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# Simulation of The Forced Convection Heat Transfer Non-Newtonian Nanofluid, Aqueous Solution of Carboxymethyl Cellulose-Aluminum Oxide, in Slip Flow Regime Through a Microtube

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## 1- Introduction

In the present study the flow and heat transfer of Non-Newtonian nanofluid, aqueous solution of carboxymethyl cellulose-Aluminum oxide with different volume fractions of nano particles in a two dimensional microtube is simulated for the first time. Slip velocity and temperature jump boundary conditions are also considered along the microtube walls. The accuracy of the results obtained is investigated by comparison with those of previous data. The results are presented as isothermal contours, Nusselt number and the profiles of temperature and velocity at different cross sections of the microtube. It is observed that Nusselt number increases with slip velocity coefficient and volume fraction of nano particles; while its rate is more sensitive at higher values of Reynolds number.

Nowadays, due to the use of microscale tools and components in industries such as: the electronics industry, aviation industry, medical and laboratory industries, it is necessary to develop and employ new and high efficiency methods in the field of heat transfer in these tools. Due to their small geometric dimensions, and depending on their applications, these tools are not able to transfer the heat flux generated by conventional methods. Hence, by employing new methods with high efficiency, we can benefit from the advantages of these tools in the industry. New methods may include use of microchannels and nanoparticle powders being added in the cooling fluid, which is one of the high-efficiency methods in cooling micro-scale tools. Nowadays, air cooling is the most common method of cooling. However, this method does not work in transferring high heat fluxes. Therefore, engineers have become interested in liquid cooling methods. The cooling liquids are usually water, ethylene glycol, different types of refrigerants, liquid nitrogen, and other coolants, depending on specific applications. These liquids usually have poor heat transfer properties, and they definitely will not be used much in the future to transfer ultra-high cooling loads.

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Microchannels are increasingly used in many industrial applications in order to achieve more compact geometries for heat transfer. Especially, microchannels; as a solution to decelerate the ozone layer depletion process, enable us to use lower doses of environmentally-harmful fluids in our applications while maintaining the efficiency. To solve the governing Navier-Stokes equations and discritization of the solution domain, the numerical method of finite volume and SIMPLE algorithm have been employed. To discretize all of the terms of the equations, second order upwind has been used. Slip velocity and temperature jump boundary conditions are also considered along the microtube walls. Walls of the microtube are under a constant temperature.

Results of the current work show a good agreement with the numerical and experimental studies of other researchers. Data are presented in the form of velocity and temperature profiles, streamlines and temperature contours as well as amounts of slip velocity, temperature jump and Nusselt number. The results show that local Nusselt number along the length of the microchannel increases with the increase in Reynold number. It is also noted that rise in slip coefficient and volume fraction of nanoparticles leads to an increase in Nusselt number, which is greater for higher Reynolds numbers.

## 2. Problem Definition

The problem being studied is a two-dimensional microtube, as shown in Figure 1. The intended nanofluid contains carboxymethyl cellulose aqueous solution, and solid nanoparticles of aluminum oxide. Nanoparticles are all spherical and have a diameter equal to $d_p = 10$nm. The cool nanofluid with a temperature of 298 degrees Kelvin and constant velocity of ui enters the microtube, and exits from its end after cooling the wall. The nanofluid flow in the microtube has been considered to be laminar, steady, non-Newtonian, and incompressible.

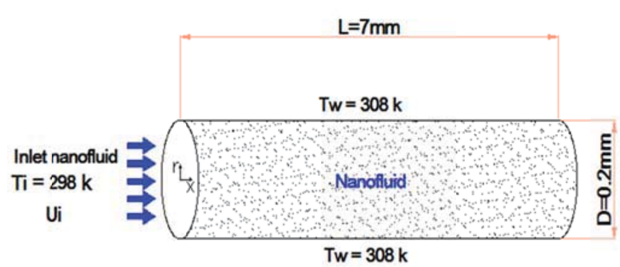


**Fig. 1. A schematic of the problem**

## 3. Boundary conditions

The boundary conditions applied to the microtube, include inlet and outlet boundary conditions and walls. In the inlet boundary condition, the flow has been considered to be uniform at unit dimensionless speed and temperature. And hydrodynamic and thermal development conditions are used in the outlet boundary condition. The temperature on the walls of the microtube has been considered to be constant. Recently, researchers have shown that no-slip and temperature jump boundary conditions may not be appropriate for flows in microscale channels, because a microscale flow of a liquid is different from a macroscale flow.

## 4. Results and Discussion

Figure 2 shows a graph of local Nusselt numbers versus the dimensionless lengths of the microtube. It can be seen that with the slip coefficient increasing, the Nusselt number increases since the temperature gradient increases along the walls of the microtube. The Nusselt number has the maximum value at the inlet of the microchannel due to the highest temperature difference between the nanofluid and the walls of the microchannel. The velocity of the nanofluid is low around the walls of the microtube. As a result, there is enough time for heat exchange between the nanofluid and the walls of the microtube. Thus, the nanofluid's temperature increases and reaches the temperature of the microtube's walls thereby reducing the temperature difference between the nanofluid and the walls of the microtube. In general, the Nusselt number increases with the increased volume fraction of nanoparticles and increased Reynolds number.

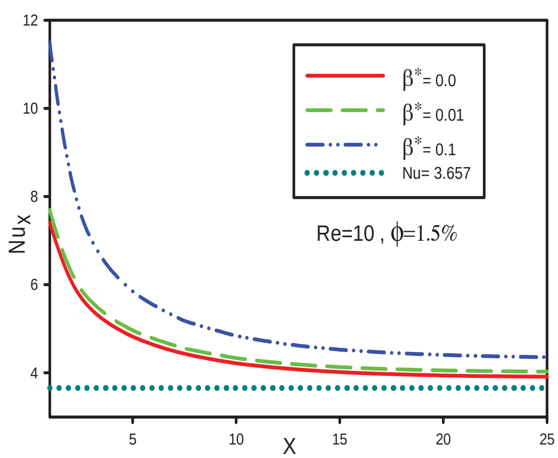


**Fig. 2. Changes in the local Nusselt number versus different values of slip coefficient**

Average Nusselt numbers of the nanofluid on the walls of the microtube for different values of slip coefficient can be seen in Figure 3. The results show that an increase in the slip coefficient increases the Nusselt number. For all values of Reynolds number, the average Nusselt number increases with the increased □. Because with the increased wt% of the solid nanoparticles, the thermal conductivity coefficient of the nanofluid increases, thus increasing the thermal performance of the nanofluid. The average Nusselt number is a dimensionless number that represents the ratio of the heat transferred by convection to the heat transfer by conduction.

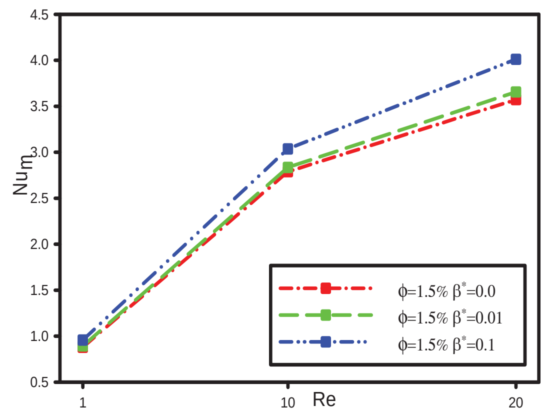


**Fig. 3. Changes in the average Nusselt number versus different values of slip coefficient**

## 5. Conclusion

The present problem dealt with investigating the heat transfer of carboxymethyl cellulose-aluminum oxide aqueous solution in a slip regime. We investigated parameters such as the Reynolds number, Nusselt number, and the volume fraction of solid nanoparticles in different areas of the microtube's walls. The Brownian motion of the nanoparticles was taken into consideration in the computations being used in the model, to calculate the thermal conductivity of the nanofluid. The heat transfer rate increases at high Reynolds numbers. With the volume fraction of the solid nanoparticles increasing, the thermal performance of the nanofluid increases, which is due to the increased volume of nanoparticles with higher relative thermal conductivity. The significant increase in the Nusselt number due to the increased volume fraction of solid nanoparticles is more manifest at higher Reynolds numbers.