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PERFORMANCE AND BEHAVIOR OF NANO FLUIDS ON LAMINAR FLOW DUE TO SUDDEN EXPANSION USING NUMERICAL INVESTIGATION

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ABSTRACT

Numerically solved for Laminar two-dimensional sudden expansion flow using nano fluid. Effect of Reynolds number, nano particle volume fraction with base fluid and different nano materials are tested and the solution procedure is validated by benchmark results. Four different nano particles are tested. It is found that when volume fraction is increased ,recirculation eddy size is reduced. The bottom wall and top wall reattachment length is increased linearly while increasing Reynolds number. Results presented for both bottom and top wall reattachment length, stream line contour and skin friction coefficient. Denser materials produce larger eddies. It is found that volume fraction influences the reattachment length and symmetry of the vortices. The skin friction coefficient values are sensitive to volume fraction.

KEYWORDS:

Flow separation;
Rrecirculation;
Nanofluid;
Laminar flow;
Nano materials:
Reattachment length;
Friction Coefficient;
Volume fraction;
Reynolds number;

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1. INTRODUCTION

Sudden expansion flow is common in many industrial applications such as heat exchanger, cooling of turbine blade, combustion chambers, electronics cooling and many

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others. Flow separate and reattach is one of the complex phenomena and itdictates the entire flow physics in the downstream. Flow shows symmetry to certain Reynolds number and further increase leads to asymmetry in the flow. This critical Reynolds number to retain symmetry flow depends the expansion ratio in the geometry. Durst etal [1] have reported experimental as well as numerical predictions of sudden expansion flow for laminar range They found good agreement among numerical and experimental results at Re = 70. However at Re= 610 they found discrepancy among experimental and numerical and the flow was asymmetry at this Reynolds number. Three dimensional laminar mixed convection in a sudden expansion flow is reported by Thiruvengadam et al. [2]. Fluid velocity distribution and Nusselt number distribution in connection with aspect ratio is reported in detail. They found that by decreasing aspect ratio the reattachment line moves upwards and closed to the sudden expansion. Zdanski and Vaz Jr. have reported the non-isothermal topology in sudden expansion [3]. Recently multiphase flow over a sudden expansion in a pipe reported by Balakrishna et al. [4] and Wang et al. [5]. Experimental investigation on heat transfer enhancement is reported by swirl generator by Zohir et al. [6]. Numerical investigation on non Newtonian fluid flows over symmetric two dimensional expansions is reported by Ternik [7]. Couette correction and Moffatt vortices are reported by them. To enhance heat transfer in sudden expansion flow swirl generators or internal protrusions are introduced. However this technique introduced additional pressure drop to the flow. Recently to enhance heat transfer nano fluids are introduced in similar situation. Abu Nada [8] and Al-aswadi et al. [9] reported laminar forced convection heat transfer in a back ward facing step flow using nano fluid. They solved numerically the backward step flow problem by assuming two dimensional laminar flow situation. Flow characteristics and heat transfer are reported in detail for laminar range. Effect of various nano material and different volume fraction with base fluid as water are discussed. In the present work, the governing equations are solved by stream function vorticity method for nano fluid flow through sudden expansion.

2. MATHEMATICAL FORMULATION AND NUMERICAL PROCEDURE

Incompressible two-dimensional laminar flow is considered for the computation. The governing Navier-Stokesequations are solved by stream function-vorticity formulation. Since the present study the hydrodynamic behavior are emphasized [9], the transient non-dimensional governing equations in stream function vorticity form are

Stream function equation

$$\varphi = -\omega \tag{1}$$

Unsteady vorticity equation

$$\frac{\partial\omega}{\partial t} + \frac{\partial(u\omega)}{\partial x} + \frac{\partial(v\omega)}{\partial y} = \frac{1}{Re(1-\emptyset)^{2.5}} \frac{}{\left[(1-\emptyset)+\emptyset*\frac{\rho s}{\rho f}\right]} \nabla^2 \omega$$

(2)

Where ψ - stream function, $\emptyset$ - volume fraction of nano particle; ρ_s is the particle density ; ρ_f is fluid density

$$u = \frac{\partial\varphi}{\partial y};\quad v = -\frac{\partial\varphi}{\partial x} \quad and\ \omega = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$

The variables are scaled as

$$u = \frac{\overline{u}}{\overline{U}} \; ; v = \frac{\overline{v}}{\overline{U}} \; ; \; x = \frac{\bar{x}}{H} ; \; y = \frac{\bar{y}}{H} \; ; \; t = \frac{\bar{t}}{\frac{\overline{H}}{\overline{U}}}$$

Stream function equation 1 is solved by Gauss Seidel method. The unsteadyvorticity transport equation 2 in time is solved by Alternate Direction Implicit scheme (ADI). The central differencing scheme is followed for both the convective as well as the diffusive terms (Roache [10]). The details about the numerical procedure for ADI method can be found from Das and Kanna [11]. The boundary conditions needed for the numerical simulation have been prescribed in Figure 1. Flow at inlet parabolic velocity profile is assumed and exit fully developed flow is assumed for all variables. Along solid walls no slip condition is assumed for velocity variables

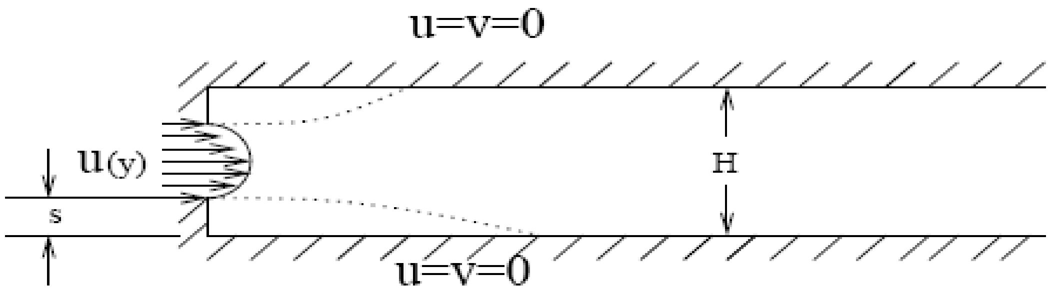


Figure 1: Schematic diagram and boundary conditions of sudden expansion flow problem

3. VALIDATION AND GRID INDEPENDENCE STUDY

To validate the numerical procedure two benchmark problems are considered. Backward facing step flow and sudden expansion flow are solved by the same procedure by Kanna and Das [12] for zero volume fraction ie. without nano particles. The numerical results were compared with both numerical and experimental results [12] for Reynolds number up to 800 for step flow
and found good agreement among other people. Further they simulated sudden expansion flow and compared with Durst et al [1] for Re=70 and Re = 610 and reported that good agreement among the present investigation [13] with Durst et al [1]. Since there is lack of nano fluid over sudden expansion flow, the same in-house solver is tested for nano fluid flows through backward step flow. The step flow is solved for Re = 400 for Copper nano particles and base fluid is water. The nnvolume fraction is 0.2. It is found that discrepancy in the reattachment length is only < 1.3% with published results of [8] and present finding (Figure 2(a)) and Table 1. Also the solver is simulated for SiO2 nano particles for Re=100 and compared with Al-aswadi et al. [9]. Velocity profile from different downstream location is compared with [9] results and we found good agreement near the wall region where velocity gradients are higher and some discrepancy in the middle of the channel (Figure 2) where vortices shear are dominant. These discrepancies are due to course grids used in the step flow simulation. However for simulating sudden expansion flow the grid independence study is carried out with Cu nano particles, Re= 200 and φ = 0.2 viz. 101x61,131x71, 151x71, 151x91 and 201x91 grids. It is concluded that

grids 151x91 are chosen for entire computation based on less than 1% variation on reattachment length. The non dimensionalised symmetry channel height is 1 and step height is 0.25. Inlet parabolic profile is assumed for velocity and other components are zero. Stream lines are constant and they are function of y at inlet.

Eiyad Abu Nada [8]	Present
5.2	5.137

Table 1 Validation backward step flow Cu nano particles. Re= 400 and φ = 0.2: Bottom Wall reattachment length

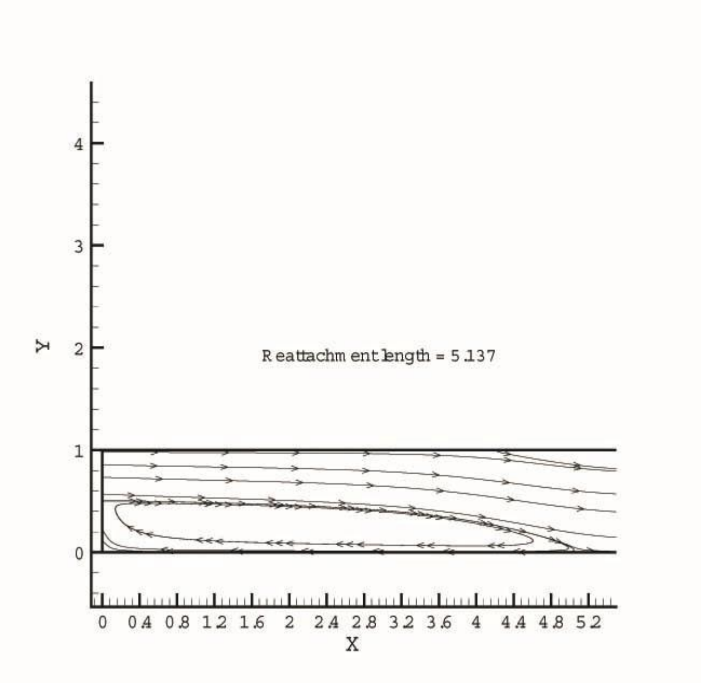


Fig . 2(a) *Cu* nano particles Re=400, φ =*0.2*: X_r =5.2[8]: streamline contour

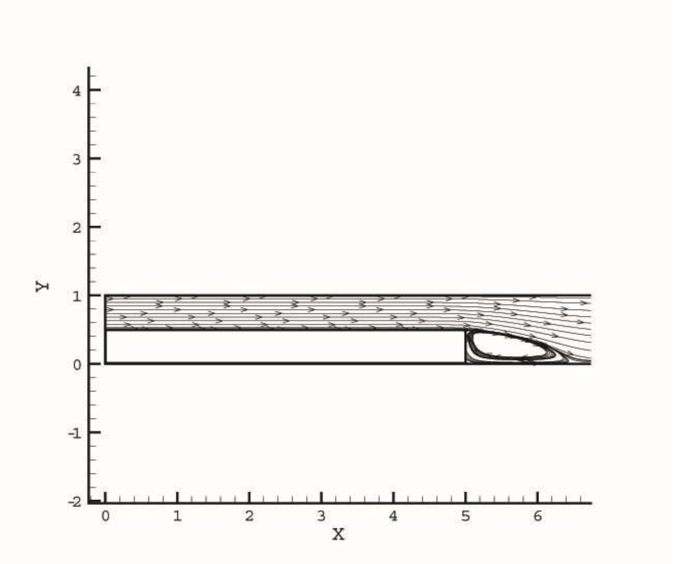
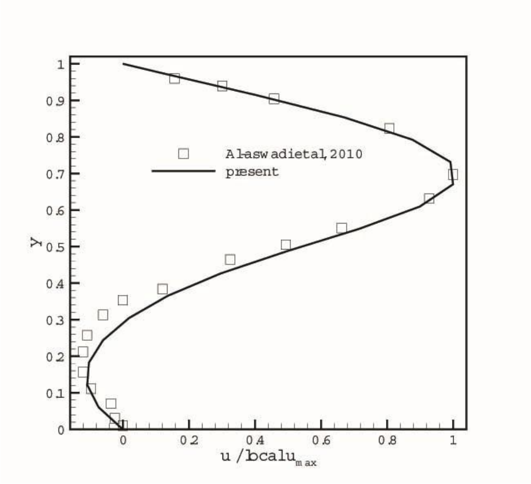


Fig. 2(b) *SiO*$_2$ nano particles [9] Re=100, φ=0.05 and streamline contour



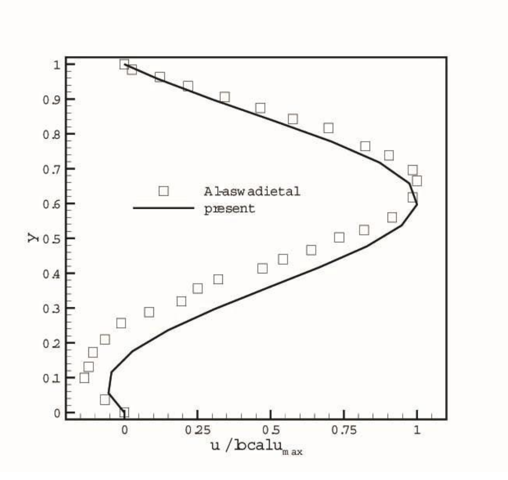


Fig. 2(c) *SiO_2 nano particles [9] Re= 100,* **Fig. 2 (d)** *SiO_2* nano particles [9] Re= 100,

φ =0.05 and X/s = 1.04 φ =0.05 and X/s = 1.92

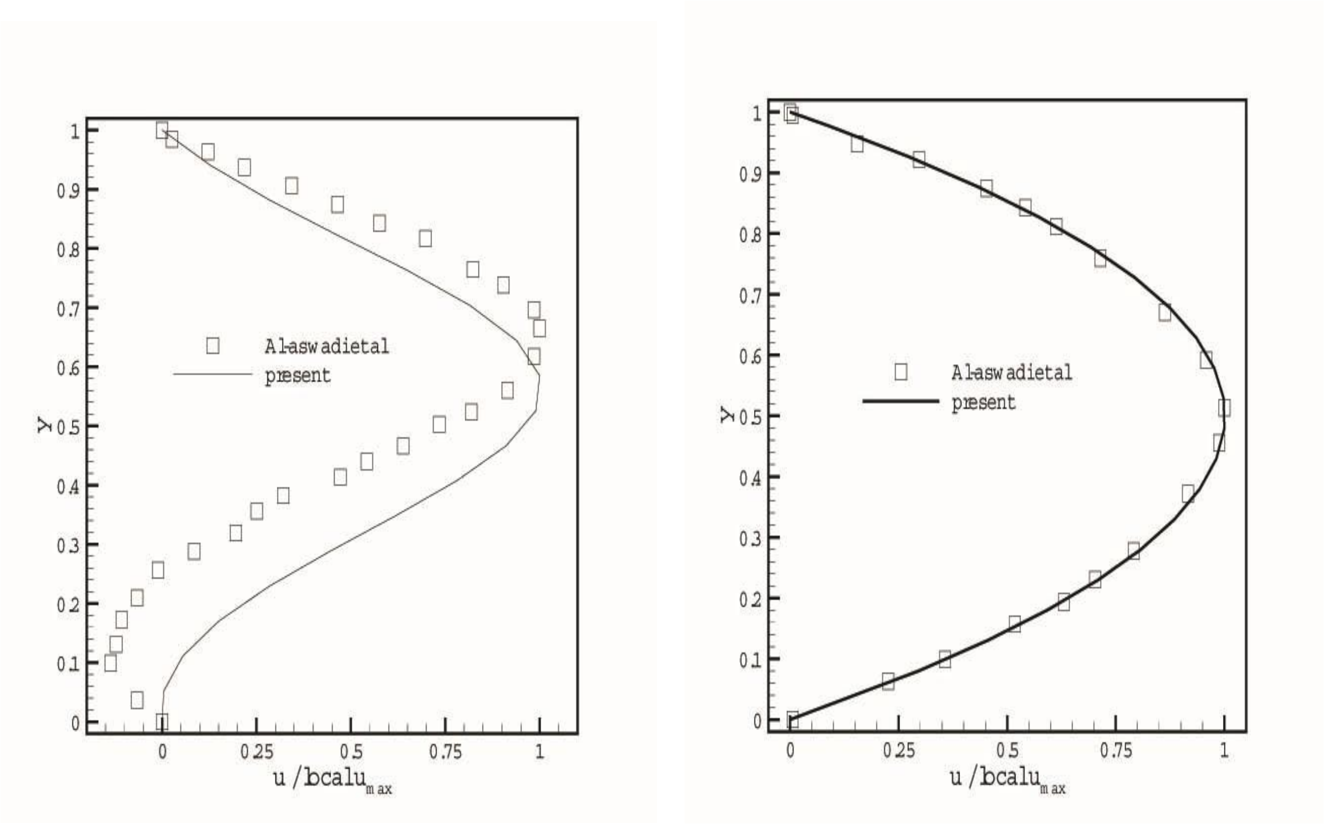


Fig . 2(e) *SiO_2* nano particles [9] Re= 100, **Fig .2(f)** *SiO_2* nano particles [9] Re=100

φ =0.05 and X/s = 2.60 φ =0.05 and X/s = 32.8

Figure 2 : Backward step flow using nano fluid: comparison of present computation with [8] and [9].

φ	Xr1	Xr2
0.0	0.626330	0.594966
0.1	0.579895	0.579895
0.2	0.564146	0.564146
0.5	0.307352	0.307352

Table 2 Bottom wall and top wall reattachment length Al2 O3 nano particles. Re= 70: Effect of volume fraction φ

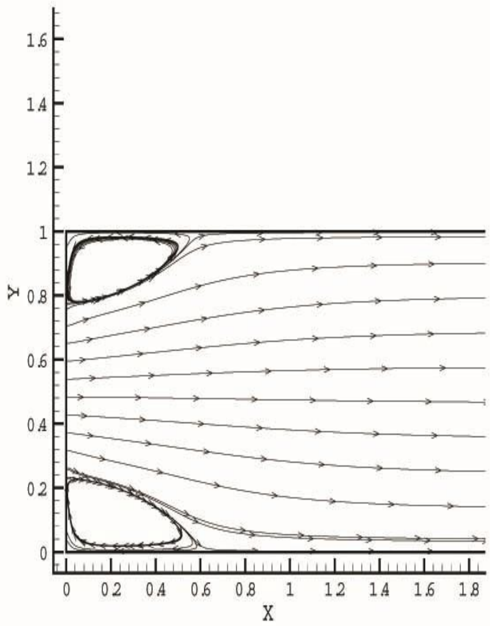


Fig. 3 (a) φ = 0

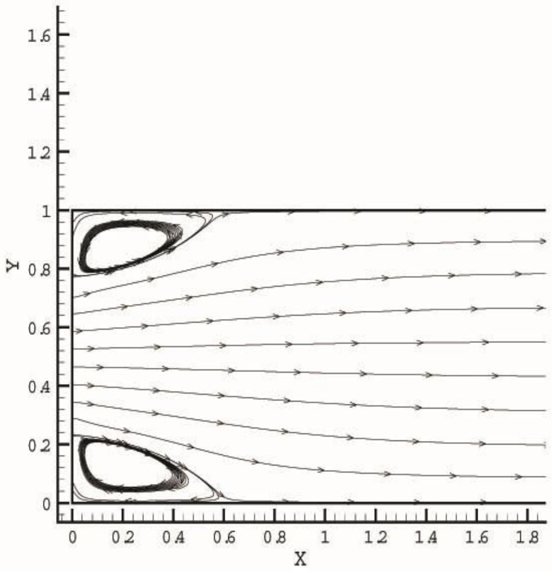
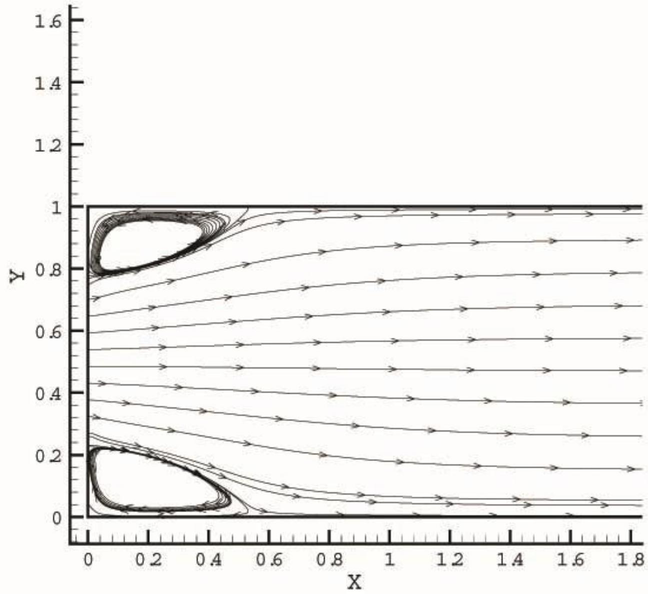


Fig. 3 (b) φ = 0.1



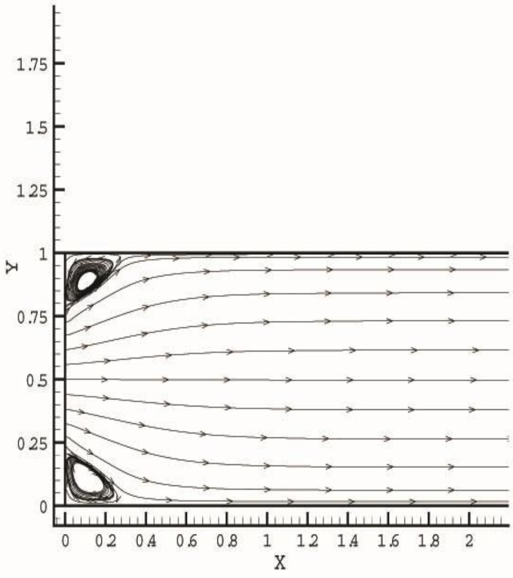
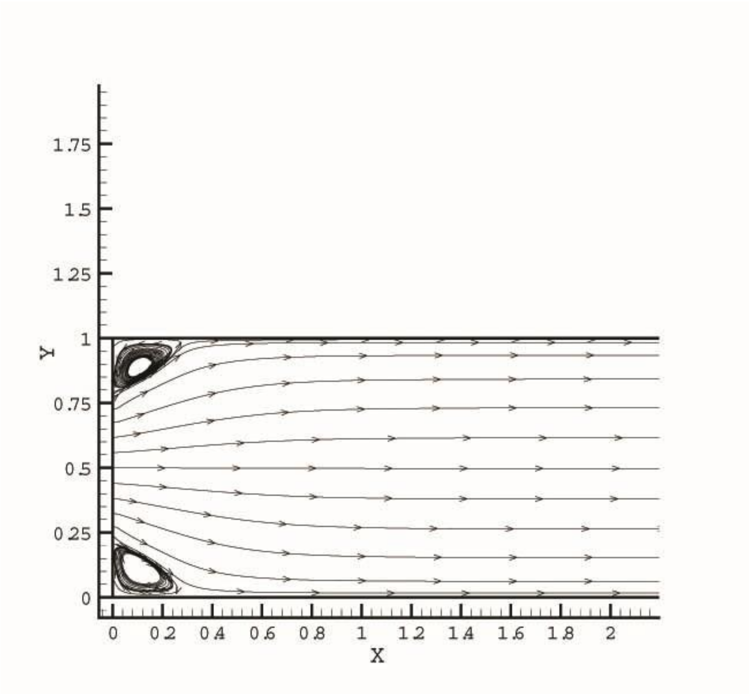


Fig . 3(d) φ = 0.5

Fig .3(c) φ = 0.2

Figure 3 : Sudden expansion flow Al2 O3 nano particles. Re= 70: Effect of volume fraction φ



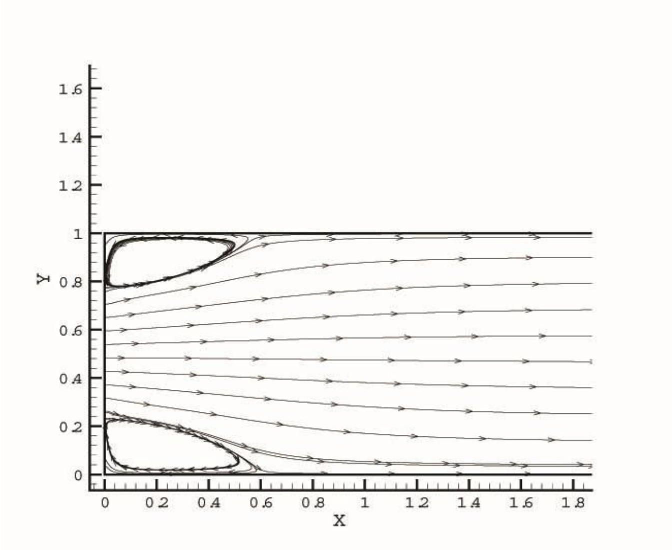
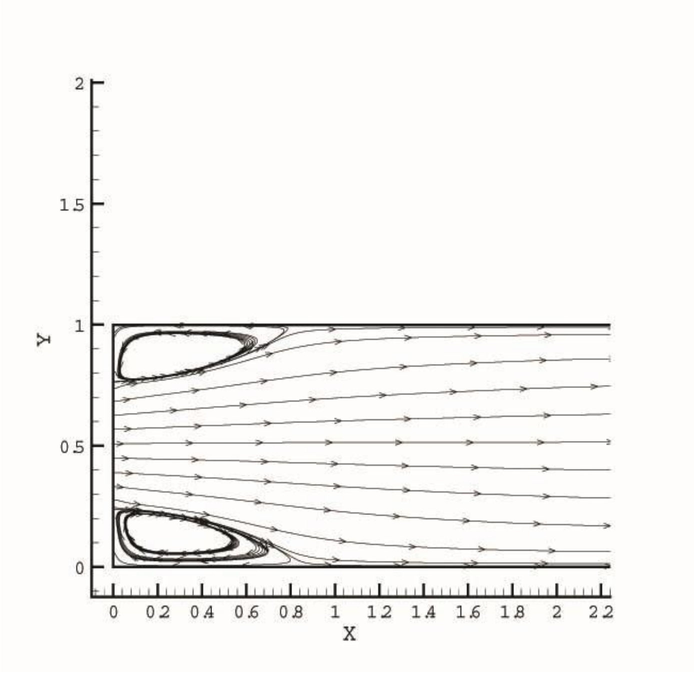


Fig. 4 (a) *Re* = 30

Fig. 4(b) *Re*=70



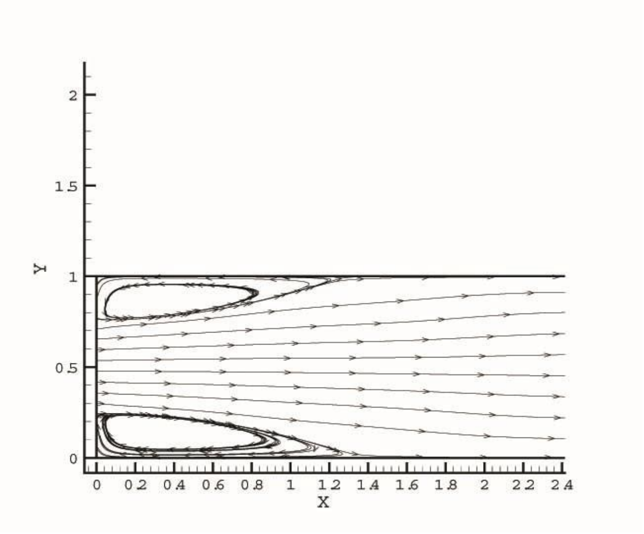


Fig. 4 (c) *Re* = 100

Fig. 4 (d) *Re* =

150

Figure 4 : Sudden expansion flow Al2 O3 nano particles. φ = 0.2: Effect of Reynolds number

4. RESULTS AND DISCUSSION

Two dimensional laminar incompressible flow using nano fluid on sudden expansion is examined to find the effect of Reynolds number and volume fraction. Also different nano particles used to learn their influence on fluid dynamics. Effect of nano materials are tested using viz. Al2 O3, Cu, SiO2 and CuO. The properties of these materials can be found from [8]. Since the flow is restricted as laminar, Re considered for the present study is 30, 70, 100 and 150. Volume fraction φ varies as 0, 0.1, 0.2 and 0.5. Though nano particles are added to enhance heat transfer present study focus to investigate the influence of nano particle in fluid dynamics.

4.1 Flow study

To demonstrate the hydrodynamics of the considered problem, the results are reported as stream- line contour, reattachment length and skin friction coefficient. Results presented for effect of nano particle volume fraction, Re and different nano material. Effect of φ is shown in Figure 3. Flow separates at the corner of the inlet and reattach at the top and bottom walls. Further it spreads downstream and reached fully developed condition at downstream. It is found that when nano particle volume fraction is increased the recirculation eddy size is reduced. It is observed that at zero nano particles condition bottom wall reattachment length, Xr1 is 5% larger than top wall reattachment length (Xr2) (Table 2). Also it is noticed that while increasing φ the asymmetry vortices turns into symmetry nature. Effect of Reynolds number is shown in Figure 4. The fluid behaves similar to zero nano particle fluid in connection with Reynolds number [1] in sudden expansion. The recirculation is linearly increasing while increasing Reynolds number. The symmetry in the flow is lost at Re ≥ 70 (Table 3). Further investigation is required to find the critical Reynolds number for asymmetry flow in connection with expansion ratio and Re.

Re	X_{r1}	X_{r2}
30	0.307352	0.307352
70	0.626330	0.594966
100	0.862983	0.827189
150	1.354193	1.308495

Table 3 Bottom wall and top wall reattachment length Al2 O3 nano particles φ = 0.2: Effect of Reynolds Number

Nano Material	Density , ρ [9]	X_{r1}	X_{r2}
SiO_2	2200	0.445836	0.445836
Al_2O_3	3970	0.579895	0.579895
CuO	6500	0.723911	0.690780
Cu	8933	0.862983	0.827189

Table 4 Bottom wall and top wall reattachment length: Re = 70 and φ = 0.2: Effect of nano Materials

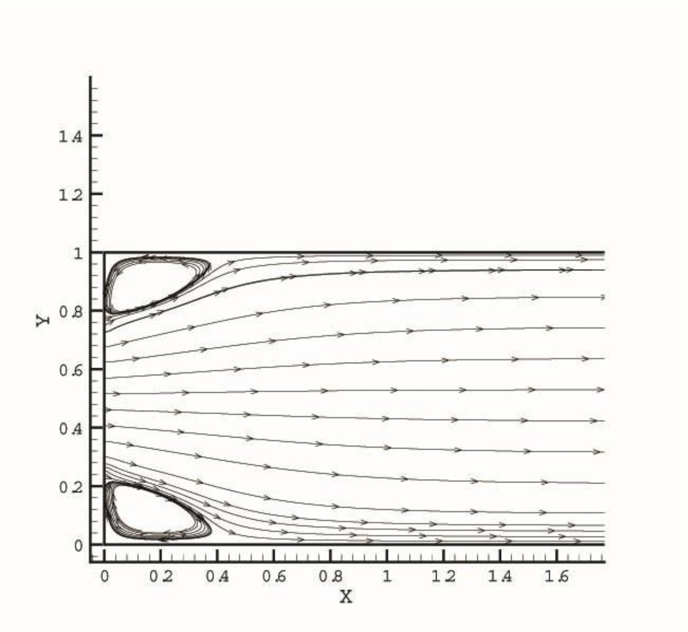


Fig . 5 (a) *SiO_2*

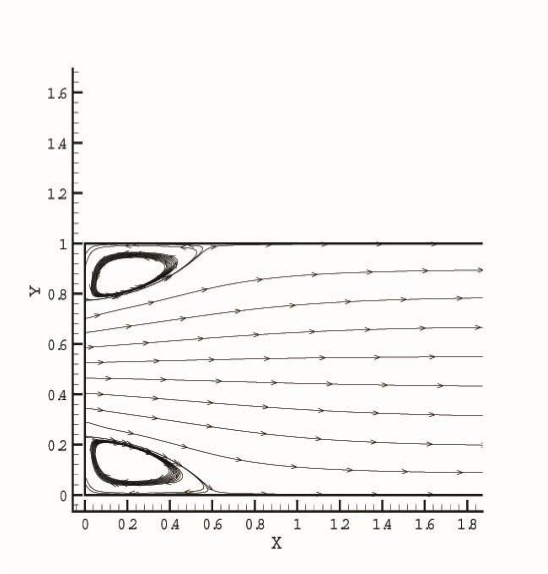


Fig .5(b) *Al_2*

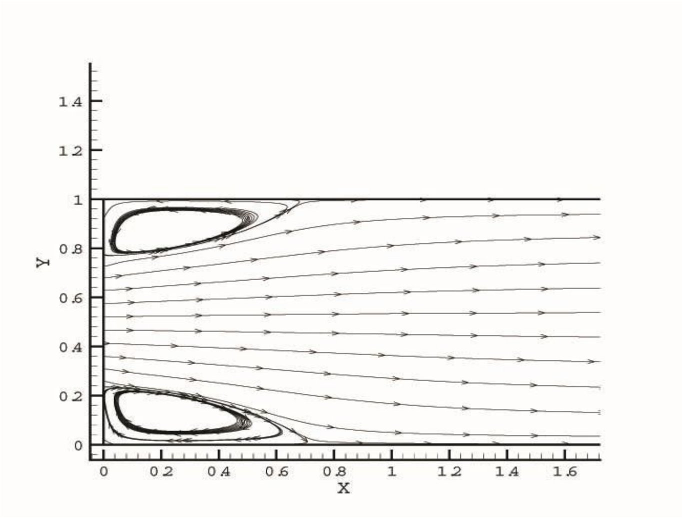


Fig . 5 (d) *Cu*

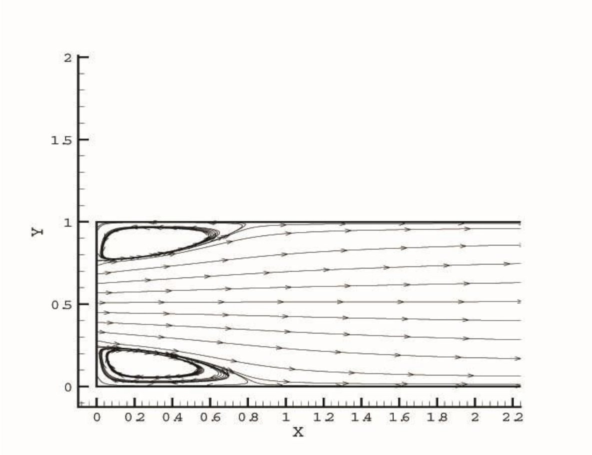


Fig .5 (c) *CuO*

Figure 5: Sudden expansion flow Re = 70 and φ = 0.2: Effect of nano materials

Stream line contour for different nano particle is shown in Figure 5. Four nano particles are considered for the investigation viz. SiO2 , Al2O3 , CuO and Cu. It is found that when higher density material is tested the recirculation eddy size is increasing for the same Reynolds number and volume fraction. It is also observed that the symmetry in the eddy is lost when the Cu based nano particle are used (Table IV). The non dimensional skin friction coefficient (2/Re) is presented in Figure 6. Effect of volume fraction and different nano material are reported for Re =70.

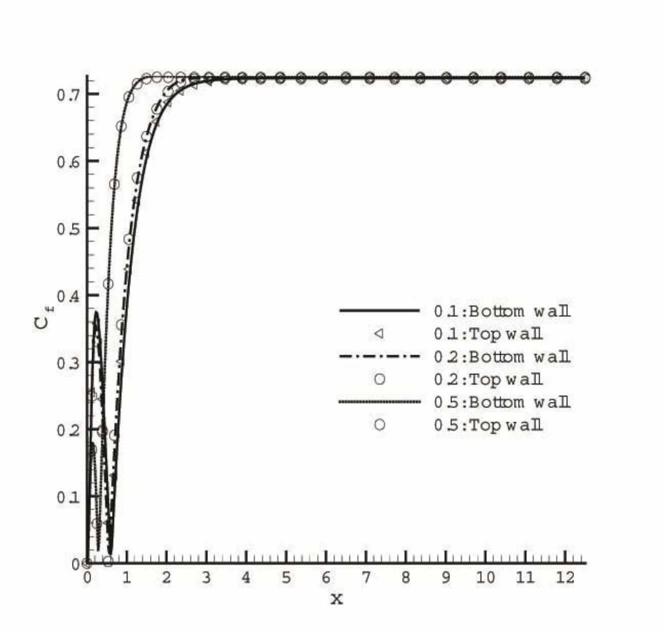


Fig.6 (a) Effect of volume fraction near reattachment

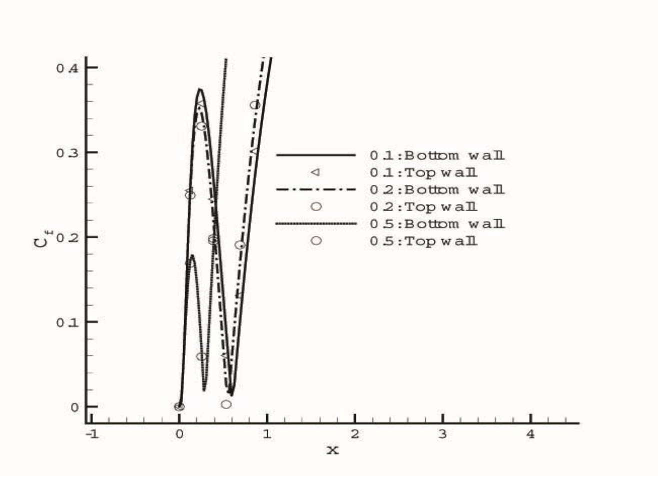


Fig .6(b) Effect of volume fraction (Á):

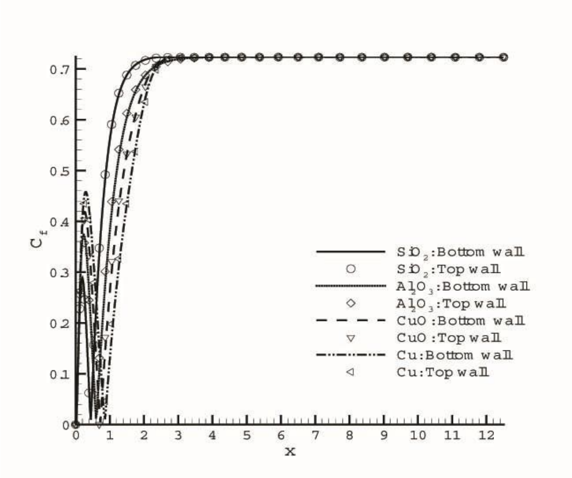


Fig . 6(c) Effect of nano materials

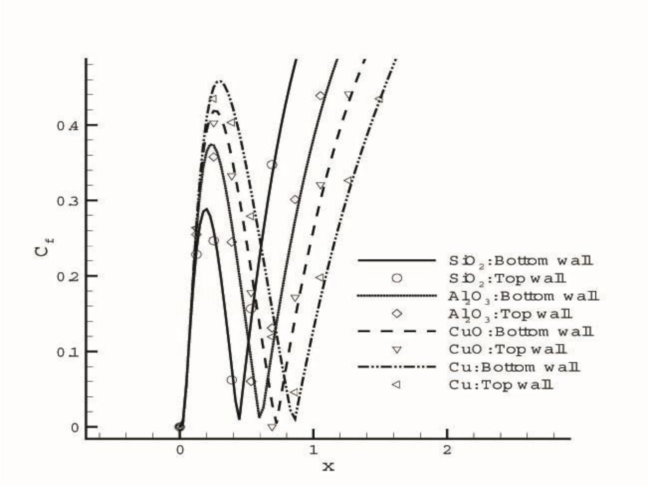


Fig .6 (d) Effect of nano material: near reattachment

Figure 6: Sudden expansion flow Re = 70: Skin friction coefficient (Cf = 2/Re *du/dy)

It is noticed that skin friction co-efficient is increasing to a local maximum value and further it decreases to a minimum value at reattachment location. Further downstream direction it increases non linearly to an asymptotic value (Figure 6). This trend is observed for both bottom wall as well as top wall. It is observed that within recirculation region the first peak Cf value is higher for low volume fraction and be- yond recirculation region in the downstream direction higher volume fraction is reaching greater Cf value (Figure 6(b)). Also it is noticed that in the downstream direction beyond developing length, changes in volume fraction did not influence the Cf . When different nano particles are tested, it is observed that within recirculation region low density material exhibiting low Cf value and beyond recirculation region it reaches high Cf value than higher density material (Figure 6(d)).

5. CONCLUSIONS

Hydrodynamic study of two-dimensional incompressible laminar flow using nano fluid over sudden expansion is reported. The numerical procedure is validated by solving backward step flow. The flow separation, recirculation, skin friction coefficient are presented in connection with nano particle volume fraction and Reynolds number. Four different nano particles are tested. It is found that when volume fraction is increased recirculation eddy size is reduced. The bottom wall and top wall reattachment length is increased linearly while increasing Reynolds number. It is found that the symmetry is lost beyond Re >70. When denser nano material is used the reattachment length is increased. Also it is found that the Xr1 is larger than Xr2. The non dimensional skin friction coefficient values are unique within recirculation region and beyond recirculation region.

Nomenclature

ψ	stream function	$\bar{t}$	dimensional time
φ	volume fraction of nano particle	t	non dimensional time
ρ_s	particle density	$\bar{u}$, $\bar{v}$	dimensional velocity components along x, y axis
ρ_f	fluid density	u, v	dimensionless velocity components along x, y axis
Re	Reynolds Number of the fluid	$\bar{x}$, $\bar{y}$	dimensional Cartesian co-ordinates
		x, y	dimensionless Cartesian co-ordinates

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