Optimized channel's aspect ratio for heat transfer applicant of nanofluid in various fin thickness

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Abstract:. New processors have high thermal flux and can't absorbed by regular air-radiator. For this problem, application of microchannel with metal nanoparticles suspension in liquid fluid as the coolant is considered. In this study, effect of microchannel's aspect ratio with various fin thickness on EER calculated numerically. The Al_2O_3/water nanofluid was considered. Results show that optimized aspect ratio is between 0.6-0.7 and it decreases with increasing thickness of fin. A correlation of optimized aspect ratio with various fin's thickness for a specific CPU obtains.

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Nomenclature:

W	Width	P	Pressure
H	Height	T	Temperature
q	Heat flux	φ or Φ	Volume fraction of nanoparticles
Re	Reynolds number	ρ	Density
Nu	Nusselt number	k	Conductivity
μ	Dynamic viscosity	w	Pump power
C_p	Heat capacity coefficient	Subscripts	
Ar	Aspect ratio	w	Base fluid
β	Fin thickness to width ratio	s	Nanoparticles
D	Diameter	nf	Nanofluid (Nanofluid)
L	Length	max	Maximum
D_h	Hydraulic diameter	av	Average

1. Introduction

Nanofluid is a liquid base fluid with a suspension of solid nanoparticles. Conductive heat transfer coefficient of metal is more than liquid, so suspension of metal's particles (even low percent volume fraction) in liquid considered as a method for heat transfer enhancement. But in act, settling of metal's particles was a major problem in channel. Scale particle down lead to decreased volume & increased contact surface with surrounded liquid. Entirely improve heat transfer characteristic and stability (Jian, Fu and Zhou, 2012). For example, micrometer to nanometer make periphery per volume more than 1000 time. Choi called the nanoparticles suspension as the 'nanofluid' and investigated its thermal operation (Choi, 1995). Until yet, research on its thermophysical properties had done. Lecture review shows the Model of the density and heat capacity are remarkable consensus, but the model of viscosity and conductive heat transfer coefficient are disputed. The dissidence depends on some effective parameters of nanofluid operation. Buongiorno (2006) presented seven mechanism of heat transfer. Accordingly, several models offered for the conductive heat transfer coefficient (Lee et al. 2010). At a time, the viscosity models presented relative to temperature, dimension, shape and volume fraction of particles (Mukesh Kumar, Kumar and Suresh, 2012). Although, results illustrated increasing viscosity and conductive heat transfer with nanoparticles suspension (Hung et al. 2012) but definitely, exact models for predicting these properties aren't available. Still, experimental data are necessary especially with significant variation of viscosity and conductivity with temperature (Xue and Xu, 2005).

Scale up heat transfer surface and reducing inefficient flow are another methods of heat transfer enhancement (Rohsenow, Hartnett and Cho, 1998, pp 11.1-11.2). Decreasing cross section of rectangular channel to micrometer increase ratio of surface to cross section and satisfy upon methods. With these qualities, Application of microchannel with presentence of nanofluid as operative flow investigated for heat transfer enhancement (Godson et al. 2010), (Mohammed et al. 2011). But, results showed the pressure drop through the microchannel along the heat transfer increased, which selection of optimized aspect ratio is necessary. Knight et al. in 1992 proposed theoretical relation of aspect ratio and fin thickness of rectangular channel for laminar and turbulence regime. Their results indicated than when the pressure drop through the channels is small, laminar solutions yield lower thermal resistance than turbulent solutions. Conversely, when the pressure drop is large, the optimal thermal resistance is found in the turbulent region. Numerical simulation of a microchannel was considered in 2007 by Li and Peterson. They presented optimized geometry for a microheat sink. Pan et al. in 2008 used theoretical correlation to investigate channel's geometry on passing flow. They developed an optimization procedure to optimize the manifold geometries and dimensional variations to obtain comparatively ideal flow distribution between microchannels. For a specific case, they showed that the division of the manifold into N rectangular channels is a valid method, and the microchannel width dominated the optimization of geometry and dimensional variations. Wang, An and Xu in 2013 studied optimal geometric structure for nanofluid-cooled microchannel heat sink under various constraint conditions. They use numerical simulation with properties depended on temperature. Three geometric parameters, including channel number, channel aspect ratio, and width ratio of channel to pitch, were simultaneously optimized at fixed inlet volume flow rate, fixed pumping power, and fixed pressure drop as constraint condition, respectively. The optimal designs of MCHS were obtained for various constraint conditions and the effects of inlet volume flow rate, pumping power, and pressure drop on the optimal geometric parameters were discussed.

In this study, effect of fin thickness and aspect ratio on energy effective ratio (EER) considers. The flow is Al_2O_3-water nanofluid. Thermophysical properties of nanofluid assume depend of temperature. The aim is to derive a correlation of optimized aspect ratio with various fin thickness in heat transfer applicant of a specific CPU.

Problem definition:

Fig. (1) shows schematic of microchannel's set. As this microchannel applicant as a CPU (with 200 kW flux) heat sink, each microchannel have 0.02 m length and 0.0008 m hydraulic diameter. Bottom surface conjunct to heat flux source and upper surface is isolate. Sided also be isolate and Al_2O_3-water nanofluid in laminar regime flow in microchannel.

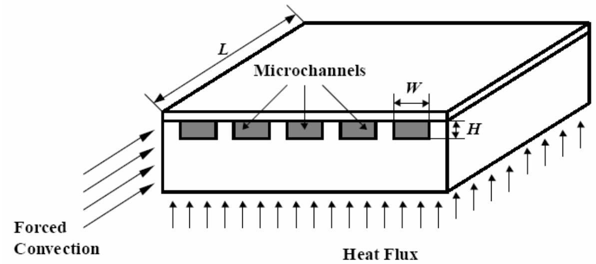

Fig. 1. Schematic of the microchannel

Government Equations:

In low concentration of nanoparticles, the nanofluid has single phase manner (Moraveji et al. 2011). Thermophysical properties are as follow:

$$\rho_{nf} = \varphi.\rho_s + (1-\varphi).\rho_w \quad (1)$$

$$C_{P_{nf}} = \frac{\varphi.(\rho_s C_{P_s}) + (1-\varphi).(\rho_w C_{P_w})}{\rho_{nf}} \quad (2)$$

The properties (significant) depended to temperature are derived from experimental data (Mena et al. 2013), (Kole and Dey, 2010), (Kleinstreuer and Feng, 2011). For each concentration is as bellow form:

$$x_{nf} = (c_0 + c_1 T + c_2 T^2 + c_3 T^3) \quad (3)$$

To validate the results, theoretical pressure drop through the channel is (Ko et al. 2007):

$$f = (\frac{D_h}{L})\frac{\Delta p}{\rho u^2/2} \quad (4)$$

Which hydraulic diameter $D_h = \frac{2WH}{(W+H)}$ and friction coefficient in laminar regime is $f = 64/\mathrm{Re}$.

In this paper, Seider-Tate equation is used to calculate Nusselt number.

$$Nu = 1.86(\mathrm{Pr}.\mathrm{Re}.\frac{D_h}{L})^{1/3} \quad (5)$$

This equation has good agreement with single phase fluid and was used for Al_2O_3 and CuO nanoparticles in water (Heris, Etemad and Nasr Esfahani, 2006). Total thermal resistance is $R_{th} = \frac{T_{\max,x} - T_{in}}{q}$, which calculated of sum of all resistances. Knight et al. presented theoretical relation for microchannel with a fin.

$$R_{th} = R_{fin} + R_{conv} + R_{cond} = \frac{1}{Nu.k_f}\frac{1+\beta}{1+2Ar.\eta}\frac{2Ar}{1+Ar}W + \frac{L}{Cp_f.\mu_f}\frac{2}{\mathrm{Re}}\frac{1+\beta}{1+Ar} + \frac{t_b}{k_s} \quad (6)$$

Which $Ar = \frac{H}{W}$ and $\beta = \frac{W_{fin}}{W}$. Also $\eta = \frac{\tanh(m.Ar)}{m.Ar}$ that $m = \sqrt{Nu\frac{1+Ar}{Ar.\beta}\frac{k_f}{k_s}}$.

Consumed power of pumping is $w = \dot{v}\Delta P$ and Energy Efficiency Ratio is being:

$$EER = \frac{\dot{q}}{w} \quad (7)$$

Results:

To solve the government equations, numerical code wrote with Fortran 90 for rectangular microchannel and used SIMPLE algorithm in solution. In this study, the viscosity and conductive heat transfer coefficient assume depended to temperature.

After checking independent of mesh, and to validate the code, results compare with Eqs. (4) and (6). For this purpose, Thermophysical properties assumed constant (Table 1).

Table 1. Comparison of numerical and theoretical results

	Φ	0 %	1 %	2 %	3 %
ΔP (Pa)	Theory	171	186.4	201.8	222.4
	Numerical	169.6	184	198.4	210.5
R_{th}	Theory	7.24	7.08	6.92	6.80
	Numerical	7.22	6.93	6.87	6.55

Base on the table (1), obtained results of numerical code have good accuracy.

Maximum temperatures of microchannel in various aspect ratio and fin thickness achieve. An addition, pressure drop of nanofluid obtains. The EER from averaged Reynolds number calculate and shows in Fig. (2).

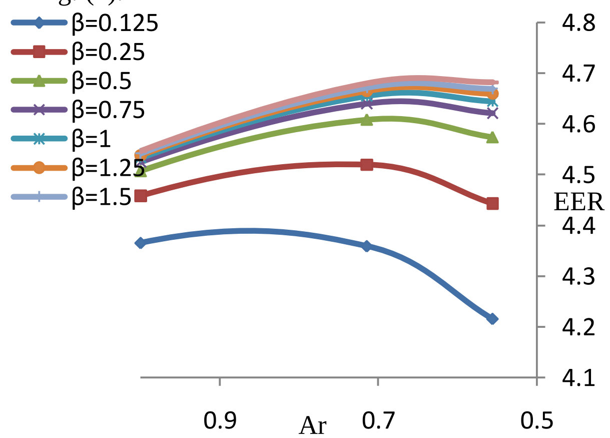

Fig. 2. The EER-aspect ratio in various fin thickness

Base on Fig. (2) The maximum points are between Ar= [0.6, 0.7]. In order to demonstration the maximum EER, fitted polynomial in this range is derived for various thicknesses and then derivative of them calculate. Table (2) shows maximum points of EER for various fin thickness.

Table 2. Maximum EER for various fin thickness

2	1.5	1.25	1	0.75	0.5	0.25	0.125	β
0.6282	0.6376	0.6449	0.6558	0.672	0.7014	0.7685	0.8552	Ar_{max}
4.659	4.673	4.671	4.66	4.62	4.608	4.524	4.393	EER_{max}

Base on calculated maximum points, the optimized relation derives as follow:

$$Ar_{max} = 0.138\beta^4 - 0.687\beta^3 + 1.225\beta^2 - 0.972\beta + 0.954 \quad (7)$$

The relation proposes for a specific CPU with 200 kW heat flux and can be develop to similar cases.

Conclusion:

In this study, effect of fin thickness and aspect ratio of microchannel on EER investigate. The operation fluid is Al_2O_3-water nanofluid. A numerical code is written for laminar flow and single phase fluid. Results show the optimized microchannel's aspect ratio is between 0.6-0.7 that decreases with increasing fin thickness. An addition, an optimized aspect ratio presents for a specific CPU.

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