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Simulation on Flow of Cutting Fluid having laminar characteristics through a Sudden Contraction Nozzle

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ABSTRACT: *In this work, the performance of a cutting fluid flow through a sudden contraction nozzle has been analysed. The flow has been considered to be laminar and the cutting fluid has been taken as water. The Nevier-Stokes equation and the continuity equation are solved by using finite volume base upwind scheme for different Reynolds Numbers and for a fixed aspect ratio. Computations have been done with respect to wall shear stress, wall static pressure and stream line contours for a sudden contraction nozzle with aspect ratio (A.R=0.28). In case of nozzle from the metallurgical point of view wall shear stress, wall static pressure and stream line contours have a great importance. The numerical result has been shown in details and discussion sections by using ANSYS FLUENT.*

Keywords: *Streamline contours, wall shear stress, wall static pressure, Reynolds number & aspect ratio*

I. Introduction

Fluid flow analysis through a nozzle is an attractive, demanding and important, research area for many researchers. In this case the flow of a cutting fluid through a sudden contraction nozzle has been analysed. Cutting fluid is any liquid or gas that is applied to work tool interface to assist in the cutting operation. Cutting fluid is used as a coolant and lubricant for metal cutting and machining processes. There are various kinds of cutting fluids such as oils, oil-water emulsions, pastes, gels, aerosols (mists), and air or other gases. In this work water is used as a cutting fluid. Historically, water was used mainly as a coolant due to its high thermal capacity and availability. The use of cutting fluid permits higher cutting speeds, higher feed rates, greater depths of cut, lengthened tool life, decreased surface roughness, increased dimensional accuracy and reduced power consumption which are some of the goals of conventional machining.

II. Literature Review

Patankar *et al* [1980] has used finite volume method for control volume discretization. The entire computational domain is divided into a number of control volumes, so that each node is surrounded by a control volume. Carrying on the the integration for all differential equations, the equations for a set of nodes are obtained. The discrete equation on the control volume for the dependent variables in then obtained. Astakhov *et al* [1994] have investigated the coolant flow through the inlet annular channels of self-piloting drills and done an experiment to determine the drill design parameters on the flow parameters. They have examined the influence of inlet channel's clearance, eccentricity on the pressure distribution and energy loss analytically. Webster *et al* [1995] have analysed the limitations of current application system and used fluid mechanics to develop flow. Li [1996] has analysed the effect of jet flow rate on cooling in machining and examined the jet flow rate of cooling on temperature distribution in the cutting region through numerical simulation of machining with cooling at different flow rates. Hammad *et al* [1996] have numerically studied the flow characteristics through axisymmetric sudden contraction nozzle that optimizes the characteristics of the jet. Man *et al* [1997] have presented a new method for the design of supersonic nozzle tip for high gas pressure laser cutting. Man *et al* [1998] have described how a coaxial and high pressure inert gas jet is used to improve the cut edge quality during laser cutting of stainless steels, titanium and aluminium alloys. They have found that the process consumes a large quantity of inert gas and has a poor tolerance to variation in process parameters.

II. 2 Boundary Conditions

Three different types of boundary conditions have been applied to the present problem. They are as follows,
i. At the walls: No slip condition, i.e. $u_z = 0$, $u_r = 0$.
ii. At the inlet: Axial velocity has been specified and the transverse velocity has been set to zero,
i.e. u_z = specified, $u_r = 0$.
iii. At the exit: Constant pressure has been specified.

II. 3 Numerical Procedure

The dimensional partial differential continuity and momentum equations have been solved according to the SIMPLE method in the finite volume formulation by use of a uniform grid in both coordinating directions. The convection terms have been discretized with the help of upwind scheme. Laminar model has been selected for simulation. For all calculations, the length, inlet and exit diameter of the nozzle is considered to be 136mm, 18mm and 5mm respectively. During computation, the numerical mesh is considered to be comprising of 2312 grid nodes. For this simulation Prandtl number can be considered constant. For this problem the value of μ, ρ and C_p is equal to 0.001003kg/m-s, 998.2 kg/m^3 and 4182 J/KgK respectively. The convergence of the iterative scheme is achieved when the normal residuals of mass and momentum equations summed over the entire calculation domain fall below 10^{-5}.The non-dimensional parameters, which have been considered in this work, are

Reynolds number, Re = $\frac{\rho w u}{\mu}$

Prandtl number, Pr = $\frac{\mu c_p}{k}$

III. Indentations and Equations

Assumptions:

It is assumed that the flow under consideration is steady, two-dimensional, laminar and axisymmetric. Here the fluid has been taken as water which is incompressible and Newtonian. The density of water is taken as (ρ)=998.2 kg/m and dynamic viscosity (μ)=0.001003 kg/ms. In this studies the dimensional velocity components and the pressures are governed by the mass and momentum conservation equations. For the laminar flow in the nozzle the dimensional governing equations along the x, y directions are as follows:

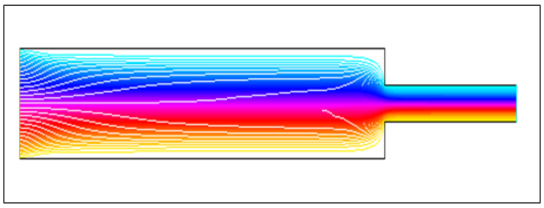
$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \text{ - }(1)$$

$$\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{\mu}{\rho}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \text{ - }(2)$$

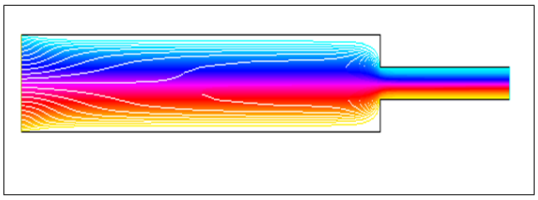
$$\rho\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\frac{\mu}{\rho}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \text{ - }(3)$$

Where, u_r is velocity in radial direction, u_z is the velocity in axial direction, p is pressure, ρ is density, μ is the coefficient of dynamic viscosity.

IV. Figures and Tables



Reynolds Number (Re) = 100



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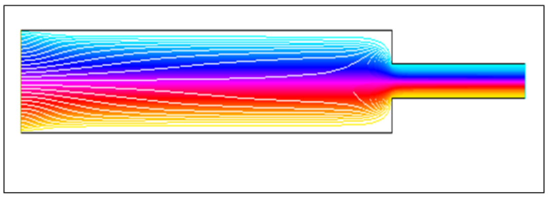
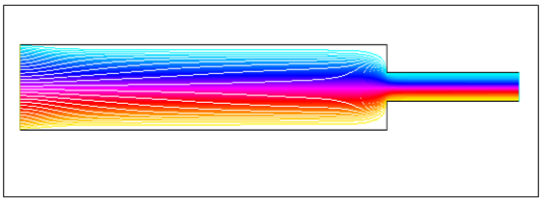
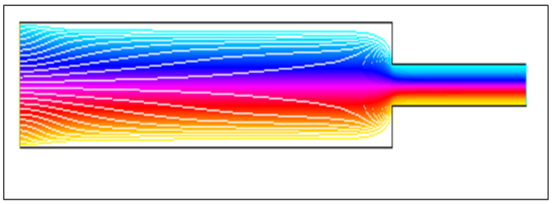


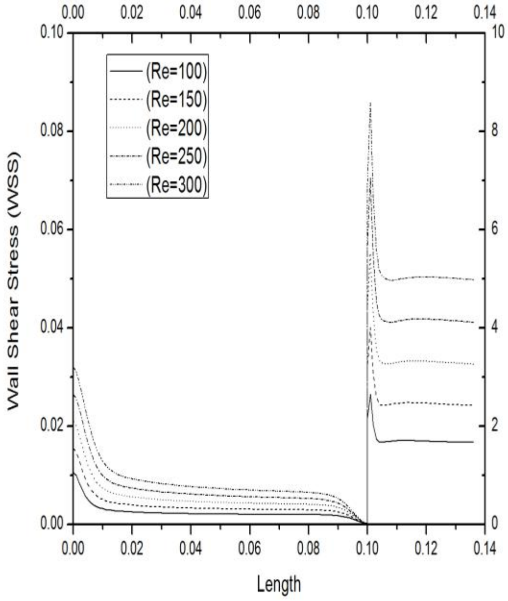
Reynolds Number (Re) = 200



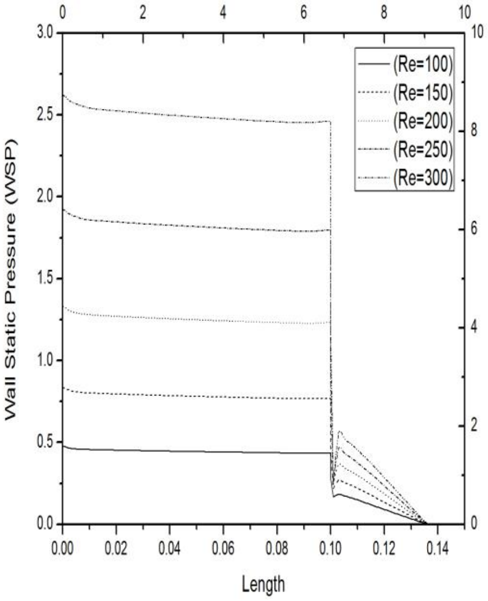
Reynolds Number (Re) = 250



Reynolds Number (Re) = 300



Variation of Wall Shear Stress (WSS)
for different Reynolds Number (Re) (A.R=0.28)



Variation of Wall Static Pressure (WSP)
for different Reynolds Number (Re) (A.R=0.28)

V. Conclusion

In the present study, the laminar flow characteristics of a water based cutting fluid flowing through a nozzle with aspect ratio (A.R.=0.28) while considering Reynolds Number ranging from 100 to 300 has been carried out. The effect of Reynolds number on wall shear stress (WSS), wall static pressure (WSP), stream line contours and the formation of recirculation bubble have been studied in details. The effect of important parameters likes Reynolds number (Re) and contraction ratio (CR) have also been investigated and this leads to the following conclusions:

i. The wall shear stress (WSS) of the sudden contraction configuration drops uniformly from the inlet and at the throat it becomes minimum. After the throat region it increases rapidly and reaches a maximum value. Then there is a gradual decrease till the end of the nozzle. It has been observed that the wall shear stresses increases with increasing Reynolds number. Less stress exerted on the wall implies more longevity of the nozzle.

ii. The wall static pressure (WSP) of the sudden contraction configuration drops uniformly till the throat region. At the throat region there is a sudden fall and reaches a minimum value. After that there is a slight rise followed by a gradual decrease till the end of the nozzle. It has been observed that the wall static pressure increases with increasing Reynolds number. Less pressure exerted on the wall implies more longevity of the nozzle.

iii. Streamline Contours have been observed for different Reynolds number (100-300) which shows the clear pictures generating flow net at the contraction zone. Recirculation bubbles are formed at the area of contraction. From the all the contours, it is revealed that the flow is appreciably affected with the increase of Reynolds no.

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