COMPARISON OF FLOW CHARACTERISTICS OF SINGLE STEP CONTRACTION NOZZLES AND DOUBLE STEP CONTRACTION NOZZLES FOR CUTTING FLUID DELIVERY SYSTEM

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Abstract

In this paper, numerical analysis has been done to compare the flow characteristics of five different types of nozzles; three different single step contraction nozzles and two different double step contraction nozzles. Three single step contraction nozzles taken are sudden contraction nozzle, concave type modified contraction nozzle and convex type modified contraction nozzle while the double step contraction nozzle considered are sudden contraction nozzle and convex type modified contraction nozzle. The flow characteristics like centerline velocity and wall static pressure has been studied and compared for these different geometries of nozzles. Contraction ratio of 4 has been taken for all the nozzles and the geometry has been considered as two dimensional and axi-symmetric. The flow has been considered as laminar, steady and Newtonian. Reynolds number of 50,100,200 and 400 has been considered for the study. The commercial CFD software Ansys 14.5 has been used to solve the continuity equation and momentum equation. From the study, it has been found that single step contraction nozzle gives maximum centerline velocity at its outlet compared to other four nozzles. This increases the coherent length of jet coming out of the nozzle and the cutting fluid can go deep into the machining zone. Thus, single step contraction nozzle gives more benefit in terms of centerline velocity. The wall static pressure is minimum in case of double step contraction nozzles as compared to other nozzles. Thus, double step contraction nozzle gives benefit in terms of wall static pressure.

***Index Terms*— centerline velocity, contraction ratio, Reynolds number, wall static pressure.**

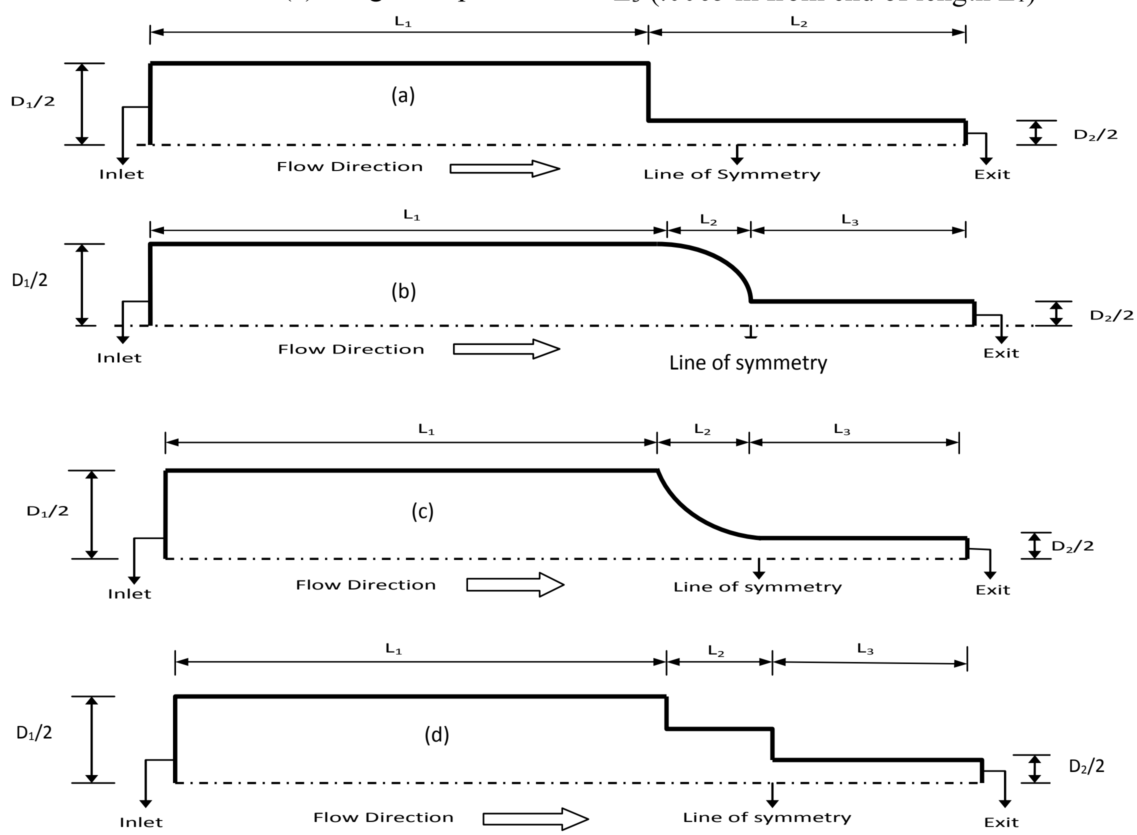
1. INTRODUCTION

Cutting fluid is used for cooling or lubricating the cutting tool and work piece at the point of contact. The application of cutting fluids can improve the tool life and results in good surface finish by reducing thermal distortion. Cutting fluid is delivered through the nozzle which increases the velocity of the cutting fluid at the expense of pressure drop. Proper nozzle geometry helps in enhancing the velocity of cutting fluid considerably. Webster et al. [1] developed a new range of nozzles having high coherency. The inner concave walls of nozzle prevent the growth of boundary layer. This increases the coherent length of the exit cutting fluid. Thus, improves the cutting fluid functions like lubrication and cooling. Results obtained by Li [2] suggest that the temperature in the cutting region can be reduced by increasing the jet flow rate of cooling. The heat transfer coefficient increases with increase in jet flow rate resulting in decrease in the temperature. This helps in reduction of thermal distortion of the tool and the work material resulting in improved surface finish. Ida et al. [3] studied the characteristics of single step contraction nozzle and double step contraction nozzle. They found that two step contraction nozzle produces more uniform high speed flow while the single step contraction nozzle generates non uniform flow. Naha et al. [4] compared the characteristics of fluid passing through sudden contraction nozzle and modified contraction nozzles. They varied the Reynolds number from 100 to 800 and contraction ratio from 2 to 6. Ozalp et al. [5] have performed experiments using Newtonian fluid flowing through an axisymmetrical 4:1 sudden contraction geometry with the help of two techniques namely quantities flow visualization technique and Particle Image Velocimetry (PIV) technique. The result shows that as the Reynolds increases, the velocity vector gets larger and the flow area of faster flowing fluids spread out and get larger. They also found that the velocity increases as the flow gets closer to contraction and the velocity becomes maximum in the middle section just above the contraction.

2 MATHEMATICAL FORMULATIONS

2.1 Computational domain

The schematic two dimensional diagrams for the computational domain for the flow through the five different nozzles-(a) single step sudden contraction nozzle, (b) single step concave type modified contraction nozzle, (c) single step convex type modified contraction nozzle, (d) double step sudden contraction nozzle and (e) double step modified contraction nozzle have been shown in fig. 2(a), 2(b), 2(c), 2(d), 2(e) respectively. Single step geometries have been taken from Naha et al. [4]. The inlet diameter (D_1) of 0.018 m and exit diameter (D_2) of 0.0045 m has been taken for all the nozzles. The distance between the inlet and throat (L_1) has been considered as 0.1 m for all the nozzles. The distance between throat and exit (L_2) has been taken as 0.036 m for single step sudden contraction nozzle .In case of single step convex modified contraction nozzle and single step concave modified contraction nozzle, the radius of the curve of throat section (L_2) and the exit length (L_3) have been chosen as 0.0065 m and 0.0295 m respectively. In case of double step sudden contraction nozzle, two contractions are given; one after length L_1 and second after length L_2 (.0065 m from end of length L_1). In case of double step modified sudden contraction nozzle, two contraction radius of length .00325 m are given; one after length L_1 and other after length L_3 (.0065 m from end of length L_1)



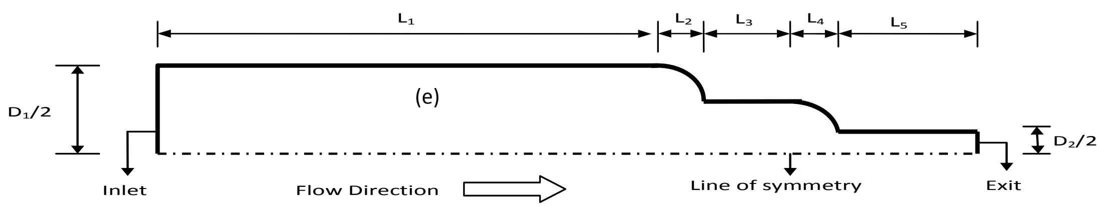


Fig. 1: Schematic 2-D diagrams of the computational domain of (a) Single step sudden contraction nozzle (b) Single step concave type modified contraction nozzle (c) Single step convex type modified sudden contraction nozzle (d) Double step sudden contraction nozzle (e) Double step modified sudden contraction nozzle.

2.2 Governing Equations

The flow has been considered as steady, two-dimensional, symmetric and laminar. The fluid has been considered to be Newtonian and incompressible. The continuity equation and momentum equations in two dimensional forms can be written in the differential form as follows:

Continuity equation:

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

Momentum equation:

$$\rho\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = -\frac{\partial p}{\partial x} + \mu\left[\frac{\partial}{\partial x}\left(\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{\partial u}{\partial y}\right)\right]$$
(2)

$$\rho\left(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right) = -\frac{\partial p}{\partial y} + \mu\left[\frac{\partial}{\partial x}\left(\frac{\partial v}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{\partial v}{\partial y}\right)\right]$$
(3)

2.3 Boundary Conditions

Three different types of boundary conditions have been taken. No slip condition has been taken at the wall. So the velocity component in x- direction and y-direction at the wall becomes zero. Axial velocity has been specified at the inlet and transverse velocity has been taken as zero. Constant pressure boundary has been taken at the exit.

2.4 Numerical Procedure

The geometric configurations, meshing of the computational domain and the solution of continuity and momentum equations have been done in commercial software Ansys Workbench 14.5. Non uniform grids with mesh volume 42140 have been taken. The second order upwind scheme has been considered for the computational analysis. Water having properties of density ρ = 998.2 kg/m^3, viscosity μ = 1.003×10^{-3} kg/m.s been taken as the working fluid.

3. RESULTS AND DISCUSSION

3.1 Validation

The numerical result obtained in this work has been validated with the experimental work carried out by Ozalp [5]. For the validation purpose, the velocities of different locations in y-direction just before the contraction region have been taken at the distance of 98 mm in x-direction from inlet.

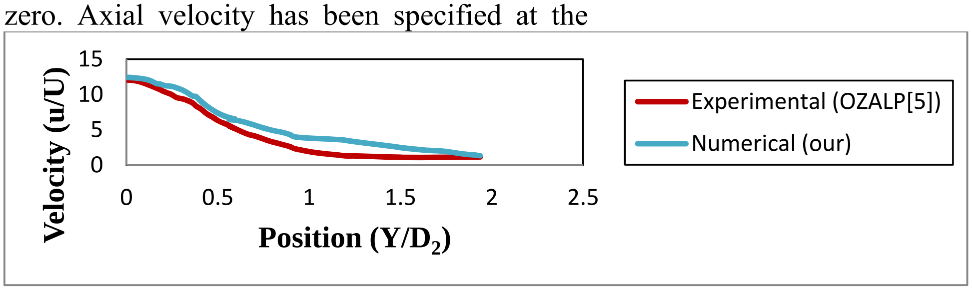
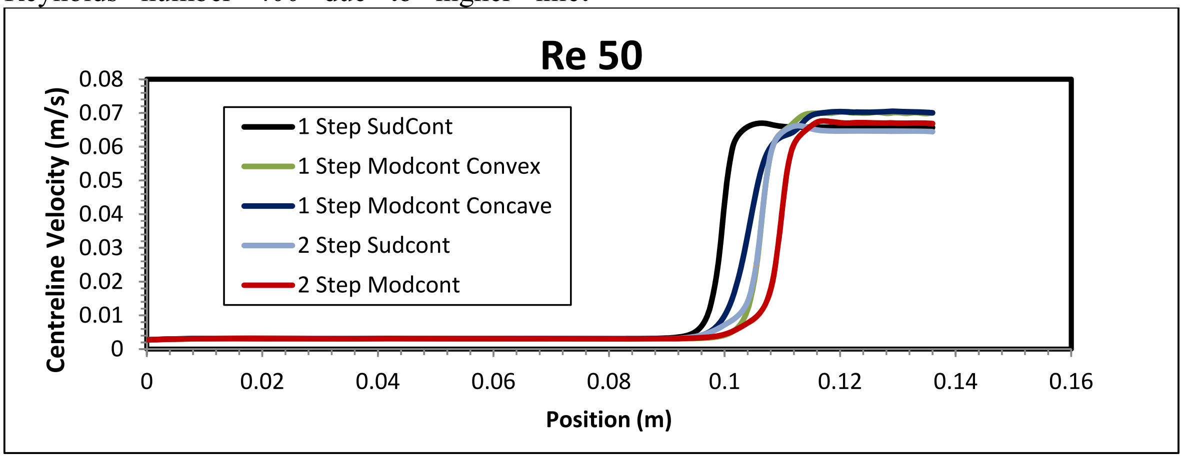


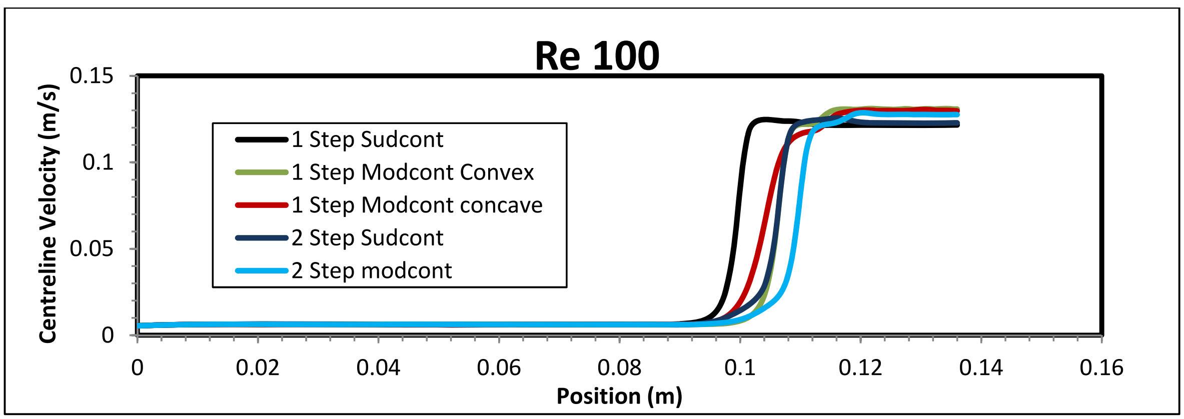
Fig. 2 Comparison of the Velocity Ratio of Numerical Data with Experimental Data

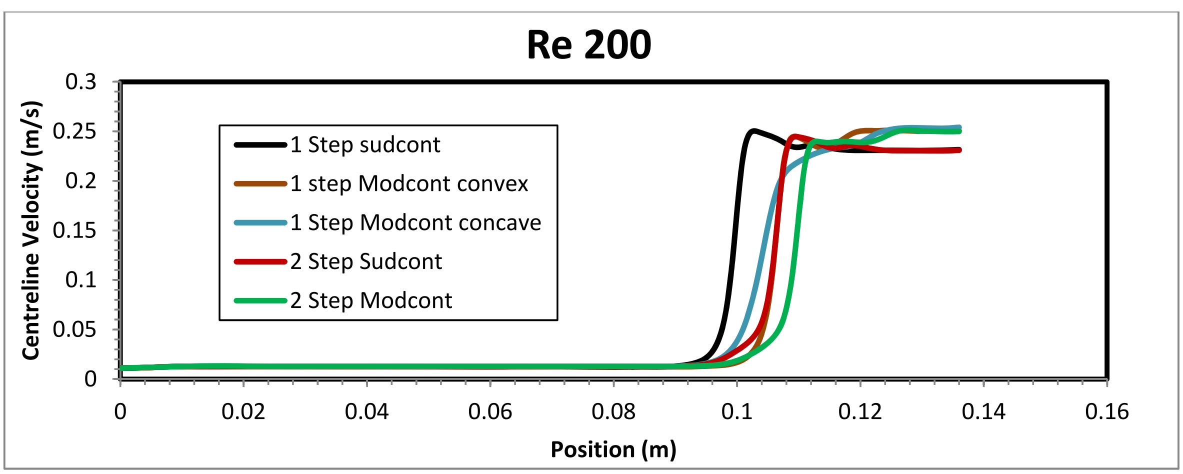
It has been seen from the comparison that the difference between the experimental value and the numerical value is very less and within the range of margin of error. Thus, the numerical work that has been carried out is close to the actual value obtained by the experiment carried by Ozalp[5].

3.2 Comparison of centerline velocity

From the figures, it has been observed that the centerline flow velocity remains almost same up to throat region for all the five nozzles. At the throat region, the velocity shoots up and there is steep rise in centerline velocity due to contraction. After the throat region, there is no significant change in centerline velocity in case of Reynolds number 50,100 and 200 while there is some rise in centerline velocity in case of Reynolds number 400 due to higher inlet velocity because of which flow is not able to gain fully developed flow after the throat region.. It is also observed that in case of Reynolds number 50,100 and 200, the velocity rise is higher in one step convex type modified contraction nozzle than in one step sudden contraction. Also the velocity in one step convex type modified contraction nozzle is higher than that in double step sudden contraction nozzle and double step modified sudden contraction nozzle. In case of Reynolds number 400, the flow velocity is highest achieved in the single step sudden contraction nozzle







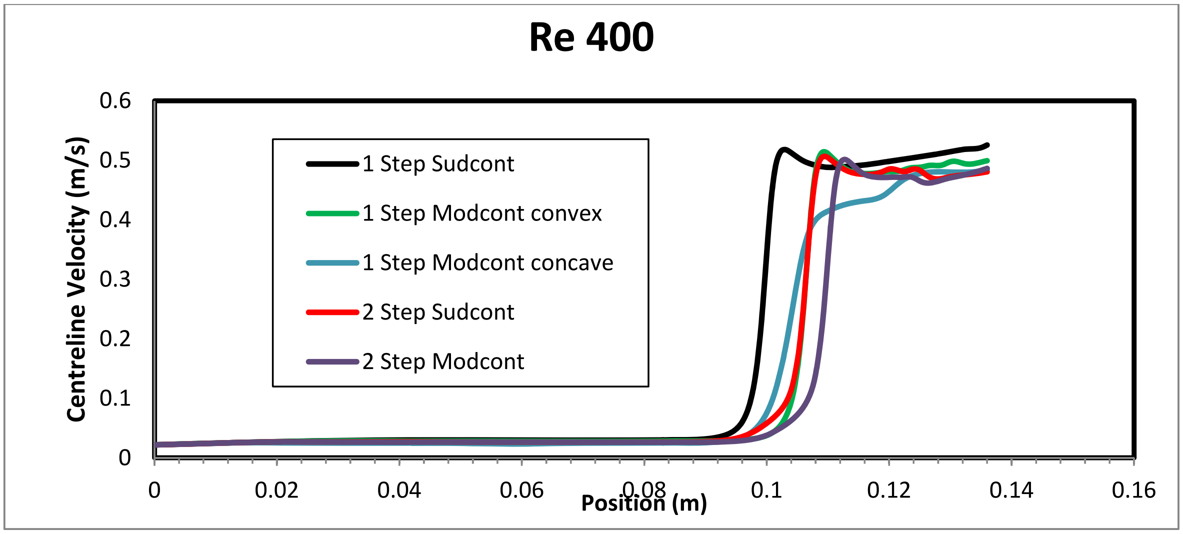
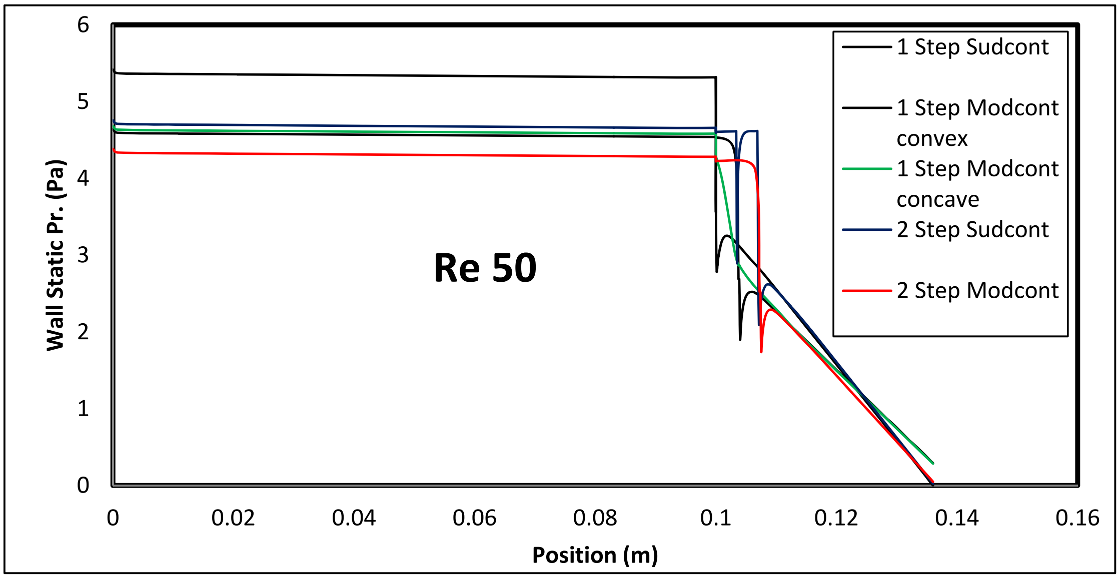


Fig 3: Comparison of centerline velocities of different geometries of nozzles for Reynolds number of 50,100,200 and 400.

3.3 Comparison of Wall static pressure

It has been observed from the figures that the wall static pressure have similar nature for all the Reynolds number and for all the types of nozzles considered. The wall static pressure remains same up to the throat section, then it exhibits a sudden drop at the throat section and then it falls linearly throughout the exit length for these five nozzles. Also it is observed that in case of Reynolds number 200 and 400, the pressure falls below atmospheric pressure which shows that some region of vacuum gets created near the throat. This is due to the vena- contracta formed just after the throat region. It is also observed that the single step sudden contraction nozzle has the maximum wall static pressure for all the Reynolds number. The minimum wall pressure is observed in double step modified contraction in case of low Reynolds number of 50,100 and 200 while for high Reynolds number of 400, minimum wall static pressure is observed in single step concave type modified contraction nozzle.



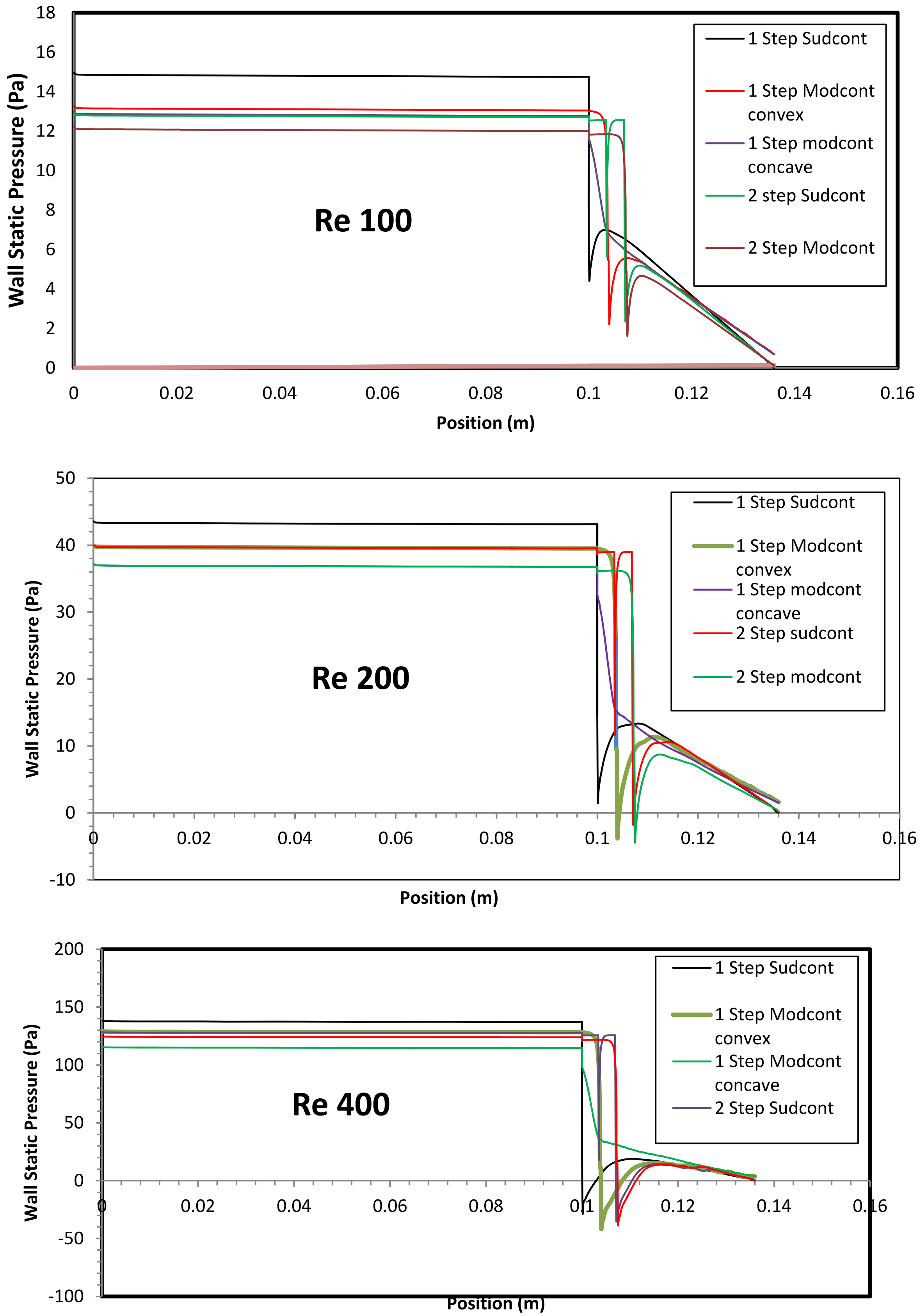


Fig.4: Comparison of wall static pressure of different geometries of nozzles for Reynolds number of 50,100,200 and 400.

4. CONCLUSIONS

1) It has been found from the results that single step modified contraction nozzles give maximum velocity at the outlet of the nozzle for low Reynolds number of 50 and 100.
2) For higher Reynolds number, single step sudden contraction nozzle gives maximum velocity at the outlet of the nozzle.
3) Double step modified contraction nozzle has minimum wall static pressure for all the Reynolds number considered while single step sudden contraction nozzle has maximum wall static pressure.
4) Single step contraction nozzles give benefit in centerline velocity while double step contraction nozzle gives benefit in wall static pressure.

5. NOMENCLATURE

Symbol	Meaning	Units
D_1	Inlet diameter of the nozzle	m
D_2	Outlet diameter of the nozzle	m
Re	Reynolds number	_
u, v	Velocity components in x and y direction,	m/sec
U	Inlet Velocity in x- direction	m/sec
μ	Dynamic viscosity.	kg/m.s
p	Static pressure	N/m^2
CR	Contraction ratio	_
ρ	Density	Kg/m^3
Y	Distance from axis in y- direction	m

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