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Computational analysis of Abrasive Water Suspension Jet with Impact of Inlet Operating Pressure, Exit Kinetic Energy and Volume Fraction

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ABSTRACT: Abrasive water suspension jet (AWSJ) is one of classified version of abrasive water jet machining which have higher power density with stabilized jet. It is an advanced manufacturing method wide been used in modern industries for machining components having complex shapes that that require to be generated from brittle and heat-sensitive materials in addition to composites. Abrasive particle in suspension mixture leads to significant skin friction which adversely affects the jet diameter due to wear and which extensively impact the jet exit kinetic energy. However, this lowers life of jet in order to get effective machining.
In concern to this aspect, the present work AWSJ has been examined using computational tool ANSYS fluent. In which impact of impact of inlet operating Pressure, exit kinetic energy and volume fraction has been investigated. From the analysis it has been found that the rate of skin friction coefficient marginally increases as inlet pressure increases which proportionally increases the exit kinetic energy of the jet. Moreover, it is interesting to know that by increasing volume fraction the skin friction coefficient and the jet exit kinetic energy can significantly been decreased.
KEYWORDS : AWSJ; kinetic energy; skin friction coefficient; operating pressure

I. INTRODUCTION

From the past decades, in the field of non-traditional conventional machining enormous development have been taken place with increase in engineering applications. Advancement in material technology in-deeds to optimize the machining method and technology, therefore sophisticated methods has been practiced via computational approach. For cutting ductile, brittle, alloyed or even composite material various machining technologies are available, among these cutting material using liquid jet is the most promising technique. High speed of water stream flowing out including abrasives makes it feasible to machine many industrial materials such as wood, paper, plastic, paperboard, building materials, rocks and also metals and their alloys. Abrasive water-jet (AWJ) has categories in various types depending upon the mode of operation, flow condition i.e. single phase, double phase, or multi-phase, application, etc. however, the studies of abrasive waterjet (AWJ) parameters on the depth and quality of produced cuts are still needs to improve and bridging of research gap should be undertaken

II. LITERATURE REVIEW

(Venkatesh (1984), has reported for the effect of feed rate, pressure, abrasive grit size, spray angle, nozzle tip to work distance, and metal removal rate. Ordinary, optical and toughened glasses were machined and the advantages and limitations of abrasive jet machining are highlighted.

Ramachandran and Ramakrishnan (1993) have given a comprehensive review of work done in the field of AJM and complex analytical findings that have been made were highlighted. The considerable scope for research and the implementing of it for commercial purposes were also pointed out.

An attempt has been done (Choi and Choi, 1997) to develop an analytical model for material removal in AWJM of brittle materials. The size of fracture for the backside of the workpiece has been predicted as the jet passes through the workpiece. The material removal mechanism in the abrasive water jet machining of polycrystalline ceramics has been addressed by Paul et al. (1998). The proposed mechanism was seemed to be micro-cutting and inter-granular fracture at shallow angles of impact.

Chen and Siores (2003) investigated for the characteristics of various materials cut surface by using a scanning electron microscope. In this investigation the effect of abrasive particle distribution in the jet on striation formation has been detailed

Computational fluid dynamics (CFD) models for ultrahigh velocity waterjets and abrasive waterjets (AWJs) have been established (Liu et al. 2004) by using Fluent6 flow solver. Jet dynamic characteristics for the flow downstream from a very fine nozzle were then simulated under steady state, turbulent, two-phase and three-phase flow conditions.

Experimental studies of the surface quality produced by abrasive waterjet (AWJ) on metallic materials have been performed (Jan et al. 2007) and a single-parameter criterion has been proposed in order to characterize the cut surface qualities. A (W,Ti)C/SiC gradient ceramic composite have been developed (Jianxi et al. 2007) to be used as nozzle, material, as it is the most critical part in abrasive air-jet machining equipment and have found that ceramics, being with high wear resistance, have great potential as abrasive air-jet nozzle materials.

Mathematical models for the particle velocity variations across and along an AWJ have been developed (Wang, 2009) and was based on an in-depth understanding of the jet dynamic characteristics from a CFD simulation study.

Axinte et al. (2010) have reported on a geometrical model of the jet footprint (kerf) in mask less controlled-depth milling applications, which was needed to found the material specific erosion (etching) rate that was obtained from the jet footprint by taking the limiting conditions of the model.

Kumar and Shukla, (2012) have presented the applications of an elastic-plastic model based explicit finite element analysis (FEA) to model the erosion behavior in abrasive water jet machining (AWJM) and have given a novel work that included FE modeling of the effect of multiple particle impact on erosion of Grade 5 Titanium alloy (Ti-6Al-4V).

(Annoni et al. 2014), that allowed the controlled injection of air inside the primary orifice to prevent the jet instabilities and to adapt the level of jet coherence to the specific machining operation. And also the fluid dynamics aspects of the outflow process were investigated by means of a 3D numerical simulation with the Ansys Fluent CFD solver.

(Sookhak et al. 2016) studied the inverse problem associated with AJM. Using 3D topographies demonstrates the ability to etch and present the methodology to evaluate the source velocity which is calculated from analytical model based on Gaussian transformation. The obtained results have been compared with available literature and conclude that the proposed method is used in machining micro channels with prescribed depth)The **headings** and **subheadings**, starting with "**1. Introduction**", appear in upper and lower case letters and should be **set in bold and aligned flush left**. All headings from the Introduction to Acknowledgements are numbered sequentially using 1, 2, 3, etc. Subheadings are numbered 1.1, 1.2, etc. If a subsection must be further divided, the numbers 1.1.1, 1.1.2, etc.

The font size for **heading is 11 points bold face** and **subsections with 10 points and not bold.** Do not underline any of the headings, or add dashes, colons, etc. (10)

III. MATHEMATICAL MODELING

The Naiver stokes flow equations are used as the governing equation which are solved by using ANSYS-Fluent solver. The simulation has been carried out steady state analysis in which performance characteristics of abrasive water suspension jet has been examined for wide range of operating pressure. The governing partial differential equations, for mass, momentum conservations and continuity, are detailed below.

Continuity
$$\frac{\partial \rho}{\partial x} + div(\rho u) = 0 \quad (1)$$

x-momentum
$$\frac{\partial(\rho u)}{\partial x} + div(\rho uu) = -\frac{\partial p}{\partial x} + div(\mu gradu) + S_{Mx} \quad (2)$$

y-momentum
$$\frac{\partial(\rho v)}{\partial y} + div(\rho vu) = -\frac{\partial p}{\partial y} + div(\mu gradv) + S_{My} \quad (3)$$

z-momentum
$$\frac{\partial(\rho w)}{\partial z} + div(\rho wu) = -\frac{\partial p}{\partial z} + div(\mu gradw) + S_{Mz} \quad (4)$$

Energy
$$\frac{\partial(\rho i)}{\partial t} + div(\rho iu) = -pdivu + div(kgradT) + \Phi + S_i \quad (5)$$

Equation of State p = p(ρ, T) and i = i(ρ, T) (6)

e.g. perfect gas p = ρRT and i = CvT (7)

For computation of particulate loading and stokes number are used which facilitates in identifying the phase of model.

$$\beta = \frac{\alpha_s \rho_s}{\alpha_l \rho_l} \quad (8)$$

$$S_t = \frac{\rho_d d_p^2}{18\mu_l \cdot \left(\frac{l}{v}\right)} \quad (9)$$

Where, α is volume fraction of the phase i.e. solid or liquid. ***ρ*** refers density, v is velocity.

IV. METHODOLOGY

The equation of motion of Abrasive water suspension jet machining is solved using FEV tool (ANSYS). The AWSJ nozzle was discretized into 31677 elements with 33811 nodes. The governing equation of AWSJ is solved by Pressure Velocity Coupled with K-ε model and scheme se "SIMPLE" which same has been detailed in [12] and the geometrical parameters and operating conditions are detailed in table 1.
On the basis of table 1 the geometrical model of AWSJ has been developed and as per which mesh model has been created which are illustrated in figure 1 and2

Table 1 the geometrical parameters and operating conditions

Design Parameters	**Value**
Inlet Diameter	4mm
Exit Diameter	1.3mm
Focus tube length	17mm
Angle of Converging ,θ	26.56^0
Converging length	4mm
Flow Parameters	
Volume fraction	5%-15%
Density of Fluid (water)	998.2kg/m^3
Density of Garnet (Abrasive)	2300kg/m^3
Slip of Phases	No Slip
Turbulence model	k-□
Abrasive particle size of (diameter)dp	63 µm
Flow	Incompressible
Mode of operation	Steady state
Stokes number	0.35

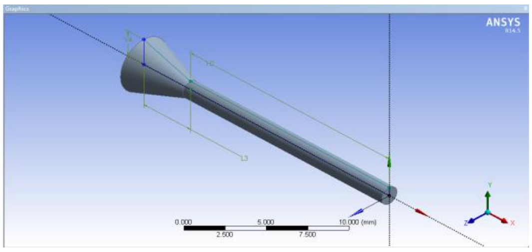

Figure 1 Model Geometry

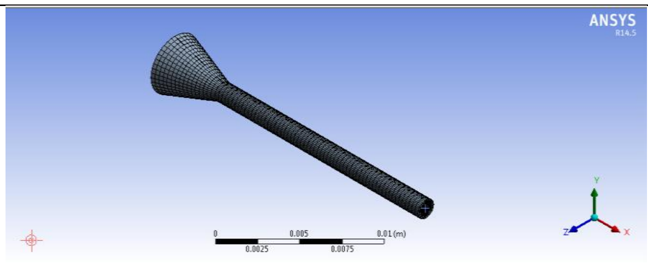

Figure 2 Mesh Model

V. RESULT AND DISCUSSION

The governing equations of the problem were solved, numerically, using a Element method, and finite Volume method (FVM) used in order to calculate the Flow characteristics of abrasive water jet machining. As a result of a grid independence study, a grid size of 10^6 was found to model accurately the AWJ machining performance characteristics are described in the corresponding results.

The accuracy of the computational model was verified by comparing results from the present study with those obtained by Deepak et al.2012, simulation, experimental and FVM results.

Fig. 3-4 shows the validation of FVM result obtained from the ANSYS tool. It has been seen that the obtained result for AWJ nozzle with diffent boundary condition shows good agreement with the analytical, Simulation and FVM of available literature.

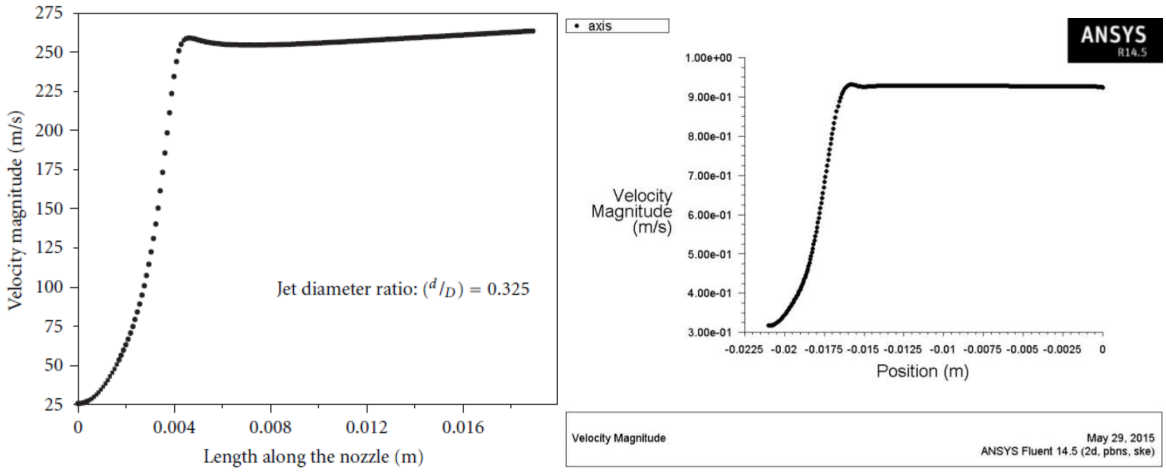

Fig. 3 Validation of Velocity Magnitude along the length of the nozzle

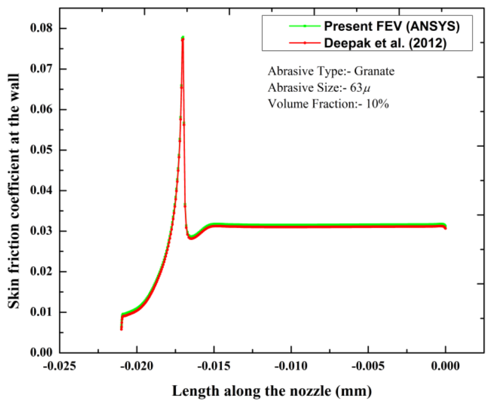

Fig. 4 Validation of Skin friction coefficient at the wall along the length of the nozzle

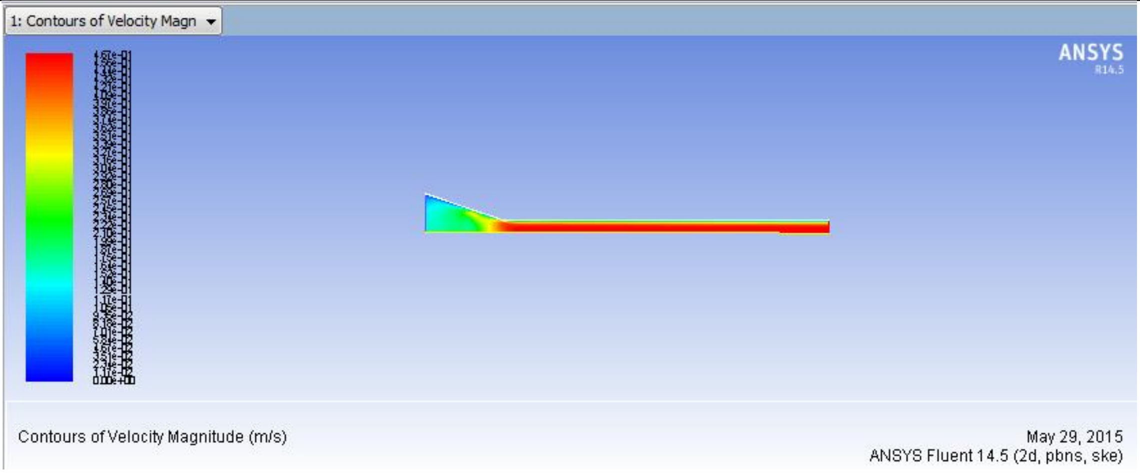

Fig. 5 Velocity distribution along the along the length of the nozzle

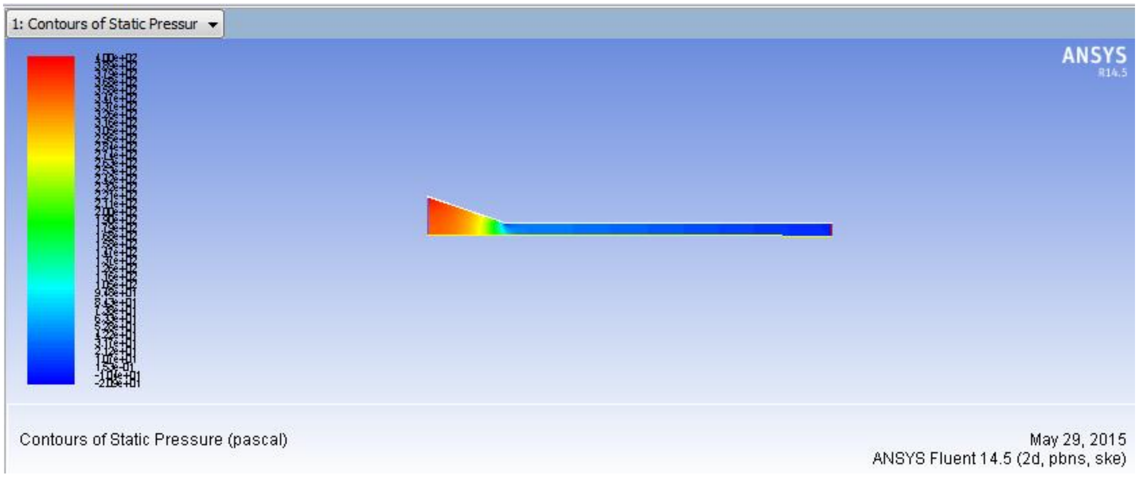

Fig. 6 Pressure distribution along the along the length of the nozzle

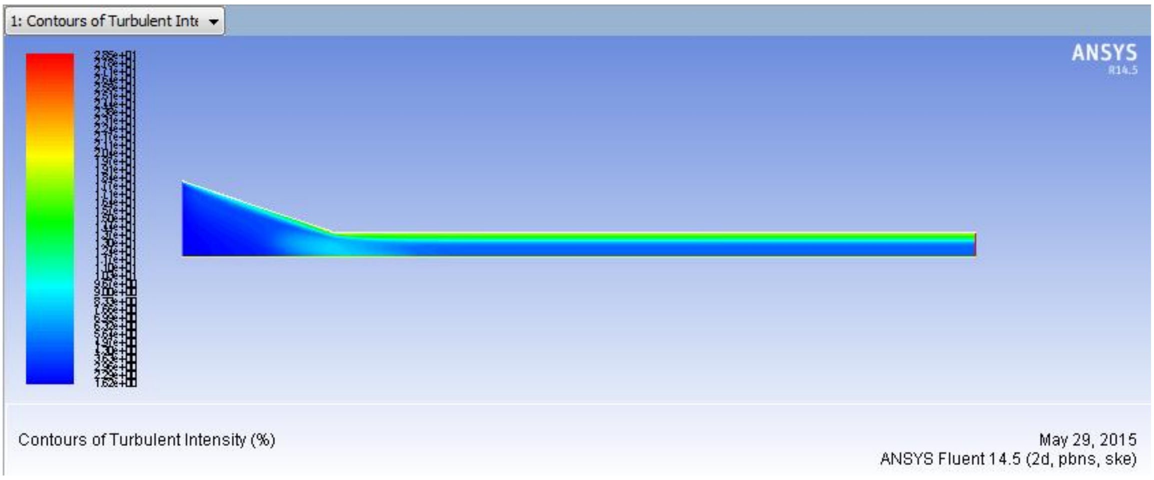

Fig. 7 Turbulence intensity along the along the length of the nozzle

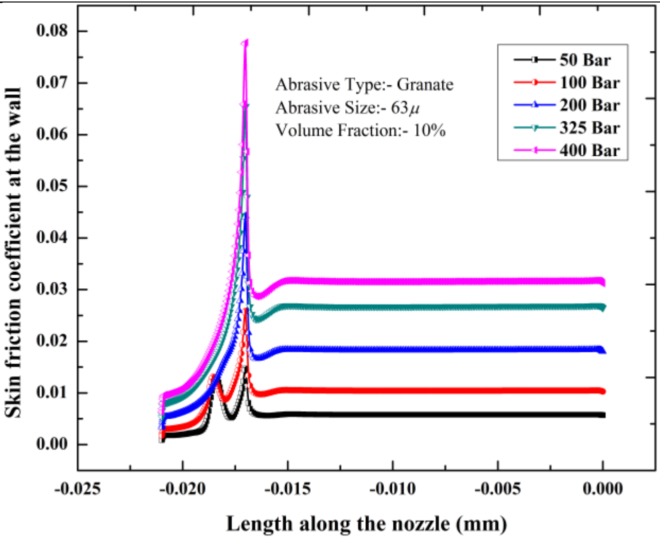

Fig. 8 Distribution of skin friction coefficient along the length of the nozzle corresponding to various inlet operating pressure

Fig. 8 shows the Distribution of skin friction coefficient along the length of the nozzle corresponding to the various inlet operating pressure. It can seen that for various inlet operating pressure, along the nozzle length skin friction coefficient inserases drastically with spike occurring followed by a short decline in its values exactly where there is a change in cross-section of nozzle changes i.e. from conical to straight region

It can be revealed local skin friction coefficient is a strong function of Reynolds number or, in other words, the subsequent velocity of flow [37]. Thus, within the conical region of the nozzle, velocity increases rapidly, and hence, skin friction coefficient spikes up as revealed in the graph. As the fluid has not fully developed in the short conical tube when flow velocity transformed rapidly.

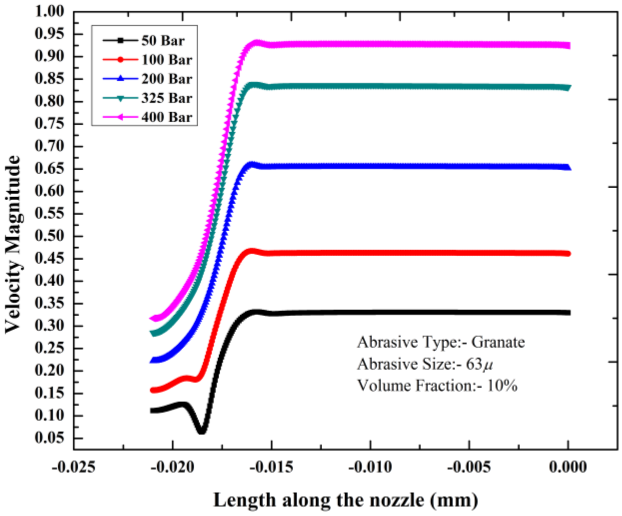

Fig. 9 Distribution of Velocity along the length of the nozzle corresponding to various inlet operating pressure

Fig. 9 shows the Distribution of Velocity along the length of the nozzle corresponding to various inlet operating pressure. It is found that velocity of nozzle marginally increases as operating perssure increases. this is because of change in flow area extensively effects the flow kinectic energy which leads to increases the velocity. This can be expalined in terms of flow geomerty that focal tube is straight through out length which improves the flow patern whereas, convergion section has decreasing area which adversly affects the velocity distribution where the peak can be observed where convergion section ends. This can be evident from fig. 5

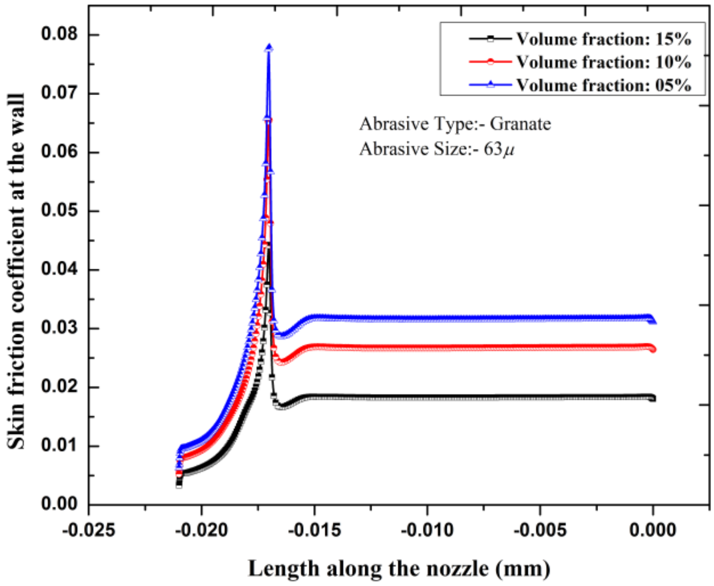

Fig. 10 Distribution of skin friction coefficient along the length of the nozzle corresponding to various Volume Fraction

Fig. 10 shows the Distribution of skin friction coefficient along the length of the nozzle corresponding to various Volume Fraction. It has been observed that on skin friction coefficient increases as the vloume fraction decreases. At the critical section of the nozzle the Skin friction coefficient attains a peak value, where the nozzle flow section changes from a narrow region to straight region and afterward remain approximately constant along the straight focus region of the nozzle.

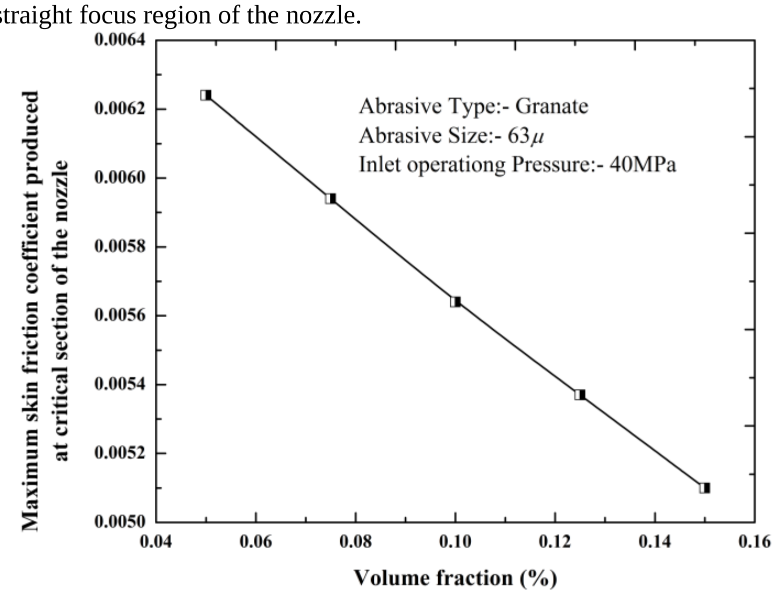

Fig. 11 Effect of volume fraction on skin friction coefficient at the critical section of the nozzle.

Fig. 11 demonstrates the Effect of volume fraction on skin friction coefficient at the critical section of the nozzle. It can be seen that skin friction coefficient decreases as the volume fraction of abrasive in suspension mixture increases. This is because of the increase in abrasive concentration in a suspension mixture as a result of increase in abrasive particles volume fraction.

During transportation of abrasive particle loss in fluid energy takes place which ultimately decreases the kinetic energy resulting in a decrease in jet velocity. This leads to reduce skin friction coefficient along the wall of the nozzle.

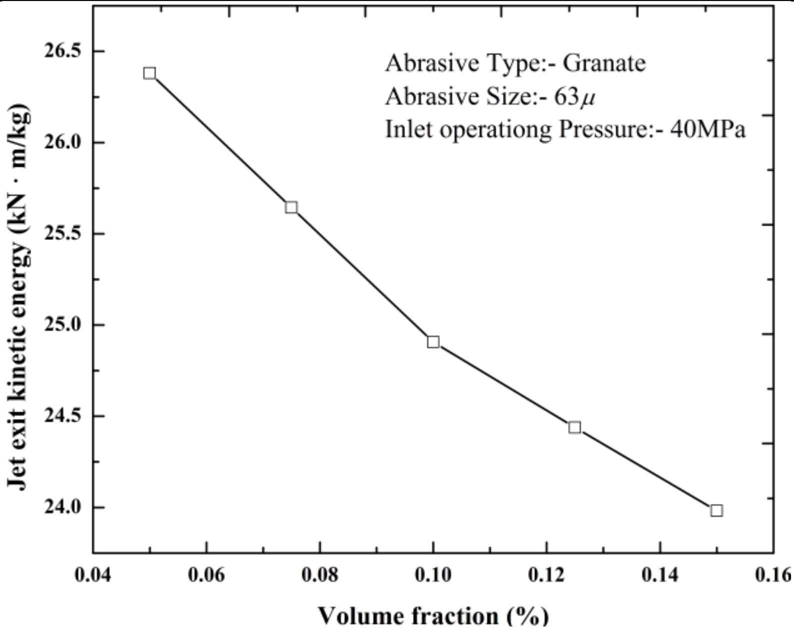

Fig. 12 Effect of volume fraction of average exit kinetic energy of the jet.

Fig. 12 illustrates the Effect of volume fraction of average exit kinetic energy of the jet. It has been observed that with the increase in the abrasive volume fraction there is a minor decrease in jet exit kinetic energy has been examined at volume fraction of 10%. As described earlier, because of the higher fluid inertial resistance due to high concentration of abrasive particles in the fluid results in decreases exit velocity.

VI. CONCLUSION

- On increasing inlet operating pressure, skin friction coefficient increases significant.
- Due to sudden change in flow passage at the critical section the skin friction coefficient advances peak values and then start decreasing.
- On changing section significantly increase change in turbulence intensity takes place in the critical region
- The average exit kinetic energy of jet increases linearly as inlet operating pressure increases.
- The decline in exit kinetic energy of the jet has been observed as the volume fraction of the abrasive particles increases.
- It has been observed that on increasing abrasive volume fraction leads to momentous decrease in the skin friction coefficient
- The net energy dissipated due to skin friction coefficient is linearly proportion to the inlet operating pressure.

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