2005 WJTA American Waterjet Conference
August 21-23,2005 • Houston,Texas

Paper 6A-3

AN EXPERIMENTAL STUDY ON DUAL-JET FLOW WITH PIV METHOD

Gensheng ,LI; Jian,SONG; Zhongwei, HUANG; Jilei, NIU; Can, YI
China University of Petroleum, Beijing,102249,P.R.China

ABSTRACT

Dual-jet is a new kind of high efficient jet, which is formed by combining a circular swirl jet with a round straight jet. This paper presents experimental results of the dual-jet flow using cross-correlation Particle Image Velocimetry. The time average velocity data and the vorticity data are experimentally acquired to analysis the attenuation of jet velocity. The results clearly demonstrate that the swirl jet determines the dual-jet hydrodynamic characteristics at short jet distance, and the round jet dominant the dual-jet at long jet distance. The swirl jet is attracted to the round jet, which prevents the formation of hole bottom convex and enlarges penetration depth.

Organized and Sponsored by the WaterJet Technology Association

1. INTRODUCTION

The erosion capability of high-speed fluid jets is widely applied to many applications in modern industry. With the development of high pressure water jets technology, it's application and service has been largely widened recently. However, the current jet forms hindrance the further development of water jets technology for some inborn faults. Two popular jets types are straight jet and swirling jet, which have their own advantages i.e., the straight jet can form a deep hole with a small diameter while the swirling jet will shape a large diameter hole with limited depth, and also the swirling jet can not avoiding the formation of the bottom convex of the hole. It is clear that none of above jet shape can meet the challenge of generating a hole with both large depth and diameter. A dual-jet system which combining the straight jet and swirling jet together that inherits their special features and theoretically avoiding the formation of hole bottom convex is a good solution to the dilemma. The dual-jet is produced by combining a central straight jet with an annuals swirling jet around the straight one. The two jets are supplied by a single high pressure hose. After entering the inlet of the nozzle, the fluid is divided into two parts: the central part flow out of the cylinder exit to generate the straight jet; the second part flows pass the curvature flow path and gets swirl velocity, then it flows out of the annular orifice and forms the swirling jet.

Though it is theoretically predicted that the dual-jet system can generate both deep and large holes on target, however, due to many different requirements, accurate predication of erosion depth and diameter is necessary to a successful jets application. A clear understanding of the jets velocity field such as the velocity distribution, velocity attenuation and vorticity distribution can help the selection of jets parameters. Studying the dual-jet velocity field with a Particle Image Velocimetry (PIV) method is an accurate way to acquire the velocity distribution and attenuation profiles and can help to define the application fields. The PIV technology was developed in 1980s and soon got popular for providing the whole velocity field with high resolution and accuracy without any minimum disturbance

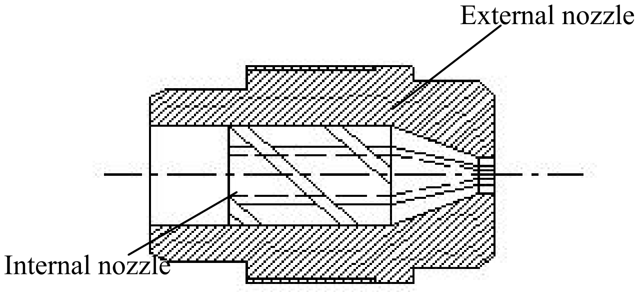

Fig.1 Structure of Dual-jet Nozzle

on the flow.

2. DUAL-JET NOZZLE

The straight jet is a widely used jet form and has been studied by many researchers and institutions. Leach & Walker have experimented many parameters on straight jets nozzle and established many optimal nozzle structure parameters. Though swirling jet also has drawn a lot attention for its feature of shear cutting and large impact area, it lacks system study. Dual-jet have been widely used in engineering applications, e.g., non-premixed bluff-body combustors, cooling systems, fluid mixers, industrial burners, and propulsion apparatus, it has not been introduced into rock erosion application. Several dual-jet systems are reported, which are mainly characteristic as double concentric, non-swirling and two fluid inlets.

The formation of the new developed dual-jet is to divide the pressurized water into two streams: one flow through the swirling path to get the swirling velocity then flow out the annulus orifice and form the swirling jet, and the other one flows directly through the inner round orifice to form the central straight jet. By this arrangement, the two jets theoretically will generate a hole with both large diameter and depth. The nozzle structure sketch is Fig1.

The nozzle structure includes two separate nozzles, the external nozzle and the internal nozzle. The swirling velocity as a main feature of the dual-jet is critical to a successful nozzle design. It was mainly influenced by the parameters of the swirling path shape, size, and the flux ration between two jets and the swirling number.

According to the measurement requirements and the empirical design experience, the initial nozzle structure parameters are determined being:
Inner nozzle diameter d_0=3mm;
Annulus width d_1=2mm;
Pitch of swirling path=36mm.
Nozzle total length=30mm;
Hose diameter=30mm;

3. EXPERIMENTAL SETUP

Fig.2 shows the experimental apparatus. The central and annular jets were supplied with a single piston pump. The water flows of central and annular jets went through inlet orifice and annular orifice to produce the straight jet and swirling jet. An 800mm long glass tube was adapted to the exit 0f the nozzle as an artificial well bore. A cubic box enclosed the tube with a dimension of 400mm×400mm×600mm, and it was adopted to eliminate the effect of the curvature tube profile.

3.1 PIV System: Including Ver.6.1c synchronizer; 3D Coordinator; Laser Pulse MiniYag12 Laser Source; PIV CAM10-30CCD Camera.

3.2 Pistol Pump: Max pressure 50 MPa with a flow rate 1.0L/s

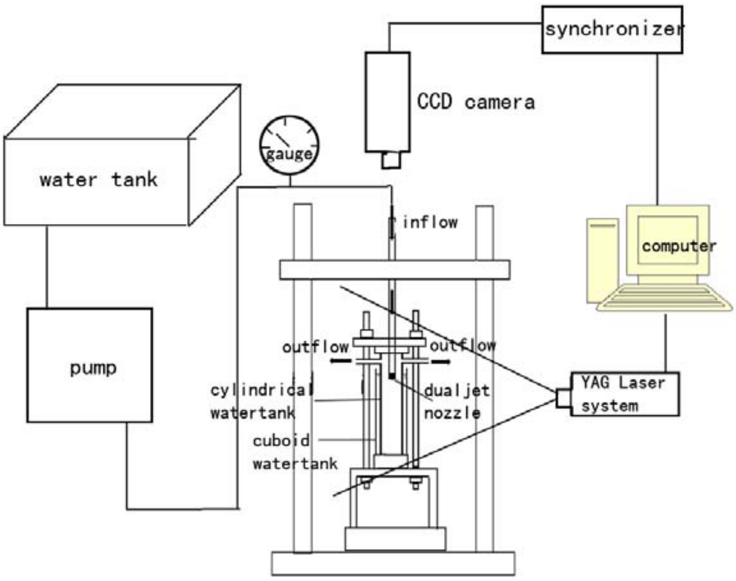

Fig.2 Experimental setup

3.3 Jet Measurement System: Including a glass artificial well bore and a glass cubic box. The size of glass well bore is: Φ90mm×800mm; The dimension of glass box is: 400mm×400mm×600mm.

The diameter of the glass well bore is more than 10 times of nozzle diameter, which will eliminate the backflow influence. The laser sheet is kept within the same surface with the nozzle axial, while the CCD camera is placed in vertical direction against laser sheet. In order to get a convincible result, many pictures should be taken at the same pressure and flow rate. After the pictures are acquired, the average data is extracted from every frame. The tracer particle in the measurement is hollow glass bead with a diameter of 0.01~0.02 mm. To testify whether the picture is trustworthy, the valid vectors should be more than 90% of the total vectors.

3.4 The time interval between two exposures

The time interval between two exposures, which is between two frames or pictures, is critical to the PIV method. A time interval should be selected to ensure that enough tracks of particles is recorded in both the two separate frames, then velocity vector of tracers can be calculated by co-correlation analysis of probing areas. By this way, the whole flow velocity field is visualized. Specially, the dual-jet has a swirling velocity, and this determines the time interval should be selected by the magnitude of the swirling velocity. If take the half depth of laser sheet δ/2 as the minimum recording time, then the correct time interval should meet the following equation:

$$\triangle t \le \frac{\delta}{2v_t} \qquad (1)$$

In the equation：

$\triangle t$ --time interval, δ --laser sheet width, v_t --swirling velocity.

4. EXPERIMENT RESULTS AND ANALYSIS

3.1 Analysis of Dual-jet velocity field

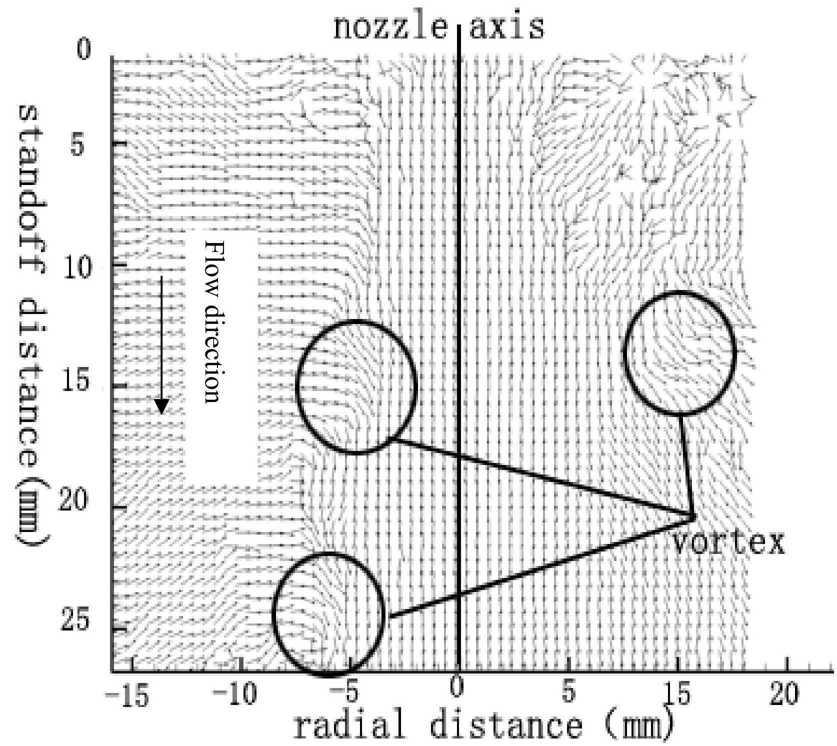

Fig.3 Velocity Vector Field of Dual-Jet

Fig.3 shows a velocity vector field of the dual-jet flow. The swirling jet has strong entrainment ability so it will generate many vortexes at boundary. Several vortexes are marked out on Fig.3. The dual-jet flow regime can be divided into 2 sections: 0-10mm is the developing section characterized the small increase in radial direction; 10mm- is the developed section characterized sharp increase in radial direction. At the developing section, the dual-jet is restricted in a small area for the entrainment effect of central jet, and the dual-jet at this section is stable and with small radial expansion. At the developed section, with attenuation of the central jet, it can no longer attract the annular jet. So the swirling jet expands sweeping area quickly and also attenuates quickly. In order to have a clear observation of the velocity attenuation, Fig.4 shows the velocity magnitude profile at different standoff distance. At the near downstream of nozzle exit, the dual-jet velocity profile has three peaks. With the increasing of standoff distance, for the strong shear interaction and entrainment effect, the swirling jet transfer its kinetic energy to the surrounding fluid. The velocity profile has a single peak.

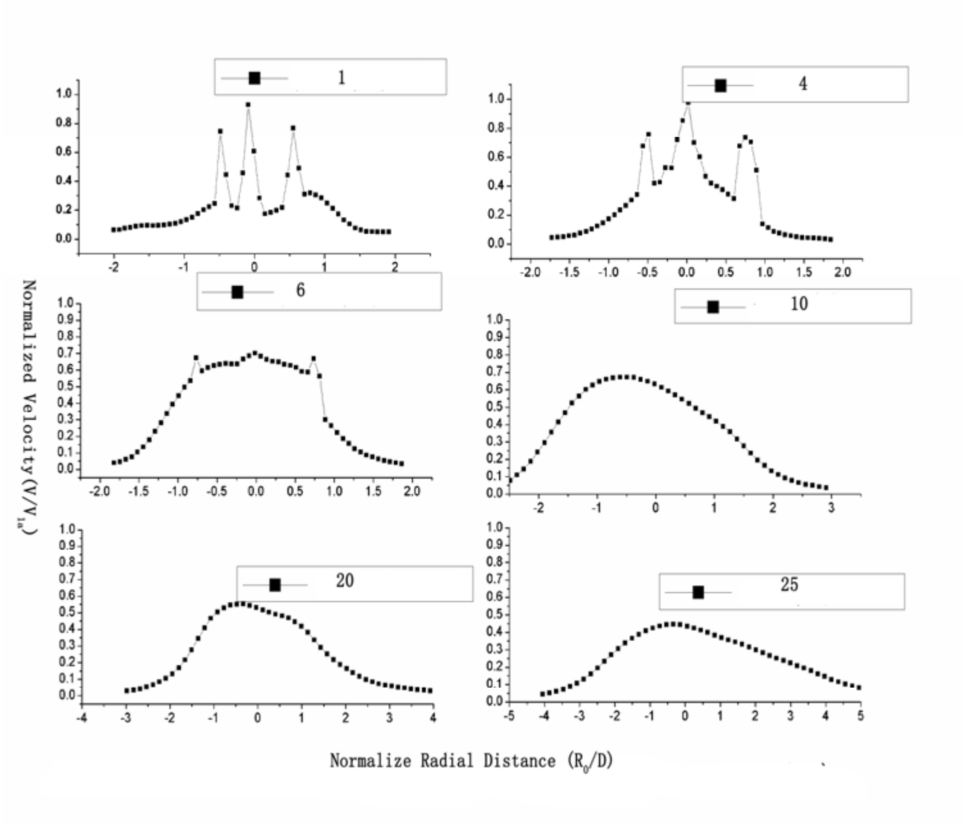

Fig.4 Velocity Magnitude profile at Different Nozzle Standoff Distance

Comparing the velocity profile of dual-jet with single jet, the dual-jet succeeds the strong radial sweep feature of swirling jet. The velocity profile cap is evener than the single jet.

Fig.5. shows the velocity distribution at the nozzle axis. From the nozzle exit, the velocity keeps the same within 5 times diameter, so the potential core length is 5 times nozzle diameter. When the standoff distance

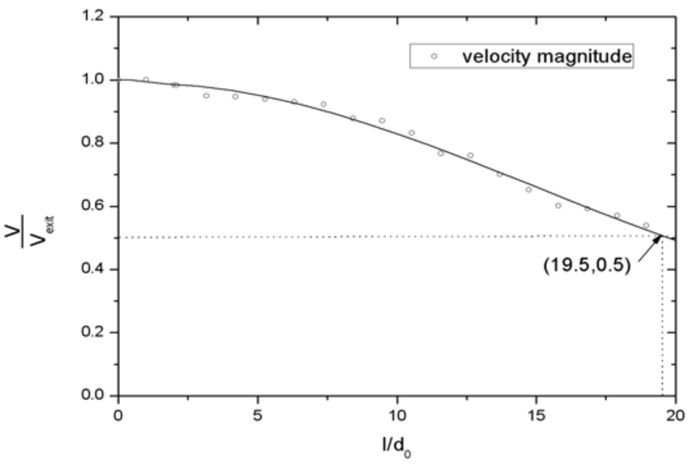

Fig.5 Velocity Distribution at Nozzle Axis

increases to 10 times nozzle diameter, the velocity is about 80% of the exit velocity. At a 19.5 times of nozzle diameter, the velocity is 50% of the exit velocity.

During the rock cutting or erosion process, a threshold velocity exists. The rock won’t be fragmented unless the jets above a certain threshold velocity. So the velocity attenuation is critical to rock cutting efficiency and ability. Though by introducing the swirling jet can decline the threshold velocity for its shear stress, slow velocity attenuation is still desirable for penetrating deep. Since the total jet energy is certain, the dual-jet just modify the energy transform method and not increase the energy. As the dual-jet has a large rock cutting area, it will have a small cutting depth. To obtain a balance between the depth and area, adjusting the flow rate ratio of the central jet and annular jet and adjusting the swirling velocity are two effective methods.

4.2. Analysis of vorticity field

Fig.6. presents the vorticity field contour. The fundamental flow characteristics are revealed. The vorticity field is symmetric about the nozzle axis. This feature validates the accuracy of the measurement. In the vicinity of the axis, the vorticity is zero which is in accordance to the straight jet. At the boundary of the swirling jet, the vorticity is large and changing sharply.

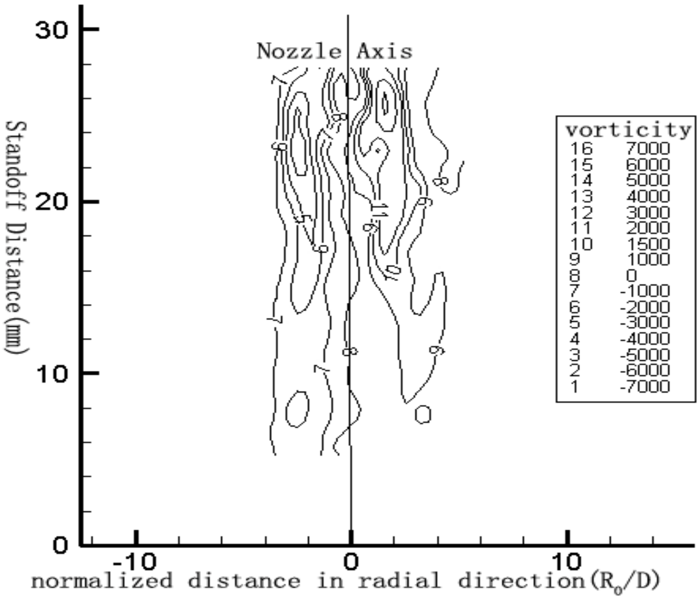

Fig.6 Vorticity Magnitude Contour

The large vorticity area is restricted in a rectangular area indicating the swirl velocity can not transfer far in the radial direction. This feature indicates the central jet even can attracted the annular jet in large nozzle standoff distance. The central straight jet attenuate gradient is smaller than that of the annular swirling jet. With the increasing of the standoff distance, the velocity difference should be enlarged. But the velocity profile in Fig.4 shows the velocity difference is decreasing instead of increasing. As a possible factor, the strong shear interaction is considered between two jets. The interaction will waste some amount of jet energy. And the velocity profile is becoming even in large distance.

There is a sharp decrease of jet velocity at 5 times nozzle diameter, where the Fig.6 shows a large vortex. In Fig.5, this sharp decrease is presents as the velocity peak diminished between the nozzle standoff distance of 5 and 6 times nozzle diameters. It is deduced that cavitation should be induced here for the shear stress. The cavitation will be studied on continuing researches by experiments and simulation methods.

5. CONCLUSIONS

1. At a small nozzle standoff distance, the velocity distribution of dual-jet is characterized as multi-jets; with the increasing of standoff distance, the jet sweep distance in radial direction and the velocity profile is becoming even and display a similar normalized distribution of single jet.
2. The velocity magnitude attenuates very fast on the nozzle axis. At a distance of 19.5 times nozzle diameter, the velocity is about 50% of the orifice speed. This feature will limit the application of dual-jet in deep drilling requirements.
3. The straight jet has a strong entrainment effect on the annular swirling jet, and the vortexes accelerate the energy transform between two jets. Especially, the vortex at a distance of 5 times nozzle diameter reveal strong cavitation could be induced, which will largely enhancing dual-jet rock cutting ability.

6. ACKNOWLEDGEMENTS

The research work has been carried out with the financial supports of National Natural Science Foundation of China (No.90410007) and National Science Fund for Distinguished Young Scholars (No.50125413).

7. REFERENCES

1. Zhonghou Shen, 1998. Water jet theory and technology. Press of University of Petroleum,

Dongying, Shandong,P.R.China.

2. Ruihe Wang, Weidong Zhou, Study on Mechanism of Rock Breaking by Swirling WaterJet. Ch ina Safety Science Journal, 1999,(9):1-5.
3. Gensheng Li, Can Yi,Experimental Study on Rock Erosion Efficiency with a Double- jet Nozzle, Petroleum Drilling Techniques 2001,29(3):9-10.
4. Yongtang Hu, Gensheng Li, Jilei Niu. Flow Field Characteristics of Dual-Jet[M]. Fluid Machinery,2002.
5. Daniel C Bjorkquist, Fingers on LM. Particle Image Velocimetry, Atl as of Visualization [M].Pergamon Press, 1992.
6. Lourence L, Krothapalli A. On the Accuracy of Velocity and Vorticity measurements with PIV [J].Experiments in Fluids, 1995, 18:421-428.
7. Yingzheng Liu, Hanping Chen, Experimental investigation into swirling recirculating flow using PIV. Journal of Hydrodynamics. 2003,18(5):601-606.