nu = \frac{hD_h}{k_f} \tag{4}$$

Thermal resistance as another index of thermal performance is obtained via:

$$R_{th} = \frac{T_{\text{w,max}} - T_{in}}{q_w W_{hs} L_{hs}} \tag{5}$$

The ratio of maximum and minimum temperature difference of heat sink substrate to heat flux is called θ and defined as:

$$\theta = \frac{T_{b,\max} - T_{b,\min}}{q_w} \tag{6}$$

4- Results and Discussion

In Table 1, the heat sink performance indicators have been shown for the nanofluid with different volume fractions, but only for ΔP=15 kPa. In Table 1, the results for the best arrangement, I-type, has been shown in bold and indicators of other arrangements have been compared with those of the I-type. As shown in Table 1, the superiority of the I arrangement at a constant pressure drop is more sensible for higher volume fractions.

In Table 2, the heat sink performance indicators with considering both temperature independent and temperature dependent properties are presented only for one volume fraction and one pressure drop. The results show that the use of variable properties has suitable effect. Generally, the temperature dependent properties have improved the heat sink performance indicators between 1.9% and 3.9%.

5- Conclusions

The summary of the results are as follows:

1. Except for that of I arrangement, with increasing volume fraction from 0 to 4%, the average Nusselt number increased between 4.72% and 5.47%, thermal resistance decreased between 1.81% and 2.34% and the ratio of maximum temperature difference of heat sink substrate to heat flux decreased between 1.28% and 1.56%,

2. The heat sink performance indicators improved between 0.1% and 0.75% by considering Brownian motion

Table 1. Performance indicators of MCHS for different volume fractions and ΔP= 15 kPa.

D	*S*	*N*	*I*	φ	
6.86	6.57	7.55	7.68	0	Nu
10.68	14.45	1.69	–	Relative difference	
7.04	6.73	7.75	7.89	2	
10.77	14.70	1.77	–	Relative difference	
7.22	6.88	7.94	8.10	4	
10.86	15.06	1.97	–	Relative difference	
1.28	1.28	1.10	0.99	0	R_{th} (K/W)
29.29	29.29	11.11	–	Relative difference	
1.26	1.26	1.09	0.98	2	
28.57	28.57	11.22	–	Relative difference	
1.25	1.25	1.08	0.97	4	
28.87	28.87	11.34	–	Relative difference	
10.90	10.90	9.30	8.00	0	$\Theta\times10^5$ (Km^2/W)
36.25	36.25	16.25	–	Relative difference	
10.80	10.75	9.17	8.02	2	
34.66	34.04	14.34	–	Relative difference	
10.76	10.73	9.18	8.05	4	
33.66	33.29	14.04	–	Relative difference	

and increased between 1.9% and 3.9% by considering the temperature dependent properties.

3. The results showed that the I arrangement is more desirable because of better uniform temperature distribution in the heat sink substrate (where the electronic chip is attached), less thermal resistance and more heat transfer.

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Table 2. Heat sink performance indicators with both temperature dependent and temperature independent properties for the volume fraction of 4% and ΔP=15 kPa.

I	N	S	D	Performance index
8.097	7.945	6.883	7.221	$Nu_{V.P}$
7.947	7.775	6.729	7.069	$Nu_{C.P}$
1.9	2.2	2.3	2.2	Relative difference
0.997	1.086	1.254	1.255	$R_{V.P}$
1.009	1.125	1.290	1.293	$R_{C.P}$
2.2	3.5	2.9	2.9	Relative difference
8.05	9.18	10.73	10.76	$\Theta_{V.P}\times10^5$
8.33	9.55	11.07	11.11	$\Theta_{C.P}\times10^5$
3.4	3.9	3.1	3.2	Relative difference

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