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Effect of Abrasive on Water Jet Nozzle

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Abstract - *Water Jet nozzle is subjected to abrasive and erosive modes of wear. The initially coherent water jet breaks into droplets that accelerate the solid particles. When the jet stream first enters the nozzle, the abrasive trajectories are different from those of the fluid motion and the abrasive hits the entrance section of the nozzle at random angles.*

This form of wear is called the erosion impact wear mode. A second mechanism corresponds to hydrodynamic drag forces imposed by the water phase on the solid particles. As a result of momentum transfer between the water and abrasives, a focused, high velocity stream of abrasive passing through the nozzle will wear the nozzle itself. Once the jet stream advances through the nozzle, erosive particles travel parallel to it.

During this movement the particles cause abrasive or shallow impact erosion of the wall. This form of wear is called the sliding erosion wear mode. Automated equipment must have the ability to detect nozzle wear early before final results exceed acceptable limits. However, currently there is no reliable wears ensuring system available. A number of approach have been investigated.

Key Words: Nozzle, Wear, Abrasive water Jet.

1. INTRODUCTION

Abrasive water jet (AWJ) machining process utilized increasingly in industrial applications. It is a nontraditional machining process and involves complex mechanics. A nozzle is required to perform abrasive water jet machining for material removal with the help of very high velocity of water suspension jet. The main problem of AWJ machining process is nozzle wear during the process.

1.1 Navier–Stokes equations

The wear depends on various parameters such as water jet characteristics, abrasive size and nozzle geometry, etc. The uncontrolled nozzle wear can affect the effectiveness and surface finish obtained through the AWJ machining process. In the present work, the effect of geometrical parameters of single step nozzle and abrasive size on skin friction coefficient at the wall of nozzle due to wall shear stress and jet exit kinetic energy has been analyzed by ANSYS software. This analysis is totally depends on nozzle geometry and nozzle material is taken same for all cases. This analysis can be highly helpful for understanding nozzle wear during the AWJ machining process.

The Navier–Stokes equations dictate not position but rather velocity. A solution of the Navier–Stokes equations is called a velocity field or flow field, which is a description of the velocity of the fluid at a given point in space and time. Once the velocity field is solved for, other quantities of interest (such as flow rate or drag force) may be found.

1.2 Mass and Energy conservation

The derivation of the Navier–Stokes equations begins with an application of Newton's second law, conservation of momentum.

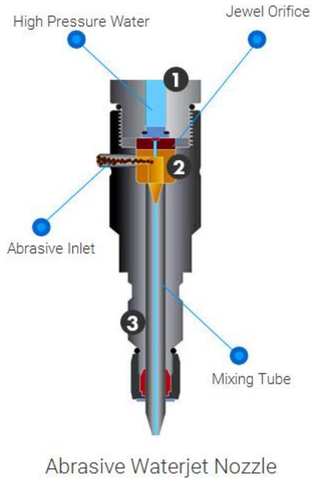

Fig -1: Abrasive Water Jet Nozzle

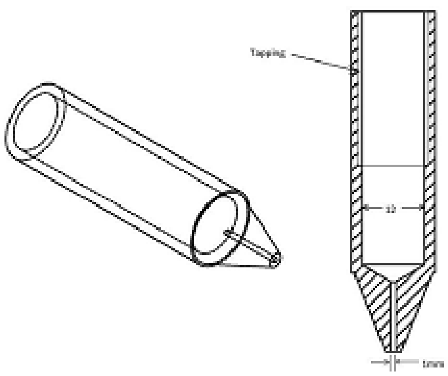

Fig -2: Water jet Cutting Head

Where v is the flow velocity, ρ is the fluid density, p is the pressure, is the (deviatoric) stress tensor and represents body forces (per unit volume) acting on the fluid and is the del operator.

2. Forces acting on nozzle

The resultant force acting on the control volume consists of three parts [1],

a) The force exerted on the inlet cross-section,
b) Outlet cross-section of the control volume and The force exerted by the pipeline.

So the resultant force can also be expressed as:

$$F = \int_{A_{in}} p_{in} n dA_{in} = \int_{A_{in}} -p_{in} n dA_{in} + \int_{A_{out}} p_{out} n dA_{out} \quad \ldots (3)$$

Where A_{in} and A_{out} are the inlet and outlet section area of system pipeline respectively,

p_{in} and p_{out} are the pressure acting on A_{in} and A_{out}, respectively.

According to Eqs (1) to (3), considering the motion direction to be positive, the reverse thrust can be written as:

$$F_j = m\,(v_{in} - v_{out}) + \int_{A_{out}} p_{out} n dA_{out} + \int_{A_{in}} p_{in} n dA_{in} \quad \ldots (4)$$

As the pressure and velocity on inlet cross-section is small, its effect on reverse thrust can be disregarded. Therefore, Eq. (4) can be simplified as follows.

$$F_j = -m\, v_{out} + \int_{A_{out}} p_{out} n dA_{out} \quad \ldots (5)$$

Where $-m\, v_{out}$ can be defined as momentum thrust while $\int_{A_{out}} p_{out} n dA_{out}$ is defined as pressure thrust.

Substituting the outlet velocity v_{out} and the pressure on outlet cross-section p_{out} into Eq. (5), the reverse thrust can be calculated.

MODELING TURBULENT VISCOSITY

Turbulent viscosity is modeled as:

$$\mu_t = \rho C_\mu \frac{k^2}{\epsilon}$$

PRODUCTION OF K

$$P_k = -\rho \overline{u_i' u_j'} \frac{\partial u_j}{\partial x_i}$$

$$P_k = \mu_t S^2$$

Where is S the modulus of the mean rate-of-strain tensor defined as,

$$S \equiv \sqrt{2 S_{ij} S_{ij}}$$

OTHER MODELS

- Realizable k-epsilon model
- RNG k-epsilon model
- Near-wall treatment

By Continuity Equation

$Q = V_N \pi d^2{}_N / 4$

The nozzle diameter as

$d_N = \sqrt{4 \times 0.15 / 18.9 / \pi}$ = 0.10 m.

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Table -1: Operating parameters.

Parameters	Operating Range
Stand – off distance (mm)	4
Type and size of abrasive	Garnet, #80 mesh
Diameter of orifice (mm)	Φ 0.7
Number of passes	1
Water pressure (MPa)	100, 170, 240
Abrasive flow rate(kg/min)	0.07, 0.11, 0.33
Jet traverse rate (mm/min)	30, 90, 150

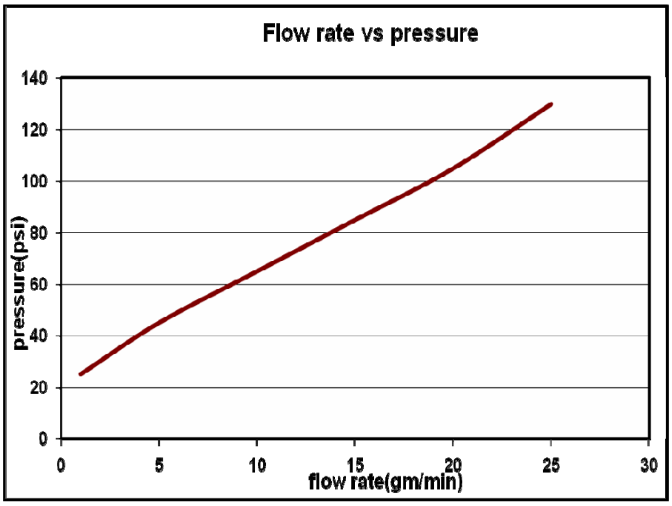

Fig -3: Graph of Variation of Flow rate with Air Pressure

Table -1: Variation of Flow rate with Air Pressure in PSI

Abrasive Flow rate(gm/min)	Air Pressure (psi)
1	25
5	45
10	65
15	85
20	105
25	130

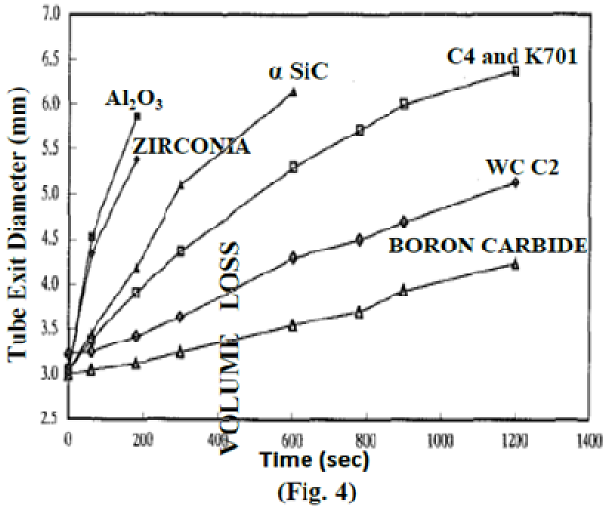

Fig -4: Friction loss and Volume loss.

3. RESULTS

The Problem had been analyzed in the fluent software and the velocity vectors, velocity contours, wear of nozzle dissipation rate has been tabulated. From figures we can analyze that for increase in pressure more number of particles is entering nozzle and there is formation of eddies in the nozzle. And not a lot of particles are moving out of nozzle as expected, some of them are again retained inside nozzle[3] itself. But due to formation of such eddies large amount of energy is created for large pressure gradients inside nozzle which will help increasing outlet velocity.

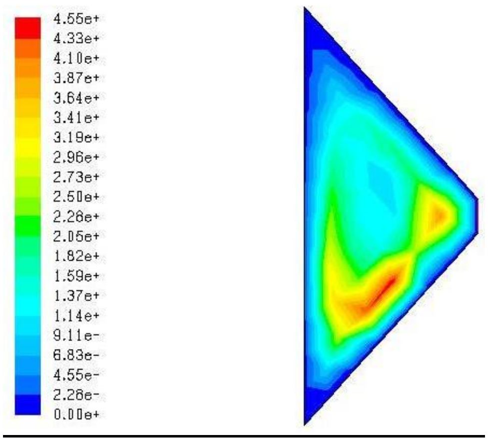

Fig -5: Counter of Velocity magnitude in m/s for Air pressure 4 Kg/cm2

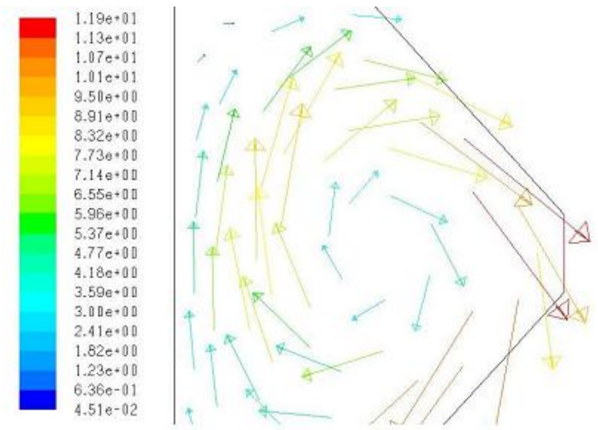

Fig -6: Velocity Vector in Contour nozzle for 4 Kg/cm2

Abrasive as seen from the figure vectors are again hitting the wall and moving inside the nozzle increase in outer diameter will result in better output but we have to sacrifice certain velocity for it.

4. CONCLUSIONS

Effect of the abrasive on different variables was investigated under steady state Flow visualizations, velocity were analyzed and were applied practically for accuracy of measurement. From the results of flow visualization we can judge that there is need to strike balance between Diameter of Nozzle and pressure and material removal rate as after certain wear of nozzle system.

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