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Experimental Investigation on Flow Pattern of a Wall Jet

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ABSTRACT

In this paper, effect of the bed roughness on the flow pattern in a wall jet is studied experimentally. Channel that experiments has been carried out included glass walls and metal floors with 0.57 meters width, 1 meter height and 10 meters length. Jet enters horizontally to the center of channel through a pipe with 20 millimeters diameter. At first the experiments were done using three dimensional velocimeter -ADV- for measuring of velocity components at three directions. Then the collected data were processed and used for drawing flow pattern along the measuring domain. It was found that the zone of the potential core of jet occurs at the distance of about five times of the jet diameter. By increasing the bed roughness, the lateral and vertical components of velocity of jet increases. By increasing the bed roughness, the growth rate of longitudinal scale decreases and the decay rate of velocity of jet increases.

KEYWORD

wall-jet , three-dimensional velocimeter , flow patterns , bed roughness

INTRODUCTION

Whenever a flow with relatively high speed, enters into a fluid with a speed lower than itself, the flow resulted from the interference of the two currents is called a Jet. The jets could be categorized in to two groups of free jet and confined jet. In engineering problems, mostly turbulent jets are discussed. Laminar jet with high viscosity at low speeds occurs at small scales. For a split flow, Reynolds number is expressed as Re = ρvd/μ. Here v the average velocity of flow, d outflow depth, ρ and μ are the density and viscosity of fluid respectively. For a pipe flow, the transition from laminar to turbulent conditions occurs when the Reynolds number is greater than $2 * 10^3$. A jet flow with Reynolds Number greater than $3*10^4$ is classified as fully turbulent [1]. The maximum velocity decay of the jet flow field can be divided into three areas: i)Potential core region (PC) where the maximum velocity Um is equal to or very close to the jet entrance velocity U, ii)Characteristic decay (CD) at which the maximum rate of decay depends on the geometry and shape of the nozzle and III)Radial decay (RD) which is independent of the shape and geometry of the flow field, and the maximum velocity decay rate is similar to that of the wall jet. The development stages of a wall jet are shown in Figure 1 [2].

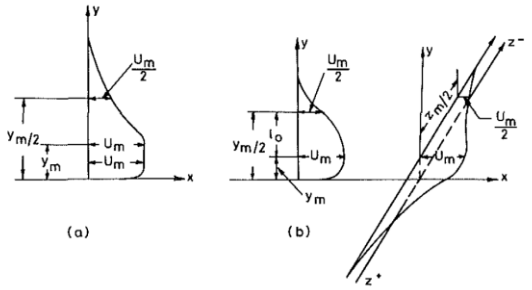

Fig.1. Velocity profiles in different regimes of a wall jet:
a) Potential core region,
b) Characteristics decay and Radial decay regions [2]

One of the most important parameters influencing the flow pattern is roughness. The resistance of water flow is dependent on the size of the bed roughness. The bed roughness may vary with changing flow conditions and indirectly linked to the particle size of bed material and its gradation. Nikuradse equivalent roughness (K_s) for a sand and gravel bed is approximately equal to d50 [3]. In this paper, $K_s$wasconsidered to be equal to d50. The review of literature shows that the studies on 3D wall jets are less as compare to 2D wall jets. Moreover, almost all the researches which have investigated the 3D wall jets have been performed on a smooth and flat bed.Table1 shows a summary of the most important conducted researches in the domain of the 2D and 3D wall jets on smooth and rough beds.

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The purpose of this paper is to study experimentally the effect of bed roughness on the flow pattern of a submerged wall jet.

Tab.1. A summary of the research done on the wall jet

Type of bed	Shape of jet	Type of jet	Researchers
Rough	Circular	Three-dimensional	Wu and Rajaratnam (1990)[4]
Smooth	Circular	Three-dimensional	Law and Herlina (2002)[5]
Rough	Rectangular	Two-dimensional	Dey and Sarkar (2008)[6]
Smooth and rough	Rectangular	Two-dimensional	Tachie et al. (2004)[7]
Rough	Circular	Three-dimensional	Present research

EXPERIMENTS

The experiments were performed in a channel with glass walls and a metal floor in the Hydraulic Laboratory of TarbiatModares University. The channelwidth was 0.57 meter, with its height of 1 meter and the length of 10 meter. Water jet was established through a pipe with internal diameter of 20 mm placed horizontally in the entrance of the channel. Water depth was regulated by a tail gate at the end of the channel. The tailwater depth was kept equal to 18 cm in all the experiments. The flow discharge was measured by a calibrated flowmeter. The depth of flowwas measured by a point gage with ±0.1mm accuracy.Figure 2 shows schematic view of the experimental setup.

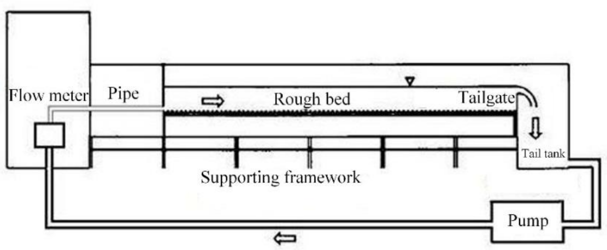


Fig.2. Schematic view of the experimental set up

The 3D velocity components were measured by using aVectrino+ velocimeter, which is a new model of the Acoustic Doppler Velocimeter (ADV). This velocimeter which has resolved most of the defects of the formerly-made instruments, has been designed and manufactured in 2003-2004, and operates on the basis of the Doppler phenomenon. The data gathered through this apparatus can be linked to a personal computer via a connecting cable. The measureming accuracy of this apparatus is about±0.005mm/s. The components of this velocimeter are:

1. Probe, which includes the signal receiver antennas(4 antennae, each with a length of3cm)
2. Connectingshaft orcableprobe to the main body(shaftheight35cm)
3. Main body(cylindrical height and diameterof 35and6cm, respectively)
4. Computer connecting cable

According to the type of the experiment, the probes attached to this velocimetrt are of different kinds, including the down-looking probe and side-looking probe. Figure 3 shows the Vectrino+assembled on a mover machine in order to facilitate and maintain the instrumentfor the velocity measurement.

Fig.3.Vectrino+ velocimeter

In order to provide a completely rigid bed with required roughness, an aluminum sheet was used. In such a manner that firstly, the surface of the sheet was well cleaned, and then was covered with special glue. Then, the dry sediment was spread over the sheet, in such a manner that the surface completely covered with sediment. Eventually, we left the sheet aside till the glue dries. After drying the glue and fixing the sediment over the metal sheet, we put the sheet inside the channel and the experiment was carried on.The specifications of the conducted experiments are presented in table 2.

The velocity data was collected at each point for three minutes. The duration of time spend for data collection for each experiment was lasting for 5 to 6 days.The data gathered by the 3D velocimeter apparatus, need a process: First, the gathered data converted into a format used in the software WinADV. Then, the data are filtered in order to eliminate the noises. The output of this software is the data which is used in further analysis.

Tab.2. Specification of experiments

U (Jet entering velocity, m/s)	Re (Reynolds number)	KS (mm)
1.671	33400	1.05
1.671	33400	3.28

ANALYSIS OF DATA

In this part the general flow pattern of a wall jet is addressed. The distribution of velocity in the central line of the wall jet with the bed roughness of k_s=1.05mm for different values of x/d is shown in figure 4. Herex is the longitudinal distance from the jet entrance and d is the diameter of the jet.As it is shown in figure 4, the zone of potential core (a zone with its velocity equal the entrance velocity of jet) is at a distance of 5 times of the jet diameter (i.e x/d=5). This zone was reported by Padmanabhamand Gowda (1991) [2] as x/d=3.25.

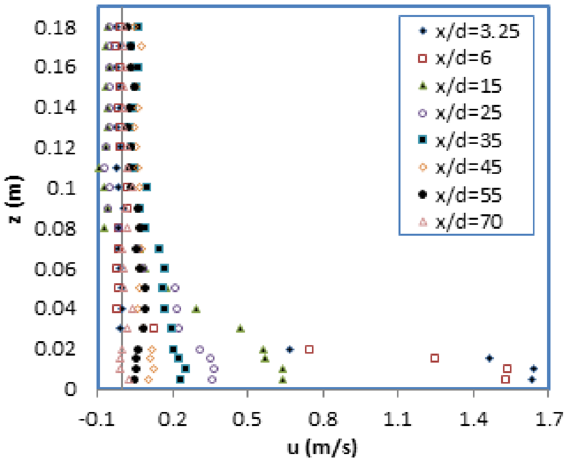
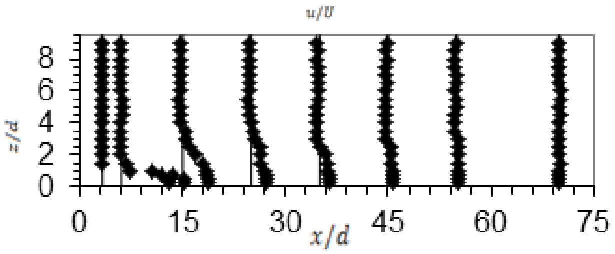
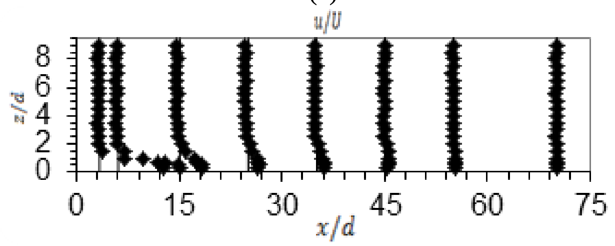


Fig.4. Distribution of the velocity in central line of jet

The dimensionless vertical distribution of the longitudinal component of velocity (u/U, in which u is the local velocity of jet), for different dimensionless height (z/d, in which z is the vertical distance from the jet), and dimensionless longitudinal distances (x/d) for two values of bed roughness are shown in figure 5. As it is clear from this figure, for z/d values near the bed, the amount of the longitudinal component of velocity u are positive. However by increasing z/d (i.e at larger vertical distances from the jet), the amount of the longitudinal component of velocity u reduces. For z/d values which are close to the water surface, the amount of the longitudinal component of velocity u are negative which indicate the presence of returning flow above the jet. It can also be observed that the more increase in bed roughness is associated by more velocity decay in the range of experiments conducted.



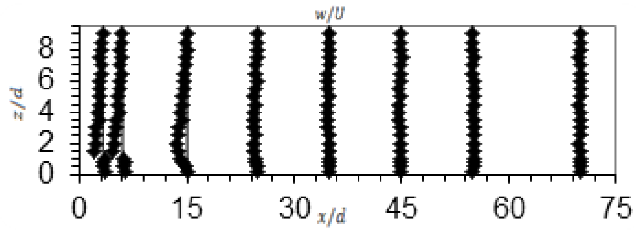
(a)



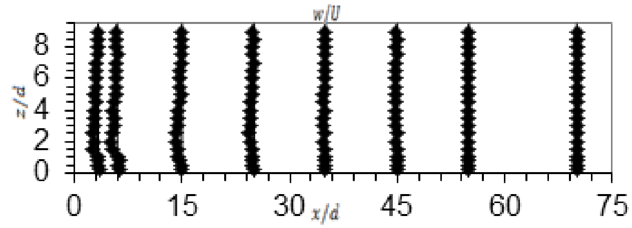
(b)

Fig.5. Vertical distribution of u/U for bed roughness:
a) k_s=3.28mm and b) k_s=1.05 mm

In figure 6, the dimensionless vertical distribution of the vertical component of velocity (w/U) for different values of x/d and different bed roughness are shown. According to this figure, the direction of the vertical component of velocity in the range of x/d=45 to x/d=55 changes from falling to rising, which can be attributed to the existence of a vortex which is developed above the jet at this zone. Further, by increasing the roughness of the bed, the decay of the vertical component of velocity w increase. In order to compare the result of present experiment with earlier research, the data of Dey and Sarkar (2008) [6] was used as shown in figure 7. This figure shows the distribution of vertical component of velocity for U=1.21 m/s and the bed roughness of K_s=1.86 and 3 mm. Thetrend of changes of velocity, considering the bed roughness's, is somehow in accordance with the present work.



(a)



(b)

Fig.6. Vertical distribution of w/U for bed roughness:
a) k_s = 1.05mm and b) k_s = 3.28mm

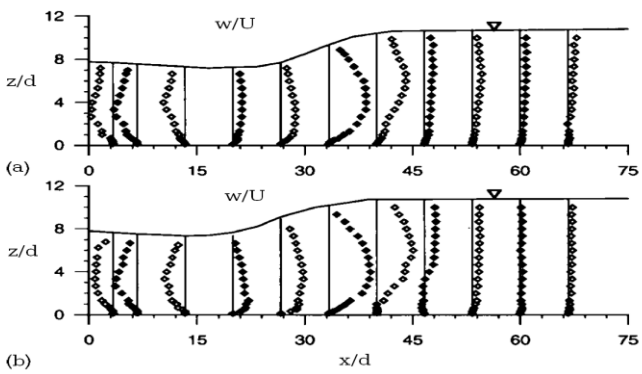


Fig.7. Vertical distribution of w/U for U = 1.21 m/s and bed roughness:
a) k_s = 1.86 mm and b) k_s = 3 mm [6]
b)

In figure 8, thedimensionless jet's vertical half-width ($z_{1/2}$ /d; $z_{1/2}$ is height in which the velocity is half of its maximum value at each section) with respect to the dimensionless longitudinal distance (x/d) for Reynolds number Re=33400are plotted. It is evident from this figure that by increasing the bed roughness, the growth rate of the longitudinal scale ($z_{1/2}$ /d) decreases. Similar trend was reported by Wu and Rajaratnam (1990) [4], Rajaratnam and Pani (1974) [8] and Law and Herlina(2002) [5]. A typical variation of $z_{1/2}$ /d for the data of Law and Herlina (2002) [5] and Rajaratnam and Pani (1974) [8] for Reynolds numbers Re=5200 to 13700 with smooth bed is presented in figure 9. The trend of variation of the longitudinal scale ($z_{1/2}$

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/d), considering the range and limits of data, is almost similar in figures 8 and 9.

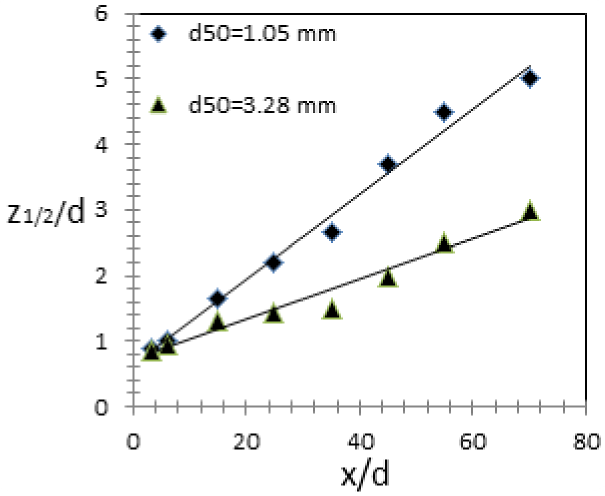

Fig.8. The growth rate of the length scale for two bed roughness

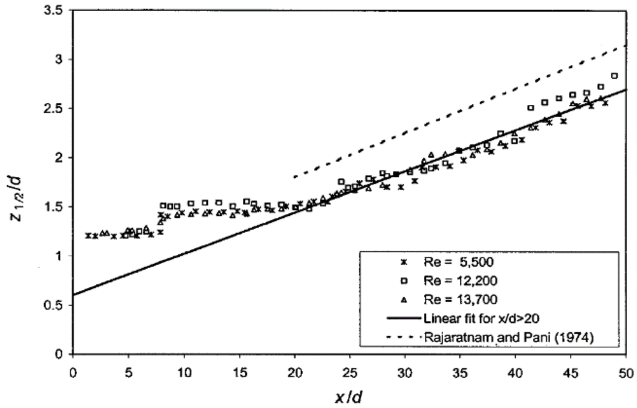

Fig.9. Growth rate of the length scale for different Reynolds number [5]

The dimensionless maximum velocity in each section along the jet (u_m/U) against dimensionless longitudinal distance (x/d)is shownin figure 10. It is clear from this figure that by increasing the bed roughness, the decay rate of the maximum velocity of jet in each section increases.

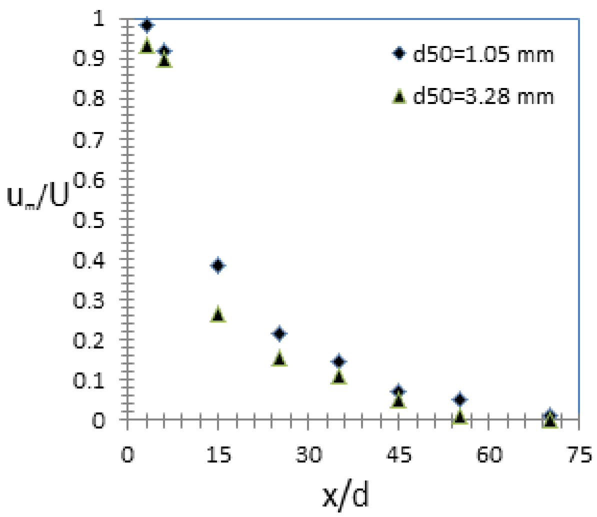

Fig.10. Decay rate of the maximum jet velocity for different roughness

Herlina and Law (2002) [5] by using the experimental data on smooth bed (figure 11) developed the following equation for decay rate of maximum velocity for Reynolds numbers Re=5200 to 13700 and x/d>20.

$$\frac{u_m}{U}=9.23\left(\frac{x}{d}\right)^{-1.066} \quad (1)$$

This equation for the data of present study give larger values of velocity decay, because the above equation is developed for smooth bed and the present experiments were conducted with rough bed. This again confirms the effect of the bed roughness on flow pattern.

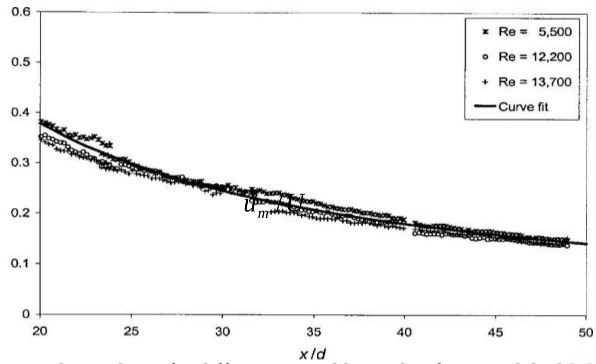

Fig.11. Velocity decay for different Reynolds number for smooth bed [5]

CONCLUSION

The results obtained from this experimental study can be summarized as follow:

- The zone of the potential core of jet occurs at the distance of about five times of the jet diameter.
- By increasing the bed roughness, the growth rateof longitudinal scale decreases.
- By increasing the bed roughness, the decay rate of velocity of jet increases.
- Due to presence of returning flow, the direction of vertical component of velocity w/U change from falling to rising in the range of x/d=45 to x/d=55.
- By increasing the roughness of the bed, the amount of decay of the vertical component of velocity w increases.
- The equation of Law and Herlina (2002) [5] overestimates the decay rate of velocity and should not be used for rough beds.

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