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PRIMARY RESEARCH

Mixed convective nanofluids over vertical channel having forward-facing step flow having a baffle

Omar. A. Hussein [1] *, **Thamer Khalif Salem** [2]

[1] Department of Mechanical Engineering, University of Tikrit, Tikrit, Iraq

[2] School of Engineering, University of Ozyegin, Cekmekoy, Turkey

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Abstract— Numerical simulations of laminar flow complex for convective heat transfer through a 2D channel wall forward facing steps using different type of nanofluids having a baffle. The Finite Volume Method (FVM) solved by equations, momentum, continuity and energy equations and the SIMPLIC calculation plan is connected to look at the impacts of the baffle wall in flow, characteristics, and convective thermal enhancement. Four distinct sorts of nanofluids [Al_2O_3, SiO_2, CuO, and ZnO], with various volumes of particles in the scope of 0.01 to 0.04 scattered in the base liquid (water) are utilized. The effects of height H_b and width Wb of baffles, on Nusselt number variety are numerically simulated. The results demonstrate that SiO_2 has the most astounding Nu contrasted and different nanofluids. The distribution district and Nu increment as the volume of nanoparticle increments and it diminishes as the particle's diameter increments.

I. INTRODUCTION

A circumstance where both the constrained and free convection effects are of equivalent request is called mixed or consolidated convection. The examination of Forced and natural convection flow over a vertical channel has got significant hypothetical and reasonable interest. The wonder of mixed convection happens in numerous specialized and mechanical issues, for example, electronic gadgets cooled by fans, atomic reactors cooled amid a crisis shutdown, a heat exchanger set in a low-speed environment, solar collectors and so on. A few creators have contemplated the issue of mixed convection in various surface geometries. Flow partition and reattachment because of sudden changes in geometry happen in numerous building applications that require heating or cooling. Fluid flow and thermal move in the field of these applications show two-dimensional (2-D) conduct of the flow. Examiners have demonstrated the experimental and numerical values [1].

The way of the approaches to improve heat or mass transfer in the isolated districts is to utilize fluids. Solid nanoparticles are liquids that are stable suspensions of nanoparticles. These are nanometer particles suspended in liquids. In this way, it doesn't bring about an expansion in pressure gradient on the face of the step. Many researchers demonstrated that nanoparticles show upgraded heat transfer properties, for example, the thermal conductivity of the heat transfer fluids contrasted with liquid; see, for instance, [2], [3], [4] and [5].

[6] analyzed theory of enhancement of the heat exchange upgrade in flat channels by backward-facing step flow utilizing a baffle establishment. They noticed the lowest Nusselt number as the installation on wall was at distance D = 0. The results show the highest Nusselt number as the installation on wall was at distance D = 0.2. The most extreme increase in all things considering Nusselt number was around 190% for 150% for the downstream area and stepped wall of the base wall. A slight development of the

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*Corresponding author: Omar. A. Hussein
†Email: omar_assi2008@yahoo.com

baffle position could bring about an exceptional change in the transfer qualities.

[7] researched numerically the upgrade flows in a two-dimensional channel of forced convection heat transfer with qualities of backward-facing step during the establishment of strong and opened baffles along the center of the channel divider. They found that the Nu was little for the state as $\emptyset_t = 10^\circ$ less than that as $\emptyset_t = 0^\circ$ in the stepped wall segment, however it was bigger at last district. In addition, the punishment of expansion in pressure drop was higher for that circumstance with baffle establishment.

The most critical conclusion, which has a vital importance to this research, is the way that the flow in a three-dimensional channel of forced convection heat transfer by the backward-facing step has a solid three-dimensional conduct and the incorporation of this estimate ought to have assistance to give a few parts of the partition reattached to the area. Furthermore a superior comprehension of this phenomenon was noticed by [8]. Conducted forecast of the stream and warmth move in stepped wall with stunned balances were researched by [9] and [10].

The investigation of heat transfer and fluid flow over a forward-facing step in vertical nanofluid mixed convection as a part of two-dimensional uniform heat flux wall limit characteristics appears to have not been explored in this study.

Hence, this study manages distinctive sorts of nanofluids, for example, [Al_2O_3, ZnO, SiO_2, and CuO] with various nanoparticles' fractions. The effect of Nu is considered and noticed to delineate the effects of various parameters of nanofluids on flow.

II. NUMERICAL PARAMETERS

A. Physical Model and Assumptions

Two-dimensional nanofluids' flow in channel having forward-facing step having baffles is clearly shown in Figure 1 as a representation of mixed convective flow, along the center of the channel. A step height (S), with extension ratio is altered at 0.005 m and 2, separately. The upstream tallness of the duct (h) and downstream height (H) are 0.025 m and 0.01 m, separately. The divider along the center of the step (X_e) is kept up at a parallel divider heat flux (q_w), the top wall structures the opposite other of the channel that is kept up at steady temperature equal to the inlet temperature (T_o). The top wall of the step (X_i) is adiabatic. The top wall is introduced a baffle of the forward-facing step designed as appeared in Figure 1. The baffle height and baffle width are kept as 0.01 m and 0.0075 m. The length of along the channel area is 0.025 m upstream and 0.25 m downstream of the step extension individually.

Heat transfer flow at the channel wall passageway is thought to be hydrodynamically relentless and the completely created flow is accomplished at the end of the step, and the streamwise inclinations of amounts at the channel exit where set to be zero. Nanofluids at the channel inlet are thought to be hydrodynamically enduring and the completely created flow is accomplished at the end of the wall, with the slopes of all amounts at the exit.

This concentrate only manages laminar flows. The type of different nanoparticles with the liquid (i.e. water) is expected to have a heat balance and no other side happens. The liquid is thought to be Newtonian and uncompressible. Radiation heat exchange and thick dispersal term are ignored. The inner thermal generation is not directed in present results. Thickness is shifted and can be satisfactorily displayed by the Boussinesq estimate. GAMBIT 2.4.6 and FLUENT 6.3, business programings were utilized as a part of the present study to play out the simulations.

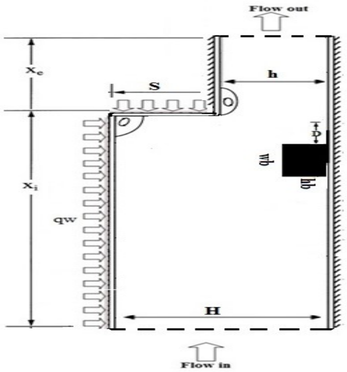

Fig. 1 . Schematic diagram for space of FFS in a vertical channel with baffle

B. Governing Equations

To finish the Computational fluid elements' examination of forward-facing step, it's critical to set up mass and momentum equations for the governing. Utilizing the Boussinesq estimate and dismissing the type of effects of dissemination and compressibility, the dimensionless administering conditions for two-dimensional heat transfer flow incompressible can be composed as following forms [11]:

$$\frac{\partial U}{\partial X} + \frac{\partial U}{\partial Y} = 0 \tag{1}$$

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$$U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}=-\frac{\partial p}{\partial x}+\frac{\mu_{nf}}{p_n u_{nf}}\frac{1}{R_e}(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}) \quad (2)$$

$$U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}=-\frac{\partial p}{\partial x}+\frac{\mu_{nf}}{p_n u_{nf}}\frac{1}{R_e}(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2})+\frac{p(\beta)_{nf}}{p_{nf}\beta_{nf}}\frac{Gr}{Re^2}\Theta$$
(3)

The energy equation:

$$U\frac{\partial \theta}{\partial X}+V\frac{\partial \theta}{\partial Y}=\frac{a_{nf}}{a_f RePr}(\frac{\partial^2 \theta}{\partial X^2}+\frac{\partial^2 \theta}{\partial Y^2}) \quad (4)$$

III. GRID INDEPENDENCE TEST

In the present study, grid independence is utilized to direct the GIT by the effect of fluid flow of various nanofluids in backward-facing step. The grid independence test is led of nanofluid as working liquid. Grid densities of 180×40, 170×30, and 130×30, were chosen to play out a grid autonomy examined. Size of grid 170×30 affirms the independence test arrangement. It indicates under 3% contrast in Nu contrasted with other sizes of grid test appeared in table 1.

TABLE 1
GRID INDEPENDENCE TEST RESULTS FOR NU AT RE = 500E

Number of nods		Ratio (length/width)		
Y	X	x-ratio	y-ratio	Nusselt number
	30			1.87653
130	40			1.76678
	50			1.76575
	30			1.93442
170	40	0.0714	0.651	2.35542
	50			2.25455
	30			2.21701
180	40			2.11369
	50			2.25102

A. Code Validation

Code acceptance is exceptionally critical step in any numerical work so as to guarantee that the numerical code is approved with different pervious works and it is prepared for further runs. The present results acquired were compared and approved with the past studies and go about as a benchmark for the project. Then again, it is not imperative just to get high precision of any numerical code additionally to pick up a superior comprehension on its capacities and confinements. In order to validate this numerical code, the noticed value of [12] was utilized. Their exploration concentrated on theoretical reproductions of heat transfer forced convection flow nearby rectangular pipe by backward-facing step to analyze effects of heat transfer, the baffle on flow conveyances as appeared in figure 2.

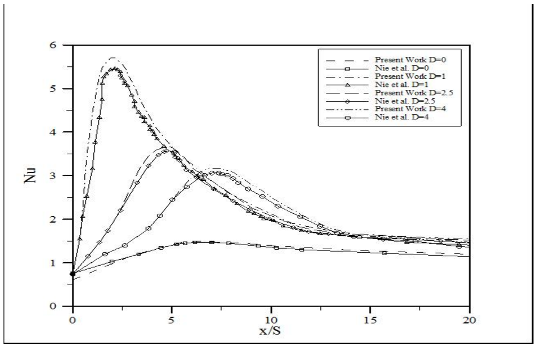

Fig. 2 . Comparison of Nusselt Number with the Tests of Nie et al. 12 for Re = 343 and qw = 50 W/m2 for Nusselt number

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B. Effective Physical Properties

By utilizing Brownian movement of nanoparticles or Heat transfer features, the effective thermal effect can be acquired by utilizing the accompanying experimental relationship [14]:

$$Viscosity: \frac{\mu_{eff}}{\mu_f} = \frac{1}{1-34.87(\frac{d_p}{d_f})^{-0.3}\theta^{1.03}} \tag{5}$$

$$The diameter of liquid molecule: d_f = [\frac{6M}{N\pi\rho_{bf}}]^{\frac{1}{3}} \tag{6}$$

The density, ρ_{nf} can be figured utilizing [13]:

$$\rho_{nf} = (1-\theta)\rho_f + \theta\rho_{np} \tag{7}$$

At constant pressure can be calculated the heat capacity $(\rho c_p)_{nf}$ by using [13]:

$$(\rho\beta)_{nf} = (1-\theta)(\rho c_p)_f(\theta\rho c_p)_{np} \tag{8}$$

C. To calculate the effect of thermal expansion $(\rho\beta)_{nf}$ by using [13]:

$$(\rho\beta)_{nf} = (1-\theta)(\rho\beta)_f + \theta(\rho\beta)_{np} \tag{9}$$

Table 2 demonstrates the thermophysical properties for base fluid and distinctive nanofluids at T= 300 K [13].

TABLE 2
GRID INDEPENDENCE TEST RESULTS FOR NU AT RE = 500E

Thermophysical Properties	Pure Water	Al_2O_3	CuO	SiO2	ZnO
Density, ρ(kg/m^3)	998.203	3970	6500	2200	5600
Dynamic viscosity, μ (Ns/m^2)	2.01×10-3	-	-	-	-
Thermal conductivity, k (W/m.K)	0.613	40	20	1.2	13
Specific heat, cp (J/kg.K)	4182.2	765	535.6	703	495.2
Coefficient of thermal expansion, β (1/K)	2.06×10^{-4}	5.8×10^{-6}	4.3×10^{-6}	5.5×10^{-6}	4.3×10^{-6}

IV. RESULTS AND DISCUSSION

The investigation for the laminar mixed convection heat transfer over two-dimensional vertical forward-facing steps area is assigned to exhibit the numerical results. The effects of various nanofluid sort, its focus and particles' distance across and baffle installation on the heat fields by vertical forward-facing step are investigated and examined.

A. The Effect of Different Nanofluids' Parameters

Different types of nanofluids which are Al_2O_3, ZnO, SiO_2 and CuO with base liquid are utilized. The effects of various nanoparticles on the thermal upgrade for every parameter ought to be settled, φ = 0.04, and d_p = 25 nm, at Re = 500 and q_w = 500 W/m^2 along the downstream divider that are examined and exhibited. Figure 3 (a-b) demonstrates the Nu in saw at the downstream plate increments by expanding the separation stepped wall to a greatest quality close to the baffle wall at little separation heated plate of the reattachment region, it then abates gradually as the separation keeps on expanding in the streamwise bearing. This is because of the temperature distinction when the switched liquid is connected by the primary vortex due to lower temperature. Obviously nanofluid with SiO_2 nanofluids has the best conduct in Nusselt number followed by other nanofluids separately. This is on account of interring the distribution regions where the nanofluids bring down thickness and thermal conductivity.

B. Effect of Different Nanoparticles' Volume Fractions

The volume concentration is really alluded to ratio of the volume of nanoparticles isolated by the mixture to all constituents before blending. Base fluid has zero volume of nanoparticles, for this segment, the nanoparticles' volume fraction in the scope of 0-4% at D = 0.01, Re = 500 and q_w =500 W/m_2 was utilized. The outcomes show that expanding the volume fraction prompts improvement in the heat transfer move as delineated in Figure 4(a-b). This happens in light of the fact that expanding of nanofluids for nanoparticles' volume fraction prompts to increase the heat transfer enhancement of the liquid.

C. The Effect of Baffle Height and Effect of Baffle Width

In Figure 5b, the outcomes represent to increment

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Nusselt number after the nearness of the effect of baffle height with D = 0.01, Re = 500 and q = 500 W/m_2 on the thermal improvement of forward-facing steps as appeared in Figure 5a. What's more an auxiliary distribution zone shows up into the region of the top wall. The baffle is lengthened to H_b = 0.0075. The primary flow of streamline is thickly stuffed than for $_b$ = 0.005, Nu number further increments as it is around three once than the instance of $_b$ = 0.0075. Also, the distribution zone on other side of the step is compacted and more grounded by the more drawn out baffle, but the distribution part on the base bottom in the bottom area extends. It is sensible to expect that even with a small baffle the thermal attributes can viably make strides. The Nu of SiO_2 with dp = 25 nm, and φ = 4% for various baffle widths largest at D = 0.01, q_w = 500 W/m_2 at Re = 500 distribution along the bottom plate divider has appeared in Figures 5(a-b). The Nusselt number increments as the baffle width increments because of addition in the distribution locale. The bulk temperature expands all the more quickly as the baffle width increments. As the confound width increments from Wb = 0.01 to Wb = 0.02, the distinctions in the non-generous heat in the area close to the forward- facing steps flow with the base wall. Correlation on the instances of Wb = 0.01 up to Wb = 0.02 uncovers the effects of widths on the greatest Nu that are unimportant. It can be seen that the Nu has the highest maximum peak inside distribution area as the baffle width diminishes until it achieves its ideal at the recirculation point. The effects of various baffle heights and widths on the streamlines have obviously appeared in Figure 6. Essential and optional distribution zones are shown in this figure.

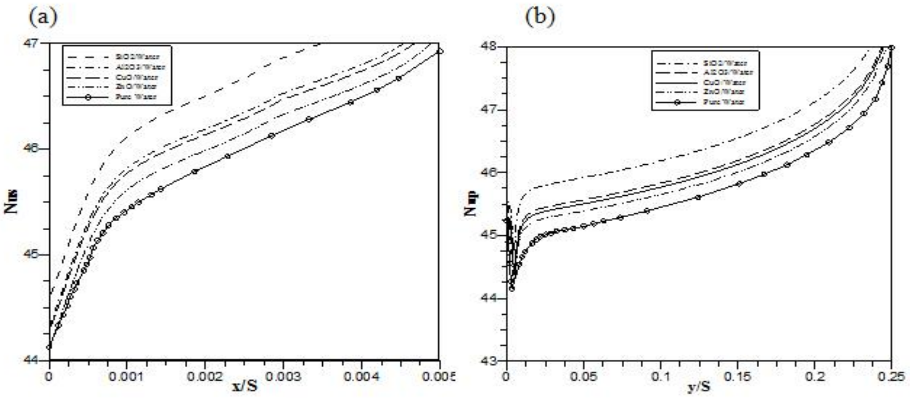

Fig. 3 . The effect of different nanofluids at Wb = 0, Hb = 0, Re = 500, d_p = 25 nm, φ = 4% and q_w = 50 W/m_2 for, (a) stepped wall, (b) distribution along the center of the channel

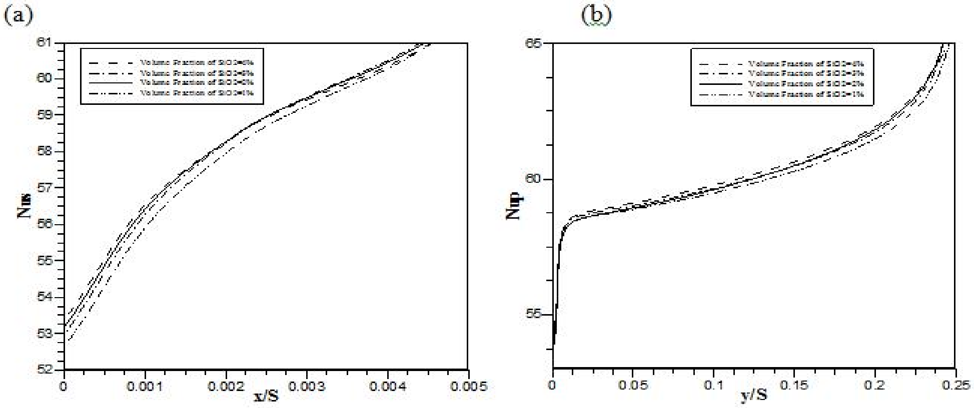

Fig. 4 . The effect of different volume fractions at Wb = 0, Hb = 0, Re = 500, d_p = 25 nm, φ = 4% and q_w = 50 W/m^2 for, (a) stepped wall, (b) distribution along the center of the channel

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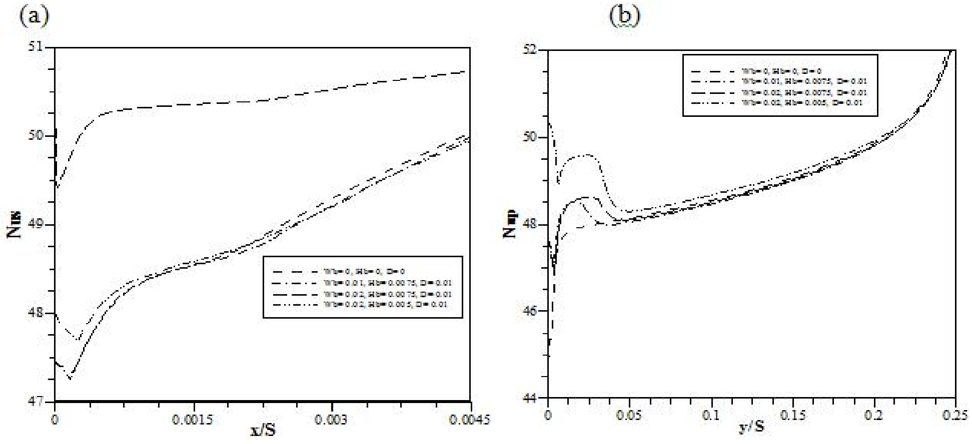

Fig. 5 . The effects of baffle height and width at Re = 500, d_p = 25 nm, φ = 4% and q_w = 50 W/m^2 for (a) stepped wall, (b) distribution along the center of the channel

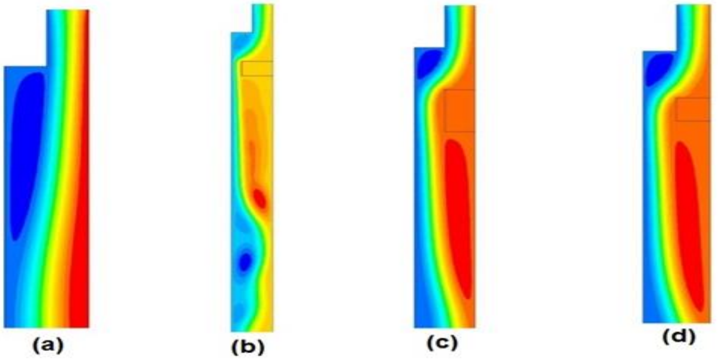

Fig. 6 . Streamlines for four different baffle installation parameters at Re = 500 (a) without baffle, (b) baffle height, (c,d) baffle width.

V. CONCLUSION

Results of simulations for the investigation on laminar mixed convection over two-dimensional forward-facing steps set in a vertical channel by baffle at its divider were displayed. The accentuation is obtained on the thermal upgrade coming about because of different parameters, which incorporate the diverse sort of nanofluids, nanoparticles' volume fraction; the bottom plate of the forward-facing step was settled at parallel heat flux limit condition of baffle geometrical parameters. The overseeing equations were tackled using finite volume method with the SIMPLE calculation. The specific conclusions of this study are presented below:

1. The results demonstrate that SiO_2 gives the most noteworthy Nu followed by Al_2O_3, CuO, and ZnO, separately, while base liquid is the least.
2. The Nu expanded with expanding the volume fraction of nanoparticles.
3. The effect of baffle width on thermal characteristic is unimportant.

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