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ENHANCEMENT OF THERMAL PERFORMANCES IN MICROCHANNEL USING SQUARE RIB WITH AL_20_3 NANOFLUIDS

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Abstract

A simulation analysis was carried out to augment the thermal performances of cylindrical pipe in a microchannel heat exchanger (MCHS) using the square shape of rib and consuming nanofluids- Aluminum oxide Al2O3 as working fluid. Research values are compared with base fluid to ascertain the thermal performances. The renormalized RNG k-ϵ turbulent model was selected for the investigation with Reynolds number in the ranges of 5000 to 20000. Dittus Boelter and Blasius' empirical equation are involved to validate the turbulent models. The parameter considers for numerical analysis are the average Nusselt number (Nu) and friction factor (ƒ). The investigation reveals that the maximum heat transfer occurred in Al2O3 at a higher Reynolds number. The enhancement of Nu values has 2.67 times greater than base fluid and 1.54 times of pressure drop in Reynolds number 18000.

Keywords:

Al_2O_3;
Nanofluids;
Heat exchanger;
Average Nusselt number.

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1. Introduction

In recent days, research is focused to utilize maximum heat energy in heat exchanger tubes and channels by varying their roughness, blending nano-fluids with base fluids (water), and integrating thermal storage systems (TES) to improve their thermal performance. Most frequently, using nano-fluids with varying volume fractions reflects promising results in the heat exchangers applications. Y. Yue et.al [1] conducted a simulation analysis in a micro-channel heat sink using Al_2O_3 with Reynolds number 100 to 400. Researchers reveal that increasing Nanoparticle size cause decreasing heat transfer and pressure drop. And increasing Reynolds number roots increasing Nusselt number and friction factor. J. Wuet et al. [2] examined the thermal efficiency of a microchannel heat exchanger (HCHS) using Al_2O_3/H_2O nanofluids. The investigation reports that maximum pumping power is required to operate the MCHS. A. Abdullabi et al [3] consumed SiO_2, Al_2O_3, ZnO, and CuO with base fluid in a microchannel tube to ascertain maximum thermal performances attained from the proposed nanofluids with volume fraction 0.01 to 0.02. The result reveals that SiO_2 nano-fluids reached a higher Nusselt number than other fluids. Xia et al [4] investigated the fan shape mico channel using Al_2O_3 and TiO_2 in volume fraction of 0.0001 to 0.001. The examination compared with rectangular microchannel and divulges that strong improvement traced in AL_2O_3 Nanofluids. Sakanova et al [5] examined the performances of MCHS with traditional straight methods in MCHS using Au, SIO_2, CuO, and base fluids and proved maximum thermal performance attained using nanofluids in the wall of MCHS. Further, Sakanova et al [6] investigated Al_2O_3 water-based nanofluids as a coolant to enhanced convection. The authors reveal that a greater concentration of nanofluids performed a good cooling process. Nebbati et al [7] examined the effect of nanoparticles and performances of heat transfer inside the cylinder. Research reports that nanofluids kindle the average Nusselt number and decrease the local temperature at bottom of the wall. S.M. Peyghambarza et al [8] used a 0.2 % volume fraction of CuO, Al2O3 in the analysis, It found pressure drop occurred in both nanofluids during the study and recorded maximum thermal enhancement reached 49% in Al_2O_3 nanofluids. A nanofluids CuO with volume fraction of 0.24% to 1.03% examined by B. Rimbault et al [9] for energetic performances. The research reveals that 4.5% of heat transfer augmentation occurred with a lower volume fraction of nanofluids. N.R. Kuppusamy et al [10] investigated the performance of thermal enhancement in TGMCHS using Al_2O_3, CuO, Sio_2, and ZnO. Result reveals that gradual heat transfer improvement was found in proposed nanofluids and significant pressure drop recorded. T.C. Hung investigated microchannel using nanofluids to increase thermal performances [11], later double-layer MCHS [12] was used for the research work. The researcher report that using double-layer coating in nanoparticle the heat transfer augmentation increase higher than normal fluids.

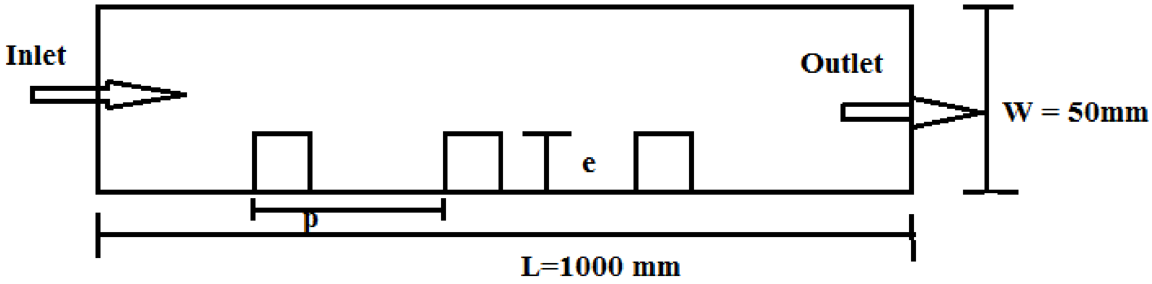
The main objective of the work is to augment convective heat transfer in a cylindrical pipe of microchannel using rough surfaces and nanofluids. From the detailed literature survey consuming nanofluid with various volume fractions performed better thermal efficiency Among them, Al_2O_3 produced a promising outcome. However, owing to the volume fraction a significant pressure drop occurred in many applications. To overcome this problem we proposed to employ a square shape of rib roughness in the cylindrical pipe in MCHS with aluminum oxides Al_2O_3 as nanofluids. The varying velocity of the working fluid in the range of Reynolds number 4000 to 20000 creates turbulence in a fluid layer closer to the wall for attained higher convective heat transfer. The parameter taken for the analysis are average Nusselt number Nu, friction factor ƒ, and the result are compared with base fluids to ascertain the augmentation of heat transfer in a microchannel. Research reported a significant heat transfer enhancement occurred by varying Reynolds number in MCHS

2 . Physical model:

2.1 Geometry:

The schematic diagram of cylindrical pipe in a microchannel is shown in Fig. 1. The length of the pipe is 1000 mm and the inner and outer diameter of the pipe is 50 mm and 52 mm. A square shape of ribs employed in the test section of the pipe at pitch distances of 100 mm was located middle portion of the pipe, 300 mm to 700 mm from the entrance. The proposed geometry was designed using ANSYS 13 Fluent. The boundary condition of the pipe at inlet velocity ranges from 4000 to 20000 and exit fixed as the pressure at atmospheric condition. Constant heat energy transferred in the outer surface of the pipe and the wall condition is assumed constant heat flux at 1000 W/m^2.

a) 2D



b) 3D

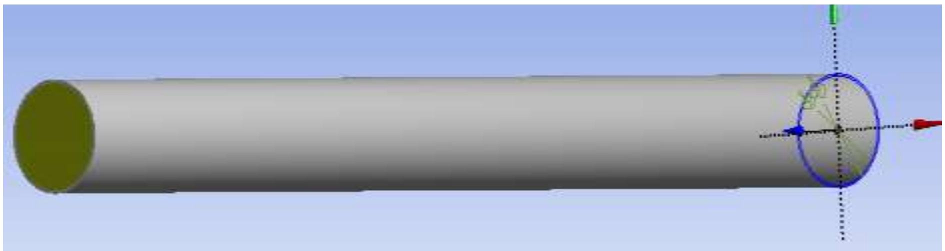
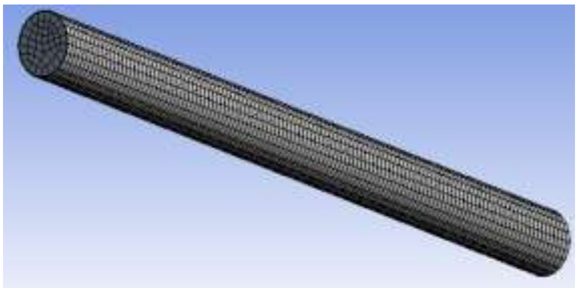


Fig.1 Schematic diagram of Cylindrical pipe with square rib in MCHS a) 2D b) 3D.

In simulation analysis, meshing a geometry plays a significant role to predict the enhancement of heat transfer that occurred in the proposed investigation. A grid-independent study plays a noteworthy role to determine the precise element size for the investigation. The varying meshing portion of the cylindrical pipe is shown in Fig.2 [a & b] and the element size selected for the research work is 3,53,156. Further, the boundary condition of inlet velocity is fixed on one side and another side positioned as an exit. The outer surface of the cylindrical pipe is assumed as a wall condition.

a)



b)

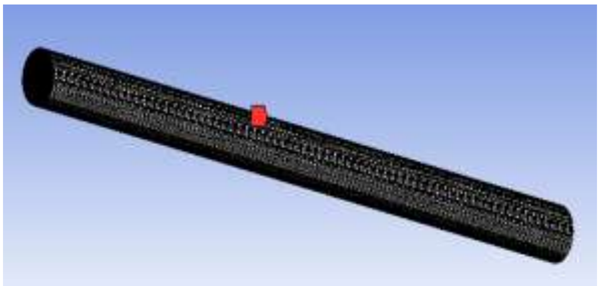


Fig. 2 a & b. Meshing portion - Varying element size of the pipe.

2.2 Solution method:

In the finite volume methods, governing equation of continuity, momentum, and energy equation are taken to solve the proposed geometry in ANSYS Fluent 13. In material selection, the thermophysical properties of Al_2O_3 and base fluids are shown in Table.1. Inlet velocity fixed as ranges of Reynolds number from 4,000 to 20,000. Pressure outlet fixed as the atmospheric condition. the outer surface of cylindrical pipe as constant heat flux 1000W/m^2.A second-order SIMPLE (Semi Implicitly Methods for Pressure Linked Equation) was used to solve Navier stokes. Convergent criteria for continuity, x, y z axis nominated as 10^{-6} and residual monitor switched ON. Later, iteration was initialed to calculate the parameter assigned for the proposed geometry.

Table.1 Thermophysical property of working fluid

S. No	Working fluids	Density ρ (kg/m^{-3})	Thermal conductivity k, ($Wm^{-1}K^{-1}$)	Sp heat C_p ($JKg^{-1}K^{-1}$)	Viscosity μ (Nsm^{-2})
1	Al_2O_3	3773.07	36	765	0.001522
2	Base fluid	998.20	0.613	4182	0.001003

3. Model selection:

In the numerical procedure, the convective heat transfer is analyzed by selecting a precise turbulent model. It found seven turbulent models are available in the fluent. Among them, k-ϵ and k-ω models are most closer to predict the heat transfer that occurred nearer to the wall region and the heat distribution that arose in the fluids layer due to shear stress occurred between fluids layers. This one was selected based on validation of Dittus Bolter and Blasius equation of average Nusselt number and friction factor values with proposed nanofluids and compared with base fluids. Among them, k-ϵ RNG turbulent models show significant performances and are selected for further investigation.

4. Result analysis:

In this research, square ribs are mounted in the cylindrical pipe of MCHS for creating a vortex in the fluid flow direction and using nanofluids as working fluids for attaining a higher heat transfer rate than the water as base fluids. Average Nusselt number and friction factor parameters are evaluated in both cases and detailed reports are presented.

4.1 Average Nusselt number:

To enhance thermal efficacy in the cylindrical pipe of MCHS, square-shaped ribs are mounted to create turbulent in the fluid flow direction, causes to increase the convective heat transfer rate, Further consuming nanofluids as working fluids results in a higher heat transfer rate. An elaborated performance of rough surface as shown in Fig.3 temperature distribution occurred in Reynolds number ranges from 4000 to 20000. It illustrates that increasing Reynolds number results in higher impact occurred between layers of fluids and generate vortex closer to the rib and walls. This leads to increase thermal performances between ribs in the MCHS.

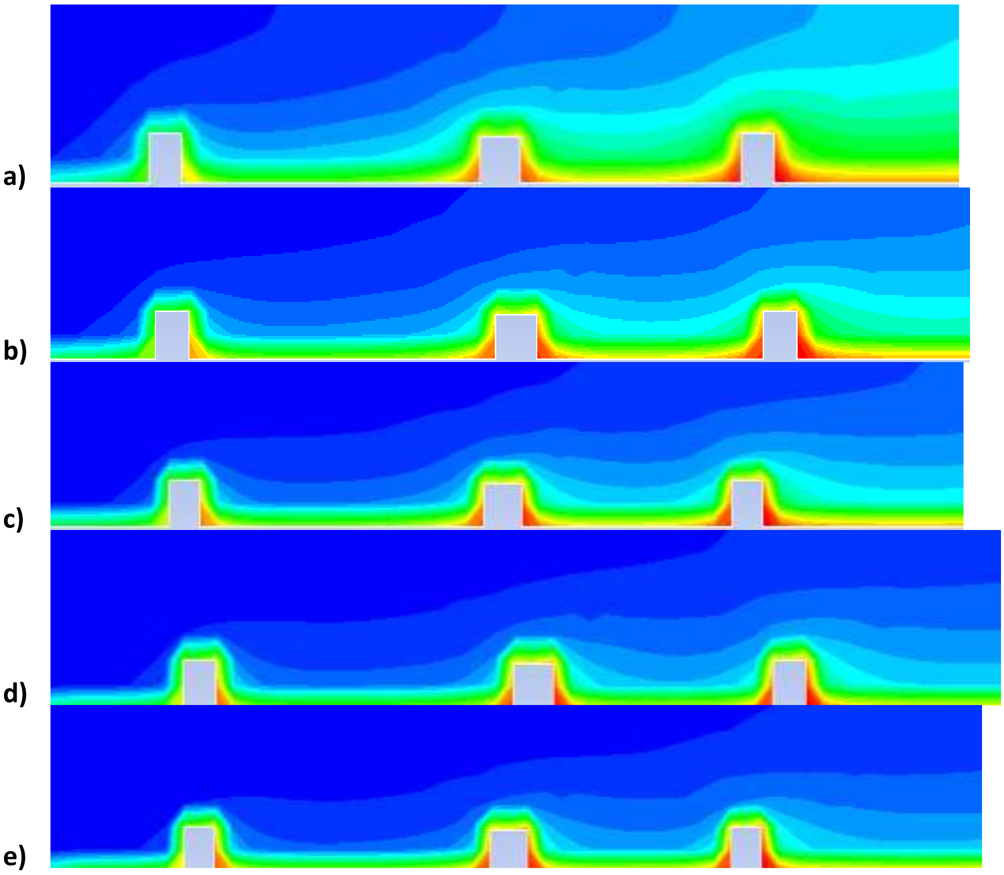


Fig.3 Temperature distribution Contour plot in square rib in a cylindrical pipe in the range of Reynolds number a) 4000 b) 8000 c) 12000 d) 16000 and e) 20000.

Further, nanofluids as working medium and verdicts are compared with base fluids. Their performances are shown in Fig. 4. It illustrates that in nanofluids, higher heat transfer arisen at lower Reynolds number and gradually increasing when increasing Reynolds number in both fluids. At a certain point at Reynolds number 16000 both fluids reach the same Nusselt number later, nanofluids lead to a higher Nusselt number than base fluids. It shows consuming nanofluids has a maximum possibility to produce higher thermal performances than base fluids.

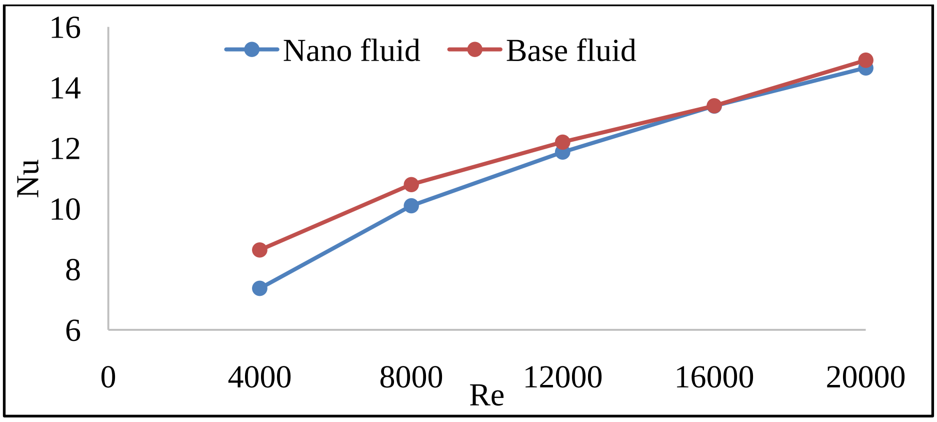


Fig.4 Average Nusselt number (Nu) Vs Reynolds number (Re)

4.2 Friction factor:

Implementing a rough surface in the pipe, it's noticed that higher pressure drop befell, and using nanoparticles with lower volume fraction cause more pressure drop. A clear trace noticed in the contour plot of velocity distribution in different Reynolds numbers as shown in Fig. 5. It illustrates the size of vortex generate top of the ribs are gradually increasing in increasing Reynolds number and shear distribution in middle fluids layers are moving forwards in higher Reynolds number. Its report that in lower Reynolds number higher pressure drop occurred and increasing Reynolds number cases decreasing pressure.

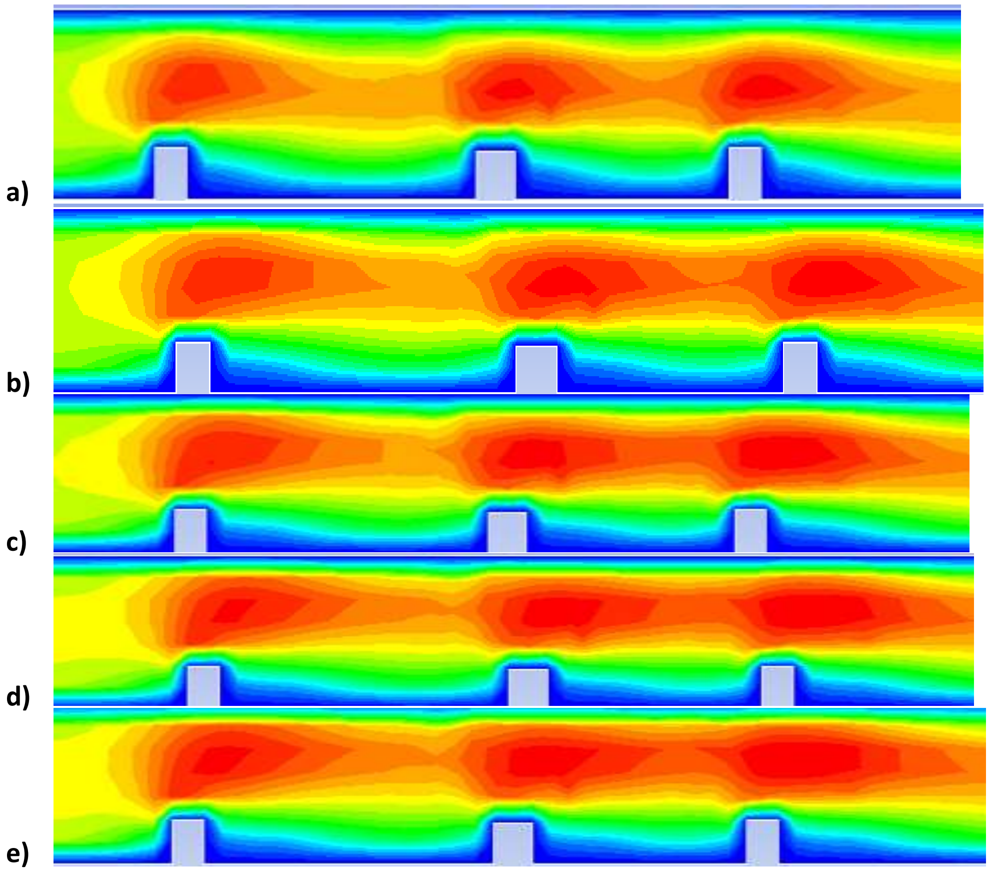


Fig.5 Velocity distribution Contour plot in square rib in a cylindrical pipe in the range of Reynolds number a) 4000 b) 8000 c) 12000 d) 16000 and e) 20000.

In Fig.6. illustrates that the performance of friction factor occurred in nanofluids with base fluids. It observed that maximum friction factor results in nanofluids at Reynolds number 4000 and base fluids at same Reynolds number lower. It happed owing to the thermophysical performances of nanofluids as shown in Table. 1. It further noticed at higher Reynolds number both fluids decreasing friction factor at Reynolds number 20000, shows increasing pumping power of fluids decreases pressure drop in both fluids.

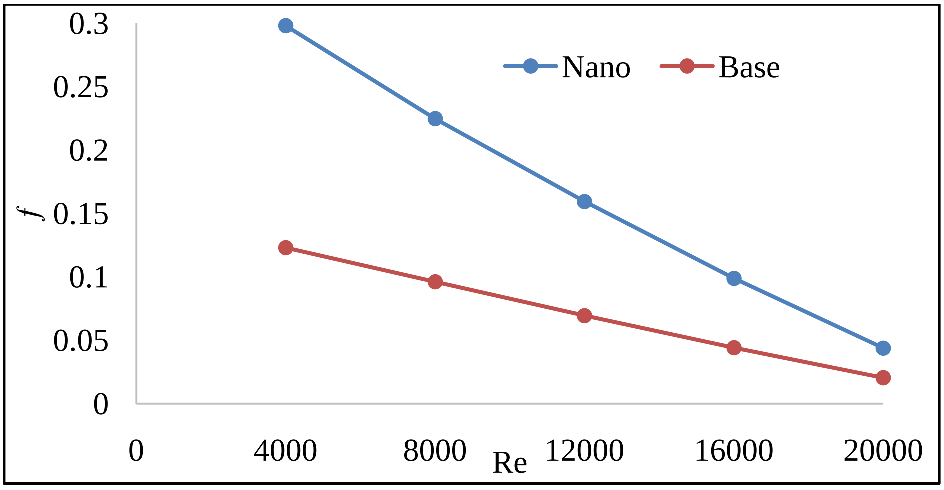


Fig.6 friction factor (ƒ) Vs Reynolds number (Re)

5. Conclusion:

In the numerical investigation of MCHS implementing square shape of rib with nanofluids produced significant thermal performances. It observed noteworthy point are as follows

1. Increasing Reynolds number produced a 2.67 times higher heat transfer rate in nanofluids than base fluids.
2. Higher friction factor produced at lower Reynolds number and lower friction factor occurred in increasing Reynolds number in both nanofluids and base fluids.
3. It also observed that 1.54 times higher pressure drop in consuming nanofluids than base fluids

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