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# Comparison of cooling performance in a microchannel with discrete heat sources under pressure gradient and electroosmotic driven

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## Abstract

Electronic devices and advanced types of equipment have various sections that generate heat is a common feature among them, and sometimes it becomes so intense that it requires the design of a new structure to help cool them. However, the challenge becomes more complex when the device is in micro or nano size, where ordinary pumps with electrical components cannot function. This study addresses this issue using electroosmotic micro-pumps and examines the effect of microchannel angle and gravity on heat transfer rate. The microchannel angle ranges from 0 to 75 degrees, and the Grashof number varies between 0 and 100. For better understanding, the results obtained from a pressure-driven flow are compared with those from a purely electroosmotic flow while maintaining a constant flow rate. The thermal performance index is employed to measure the efficiency of flow patterns in both cases. The calculated variations range from approximately 11% to over 44%, indicating that two factors, increasing the microchannel angle relative to the horizontal plane and decreasing the Grashof number, exhibit similar behaviour and enhance the heat transfer efficiency.

**Keywords:** Electronics Cooling, Electroosmotic, Microchannel, Heat transfer, Nusselt Number

## 1. Introduction

The advancement of technology has forced humankind to study physical phenomena at the micro and nano scales. The knowledge and application of these phenomena, which generally deal with heat and mass transfer, leads to more efficiency of modern equipment. Electrokinetic is one of the well-known phenomena to stimulate fluids to move through these environments, in which the use of electric potential causes the fluid to move and create a plug flow. In addition, electronic devices, which are a reference for using pumps, usually produce a large amount of heat [1]. In recent years, compared to other micropumps, electroosmotic pumps have attracted the attention of many researchers. Among their advantages is creating pulse-free currents and removing moving parts [2].

Al-Rjoub et al. [3] used electroosmotic flow for cooling and thermal management of micro-scale multi-channel heat exchangers in electronic devices with hot spots. A constant flux heater was used to simulate heat transfer produced by electronic devices. They used different liquids such as de-ionized water, distilled water, borax buffer and a solution of aluminium oxide nanoparticles for cooling. They found that among all the cooling liquids, aluminium oxide nanoparticle solution has the highest specific heat energy with an increase of 69% compared to distilled water. They also concluded that increasing the flow rate increases the heat transfer from the hotter spots of the microelectronic devices without the need for high-pressure pumping systems.

Chang and Hung [4] numerically investigated the mutual effects of electrohydrodynamic forces and gravity on the circulation of the working fluid inside an inclined heat microtube driven by electroosmotic flow. They concluded that the application of electrohydrodynamic forces and gravity on a thermal microtube affects its thermal performance. Therefore, the balance between electrohydrodynamic forces and gravity is of vital importance.

Heydari et al. [5] numerically investigated the performance of electroosmotic/pressure actuators in the cooling of a microchannel filled with micropolar nanofluid. They concluded that increasing the micropolarity and the ratio of the characteristic length of the microchannel to the characteristic length of the flow decreases the flow rate and increases the heat transfer.

Saffian et al. [6] investigated the hydrodynamic and heat transfer characteristics of the electroosmotic flow inside a rectangular microchannel using electric and magnetic fields. In this study, the Poisson-Boltzmann equation with the Debye-Hackel approximation was used to model the electric potential in the electrolyte near the walls. They found that after a certain value of the Hartmann number, increasing the magnetic field leads to an increase in the Nusselt number. Also, in weak lateral electric fields, the Nusselt number increases continuously with the increase of the Hartmann number.

The research conducted by the authors shows that in electronic cooling, electroosmotic micropumps are a better alternative to pumps that work based on pressure gradient. However, there is no study regarding the effect of angle on their performance in cooling. The present study shows the advantage of using an electroosmotic micropump in situations where gravity creates a reverse pressure gradient on the fluid flow. To analyze this issue, the thermal performance of the fluid flow of a pure electroosmotic actuator with a pure pressure gradient is compared. Also, comparing the results of both flow modes is a new approach to describe the efficiency of these devices.

The innovations are summarized as follows:

- Numerical modelling of fluid flow in an inclined microchannel with discrete heat sources under electroosmotic stimulation and pressure gradient;
- Comparing the efficiency of electroosmotic micropump and pump with pressure gradient drive in electronic cooling.

## 2. Methodology

The microchannel is equipped with two constant flux heaters that are placed opposite each other on both sides of the microchannel. The rest of the channel wall consists of charged plates that use the anode and cathode at both ends of the microchannel for fluid. In this study, it is assumed that the length of the channel is much larger compared to its width (L/W=12) and the Reynolds number is considered to be 10. Also, the flow is assumed to be thermally and hydrodynamically developed. Also, the fluid flow is incompressible and the Parantel number is 7 (water).

The governing equations of the flow, including continuity, movement, energy, Poisson-Boltzmann and Laplace, were considered to model the flow in two-dimensional mode. In addition, the effect of buoyancy on fluid movement is applied using the Boussinsque approximation. Also, since Joule heating (at low voltages) is negligible compared to the heat produced by the heaters, the calculation of this value is neglected in this study.

$$(\frac{\partial \mathrm{u}}{\partial \mathrm{x}}+\frac{\partial \mathrm{v}}{\partial \mathrm{y}})=0 \tag{1}$$

$$\begin{aligned}&\left(\mathrm{u}\frac{\partial \mathrm{u}}{\partial \mathrm{x}}+\mathrm{v}\frac{\partial \mathrm{u}}{\partial \mathrm{y}}\right)\\&=-\frac{\partial \mathrm{p}}{\partial \mathrm{x}}+\left(\frac{1}{\mathrm{Re}}\right)\left(\frac{\partial^2 \mathrm{u}}{\partial \mathrm{x}^2}+\frac{\partial^2 \mathrm{u}}{\partial \mathrm{y}^2}\right)\\&+\frac{\beta \mathrm{L}}{\mathrm{DRe}}\sinh(\alpha\psi)\left(\frac{\partial \phi}{\partial \mathrm{x}}\right)\\&+\frac{\mathrm{Gr}}{\mathrm{Re}^2}\mathrm{T}\sin\theta\end{aligned} \tag{2}$$

$$\begin{aligned}&\left(\mathrm{u}\frac{\partial \mathrm{v}}{\partial \mathrm{x}}+\mathrm{v}\frac{\partial \mathrm{v}}{\partial \mathrm{y}}\right)\\&=-\frac{\partial \mathrm{p}}{\partial \mathrm{y}}+\left(\frac{1}{\mathrm{Re}}\right)\left(\frac{\partial^2 \mathrm{v}}{\partial \mathrm{x}^2}+\frac{\partial^2 \mathrm{v}}{\partial \mathrm{y}^2}\right)\\&+\frac{\beta \mathrm{L}}{\mathrm{DRe}}\sinh(\alpha\psi)\left(\frac{\partial \phi}{\partial \mathrm{y}}\right)\\&+\frac{\mathrm{Gr}}{\mathrm{Re}^2}\mathrm{T}\cos\theta\end{aligned} \tag{3}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{1}{(\mathrm{Re\ Pr})}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \tag{4}$$

$$\left(\frac{\partial^2 \psi}{\partial \mathrm{x}^2}+\frac{\partial^2 \psi}{\partial \mathrm{y}^2}\right)=\beta\sinh(\alpha\psi) \tag{5}$$

$$\left(\frac{\partial^2 \phi}{\partial \mathrm{x}^2}+\frac{\partial^2 \phi}{\partial \mathrm{y}^2}\right)=0 \tag{6}$$

To solve equations (1) - (6), a Fortran code is used by finite volume method and SIMPLE algorithm with a hybrid scheme. Also, the criterion of convergence is that the residuals decrease below $10^{-7}$.

## 3. Results and Discussion

In this study, the effectiveness of electroosmotic pumps in the cooling process is assessed through a comparison of average Nusselt numbers across various Grashof numbers and angles. Introducing the thermal performance index, which indicates the percentage increase in the Nusselt number due to electroosmotic flow compared to pressure gradient-driven flow, highlights the enhanced heat transfer efficiency. The findings reveal a notable improvement, with the average Nusselt number increasing by 11-44% when utilizing electroosmotic pumps.

Figures 1 and 2 show the contours of flow temperature inside a microchannel with a constant flux heater at different angles. As can be seen, increasing the angle of the microchannel at a constant Grashof number (0 and 100) increases the temperature of the fluid flow. In addition, the temperature contours in Figures 5 and 6 show that increasing the Grashof number at a constant angle from 0 to 100 significantly reduces the temperature of the fluid flow.

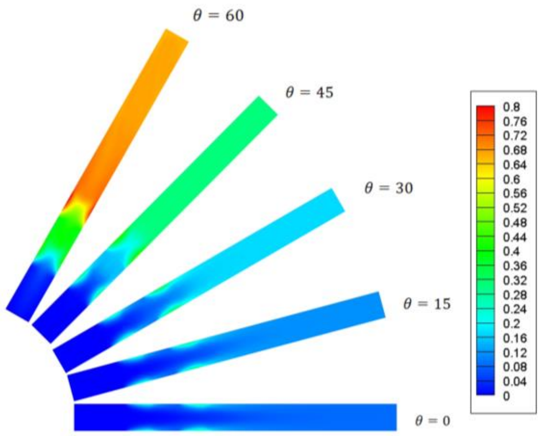

**Figure 1. The contour of the temperature inside the microchannel at different angles, and Re=10, Gr=0**

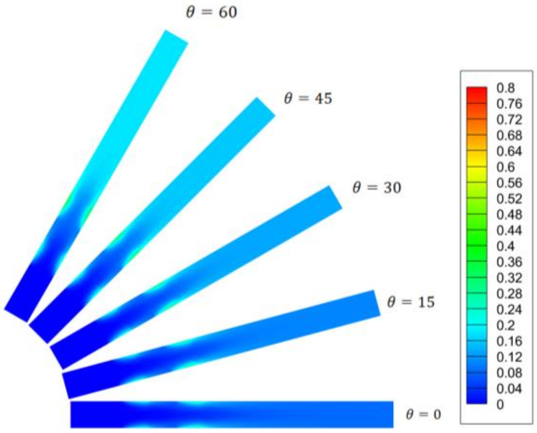

**Figure 2. The contour of the temperature inside the microchannel at different angles, and Re=10, Gr=100**

Figures 3 and 4 show the velocity field at the lowest and highest Grashof numbers. The velocity of fluid becomes negative in some central regions of the microchannel, where the fluid mass moves by the net force induced in electric double layers. Reverse streams are created due to the absence of charged plates throughout the microchannel and also the boundary conditions at the entrance of the microchannel (caused by the effect of fluid weight). Increasing the Grashof number as well as buoyancy force, results in an increase in velocity and the disappearance of swirling flows. Another interesting point in these results is the higher temperature of the fluid that leaves the microchannel while the average Nusselt number in the sources reaches its maximum value. This phenomenon can be explained due to the increase in fluid flow rate at higher Grashof numbers.

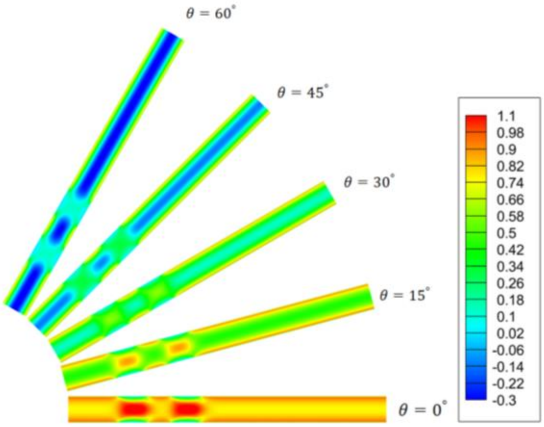

**Figure 3. The contour of the velocity inside the microchannel at different angles, and Re=10, Gr=0**

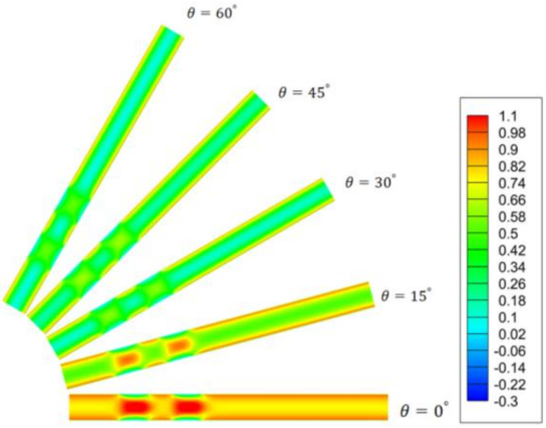

**Figure 4. The contour of the velocity inside the microchannel at different angles, and Re=10, Gr=100**

## 4. Conclusions

This study investigated the impact of utilizing microchannels equipped with electroosmotic pumps on heat transfer efficiency. The findings revealed a notable increase in heat transfer efficiency within the microchannel. A new metric, the thermal performance index, was introduced to quantify the percentage increase in the average Nusselt number in the microchannel's bottom layer. Results showed changes ranging from approximately 11% to 44% across Grashof numbers from 0 to 100 and angles from 0 to 60 degrees. Increasing the microchannel angle relative to the surface and decreasing the Grashof number exhibited similar effects, both enhancing thermal efficiency. The study underscores the practicality of employing electroosmotic micropumps for electronic cooling, particularly when the microchannel is inclined relative to the horizontal axis.

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