Investigation of effect of triangular rib in heat transfer of finned rectangular microchannel with extended surfaces

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Abstract: In this study, Increase the heat transfer rate at the microchannel by using extended surfaces and a triangular rib Investigated numerically. The temperature-dependent fluid as the coolant is modeled by numerical simulation. The results show increasing pressure drop with various thermal manner, which obtained the energy efficiency ratio for optimization. Fluid flow with Reynolds number range [130-170] and the triangular rib at the top of the microchannel with height to rule 0.5 is the best suggestion in the application of this case.

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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	Nanocolloid (Nanofluid)
L	Length	max	Maximum
D_h	Hydraulic diameter	av	Average

Introduction

Increase the rate of heat generation in modern electronic equipment is a important concern. So that is a limitation to the development and upgrading them. This equipment also has been shrinking since it reduces the heat transfer surface, so that the cooling air are typically inefficient. A microchannel is a micrometer tool used for replacement of cooling (Khan and Fartaj, 2011). Increase the contact surface area (per cross section) of fluid flow is an important component of this selection. The internal extended surfaces, change the fluid type, change flow path and add the sided fins might be able to increases heat transfer rate. Although these all schemes enhance heat transfer but influence the pressure drop across microchannel that negatively affect the pumping power. Further increase the solid zone and consequently distance between heat generation device and fluid lead to increase maximum temperature of device.

Achievement proper geometry dimension for microchannel's application as a heat exchanger has been studied (Knight et al. 1992), (Li and Peterson, 2007), (Pan et al. 2008), (Husain ans Kim, 2008). In parallel, other researchers have been studied on the effects of different ribs and extended surfaces in the channels. Kilicaslan and Sarac (1998) in an experimental study on a cylindrical rib found that this geometry is optimum heat transfer for conversion of the pressure drop. Tian et al (2009) studied the wavy fin-and-tube heat exchangers which have three-row round tubes in staggered or inline Arrangements. Their results illustrated augmentation of heat transfer performance for wavy fin-and-tube heat exchanger with modest pressure drop penalty. Kamali and

Binesh (2008) studied effect of several rib shapes in duct. Their results showed that features of the inter-rib distribution of the heat transfer coefficient are strongly affected by the rib shape and trapezoidal ribs with decreasing height in the flow direction provide higher heat transfer enhancement and pressure drop than other shapes. Also, Chai et al. (2013) in 2013 studied various dimensions and positions of rectangular ribs in the transverse microchambers. They emphasized to optimization of effective parameters.

In this study, the position and size of the triangular-shaped rib on heat transfer and pressure drop characteristics of a microchannel with half-circle extended surface is investigated. Water as the coolant simulates with temperature's dependent properties. Flow with low Reynolds number is simulated in a laminar zone. In order to offer optimized case, the energy effective ratio (EER) is defined and according to it's the proper position, ratio of triangular rib obtain.

Problem definition:

Fig. (1) shows schematic of set of microchannels. Each microchannel has 2 cm length, 0.08 cm width, 0.65 width to heigth ratio and 1 fin's width to microchannel width. In middle of length, two half-circle with 0.03 cm radius and 0.1 cm distance of each other located to bottom of microchannel. Triangular rib in three different states with constant rule (0.02 cm) and varying height examines. For this purpose dimensionless parameter $\gamma = Height / base$ is defined.

As this microchannel applicant as a CPU heat sink, Bottom surface conjunct to heat flux source and upper surface is isolate. Sided also be isolate and fluid in laminar regime flow in microchannel.

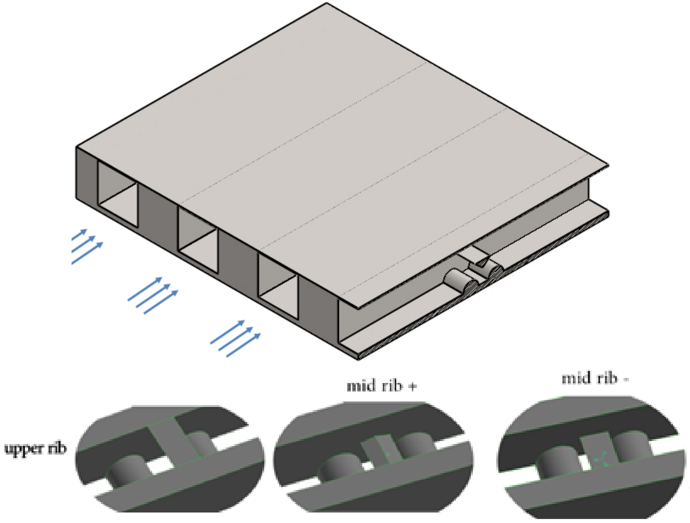

Figure 1. *Schematic of the microchannel*

Government Equations:

The fluid has single phase manner. We assume the thermophysical properties are depended to temperature, the properties (significant) depended to temperature are derived from experimental data (Fricke and Beker, 2001), (Kampmeyer, 1952). As follow:

$$x_f = (c_0 + c_1 T + c_2 T^2) \quad (1)$$

Total thermal resistance is $R_{th} = \dfrac{T_{\max,x} - T_{in}}{q}$, which calculated of sum of all resistances.

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

$$EER = \frac{\dot{q}}{w} \quad (2)$$

Results:

To study the effects of rib on heat transfer and hydrodynamic characteristics of the microchannel is used Fluent 6.3 software. Due to the presence of extended surfaces and a rib, non-structured grid is used. This work was done by Gambit 2.3 software.

In this study, the viscosity and conductive heat transfer coefficient assume depended to temperature and used in solution SIMPLE algorithm.

Grid Independent and validation:

To check the independence of the grid, different nodes generated and the developed velocity in outlet and temperature profile through the centerline was obtained (Fig. 2).

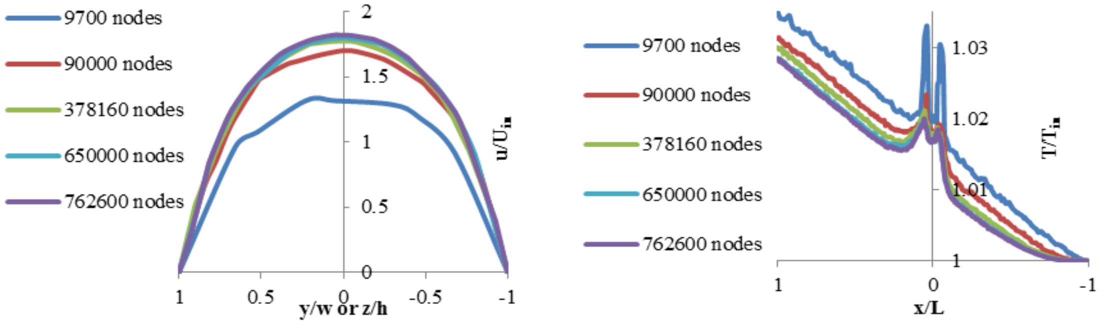

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Figure 2. *a) profile of the developed velocity b) profile of temperature along the microchannel*

By using the results of Figure (2), approximate number of nodes 378,000 used for this case study. To validate the numerical simulation also used results of Tian et al. (2009). In order, the micro-scale channel 0.2*12.5*200 mm with only two half-circle with 5.275 mm radius and 25 mm distance from each other simulates. Figure (3) compares the results of this study and the Tian et al.

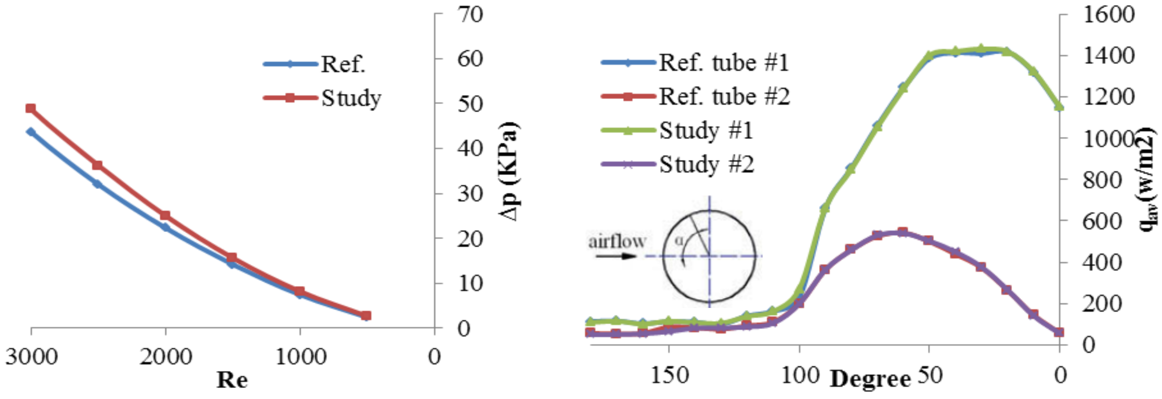

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Figure 3. *Comparison the pressure drop through microchannel and heat flux from extended surface*

In this study, laminar flow governed through microchannel, so by increasing Reynolds number the pressure drop will be greater than the experimental pressure drop. It's being due to transition from laminar to turbulent zone. In this study, range of Reynolds number is in laminar state and as Fig. (3-a) hydrodynamic results is satisfactory. Fig. (3-b) shows the results obtained from numerical simulations in laminar flow and have good agreement with Tian et al. results, while the greatest difference is only 12% and the mean error is 3%.

Effect of rib on pressure drop and thermal resistance:

After validating the numerical solution, the effect of the triangular rib on high pressure and heat resistance is examined. Figure (4) shows the total pressure drop due to raise triangular rib in the microchannel. Increasing rib's ratio (γ) increases the pressure drop. Pressure and frictional are two separated parts of pressure drop. The Pressure and frictional components of the pressure drop show in Table 1. In a laminar zone the friction is greater than the pressure, so increasing surface has a direct impact on the pressure drop. But, the greater height of the rib increase impact of pressure term. It will be more effective with increasing Reynolds number. Decreasing pressure drop in small γ of upper rib is due to decreasing surface and changing local velocity.

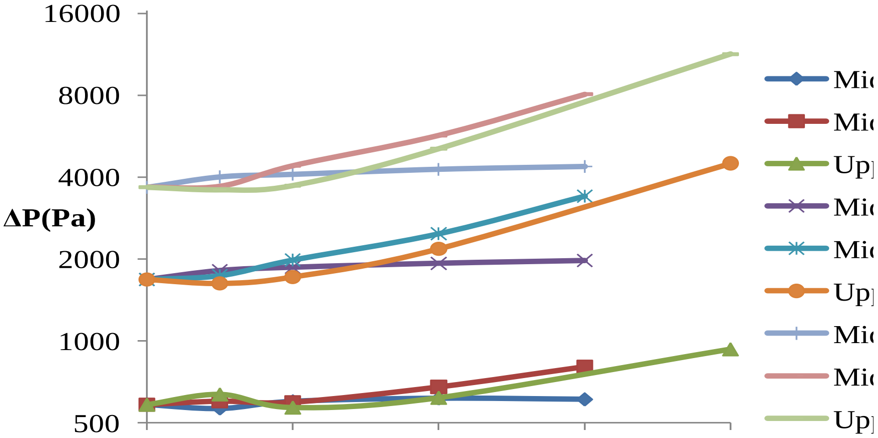

Figure 4. *Pressure drop through the microchannel with triangular rib*

Table 1: Comparison two types pressure drop together

at Re=415

γ	**0**		**0.25**		**0.5**		**1**		**1.5**	
Position	Pressure	Viscosity	Pressure	Viscosity	Pressure	Viscosity	Pressure	Viscosity	Pressure	Viscosity
Mid+	251	1430	307	1429	402	1578	830	1643	1756	1642
Mid-	251	1430	279	1534	300	1563	345	1581	390	1581
Upper	251	1430	245	1380	349	1367	742	1437	1876	1460

at Re=690

γ	**0**		**0.25**		**0.5**		**1**		**1.5**	
Position	Pressure	Viscosity	Pressure	Viscosity	Pressure	Viscosity	Pressure	Viscosity	Pressure	Viscosity
Mid+	641	3028	734	2959	990	3410	2097	3601	4489	3586
Mid-	641	3028	671	3334	728	3365	842	3428	972	3399
Upper	641	3028	611	2978	888	2832	1954	3128	1954	7234

When the rib is placed at the centerline of the microchannel and downward, pressure drop is less due to the geometry configuration, because flow path leads upwards after passing a first half-circle. This effect sees on pressure component of drop. But, in upward rib pressure component increase strongly. Friction is the same procedure but variation is slight because change the contact surfaces are negligible. However, the reported results are included surface contact of the smooth walls with fluid in the areas before and after the extended surface.

Figure (5) shows thermal resistance of water flow in microchannel at different Reynolds numbers.

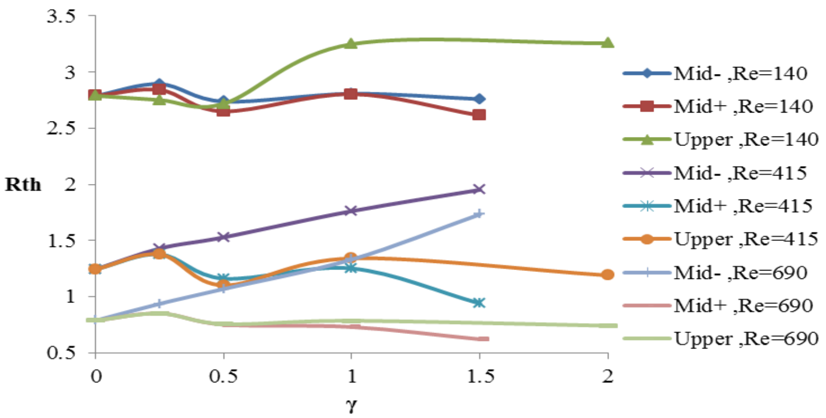

***Figure 5.** Thermal resistance of microchannel with triangular rib in various Reynolds number*

Results of Fig. (5) show decrease thermal resistance with increase velocity. The scale velocity up should cross heat flux surfaces to increase heat transfer. Since the bottom surfaces have more effective heat transfer chance to fluid than rib to fluid via sided fin, so leading fluid path to down of centerline improve heat transfer and consequently decrease thermal resistance. The aim of middle position of rib was using heat flux of sided fin. Thermal performance of upward middle rib in Fig. (5) is obvious. This location increase fluid flow to extended surface with more velocity, so increasing rib ratio decrease thermal resistance. Upper rib in actually does this task that only can competition with upward middle rib by increasing its height. Beside, increasing rib ratio (γ) for downward middle rib decrease fluid flow through extended surface and increase thermal resistance. Generally, figure (5) illustrates upward middle rib has better effect on thermal resistance improvement.

Thermal efficiency:

Better position of the rib and its ratio must be calculated by Energy Efficiency Ratio. Figure (6) shows the EER for three rib's situations in various Reynolds number.

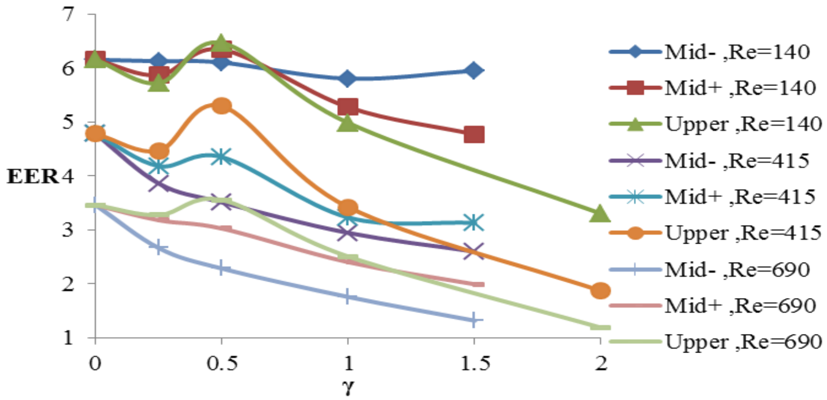

***Figure 6.** EER for three rib's situation in different Reynolds number*

Figure (6) represents the maximum thermal efficiency ratio occurs at $\gamma = 0.5$. Also rib's position at the top of the microchannel is much better than the other. due laminar flow, major friction's influence on pressure drop in low velocity and lowest contact surface of upper rib, this situation cause less pressure drop along proper heat transfer. Base on Fig. (5) increasing more than enough rib's ratio increase pressure drop greatly alongside low heat transfer enhancement and consequently leads opposite effect on EER.

Effect of the Reynolds number:

Fluid flow rate is required addition the rib dimensions in practical applicant. Figure (7) provides a thermal efficiency of the triangular upper rib in various Reynolds numbers.

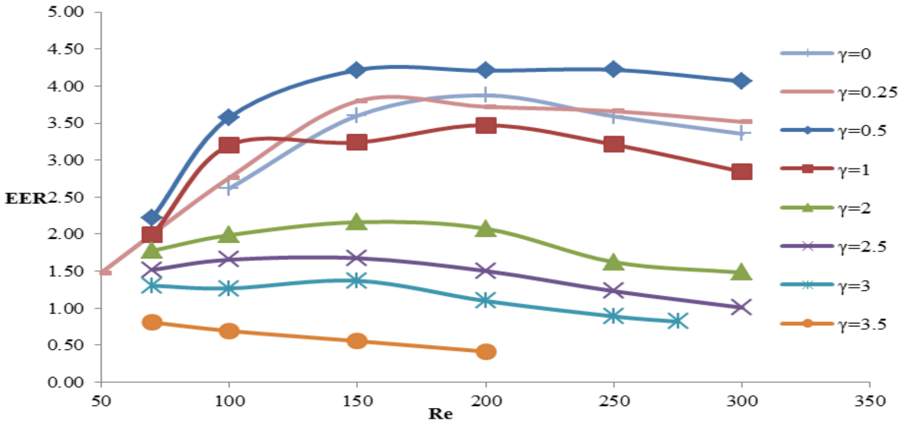

Figure 7. *EER for microchannel with upper triangular rib in various Reynolds number*

According to Fig. (7) the suitable Reynolds number is variable based on the ratio γ but generally range from 130 to 170 for the use of this microchannel proposes. This range for most γ has greatest energy efficiency. This finned microchannel with extended surfaces and upper rib proposes for a specific CPU with 200 KW heat flux and can be develops to similar cases.

Conclusion:

In this study, effect of position, ratio and Reynolds number on EER investigate. The operation fluid is Water. A Simulation was performed for laminar flow and single phase fluid. Add a rib to the middle of the finned microchannel causes better distribution heat flux to the fluid, while the pressure drop also greatly contributes directly.

Thermal efficiency ratio showed that the upper rib has a better performance in the similar cases. The best efficiency in the range of Re= [130-170] and of γ=0.5 is obtained.

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