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An Experimental Study of Sand Jet in Stagnant Water

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ABSTRACT: *The study of sand-laden turbulent jet is one of the interest areas for researchers in the field of hydraulics as it has many important engineering applications such as marine bed capping, mining operations, hydro-transport, dredging material disposal, and discharge of domestic and industrial wastewater. Several in-depth studies have been conducted previously focusing on various parameters. In this paper, results from a simple experimental study have been presented. Sand jet of same sized particle diameter has been used during the whole experiment. Three types of nozzle diameters and for each diameter of nozzle different sets of sand masses have been used for the study. The optical probe has been used in six different positions to register the voltage data and thus to facilitate sand particle frontal velocity calculation. The last position of the probe has been set depth enough to ensure that the sand particle has attained its terminal velocity in most cases. Several experiments have been conducted to see the effect of nozzle diameter and sand mass on sand particle frontal velocity.*

Keywords: *sand jet, two-phase flow, frontal velocity, terminal velocity, optical probe*

I. INTRODUCTION

Sand-laden turbulent jet is typically two-phase flow which is used in many engineering applications such as marine bed capping, mining operations, hydro-transport, dredging material disposal, and discharge of industrial and domestic wastewater. It is obvious that the study of sand jet has great importance from the engineering point of view which can help in many ways such as proper design of jets and diffusers, optimization of the existing discharge systems, prediction of the system respond in different conditions, and so on.Understanding the dynamic interactions of the particle phase (i.e., sand) and turbulent water jets are important to properly design and optimize the mentioned engineering systems [1]. The behavior of these jets is determined by the size, concentration and density of the suspended particles [2]. Many researchers have previously shown great interest in this phenomenon and many experimental and numerical studies have been conducted to evaluate the behavior of these sand-laden jets in homogeneous or stratified ambient fluids. Falling clouds of particles in a viscous fluid medium were studied by Metzger et al., 2007 [3]. In their study, they have investigated both experimentally and numerically the time evolution of clouds of particles which were settling under the action of gravity in a pure liquid at low Reynolds numbers. The authors have also reported that when the particles are small or the liquid highly viscous, interactions between particles are governed by hydrodynamic forces, provided that surface forces, e.g. van der Waals forces, and Brownian motion are negligible. Particle clouds in both homogeneous and stratified ambient were investigated by Bush et al., 2003 [4]. In their study, the authors have examined the settling of mono-disperse heavy particles released into a fluid when the resulting motion was sufficiently vigorous that the particle cloud initially assumed the form of a turbulent thermal. Nicolas, 2002 [5] has done his study on gravity-driven dense suspension jets where he has classified the settling of particle cloud in water and glycerin into four different regimes. Hydrodynamic properties of a turbulent confined solid–liquid jet evaluated using PIV (Particle Imaging Velocimetry) and CFD (Computational Fluid Dynamics) were studied by Virdung and Ramuson, 2007 [6]. Experimental study on sand and slurry jets in water was performed by Hall et al., 2010 [7]. Azimi et al., 2012 [2] has investigated particle-laden turbulent jets in still water with giving special emphasis on effect of particle size and nozzle diameter. They have measured frontal velocity along the centre line of the jet axis and compared to that of single-phase buoyant jets and particle thermals. The authors have also found that the jet front settling velocity of small particles was as large as 5 times that of the individual particle settling velocity. So it can be seen that many studies have been conducted on jets giving emphasis on different parameters. In this paper, results from an experimental study performed on sand jet front in stagnant water with special emphasis on nozzle diameter and different masses of sand particles of same size are discussed and presented.

In this current study, the main objective was to see how the frontal velocity and terminal velocity of the falling sand cloud varies with the following:

i) Nozzle diameter
ii) Different sand masses

II. EXPERIMENTAL SETUP

A schematic diagram of the experimental setup is presented in the following Fig. 1. All experiments were conducted in a 133 cm. square tank which was filled with tap water. The tank was open at top and was rested on a solid base and the four vertical faces were of glass. The depth of water in the tank was always kept as 192 cm. Three different diameters of plastic nozzles were used and the nozzles were controlled by a thin moveable plate which was pivoted around a pin. The plate was actuated by a computer controlled solenoid valve and a spring for operating the nozzle without disturbing the jet and the water surface. The sand mass was released into the nozzle through a funnel. The release point of the sand mass was kept 5 mm. above from the free water surface. An optical probe was held at different positions to register the voltage data when sand mass passes through the probe face. The collected voltage data in a computer (which was connected through wire with the probe) could be analyzed with a written MATLAB code to get the frontal velocity of the sand cloud at different locations and thus the variation of frontal velocity could be measured.

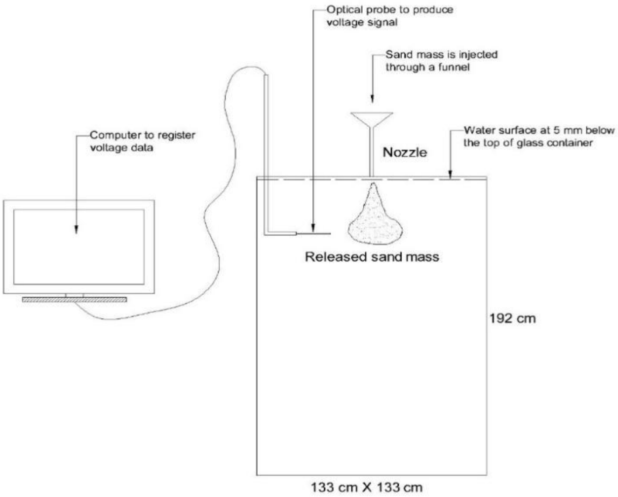

Figure 1: schematic diagram of the experimental setup

As mentioned before, three types of nozzle diameters have been used in the study. They are large, medium and small. The diameters of the nozzles used for the experiment are given in the following TABLE 1.

Table 1: Nozzle diameters used in the study

Nozzle type	Nozzle diameter, (cm)
Large	20
Medium	15
Small	10

As the diameters of the nozzle get lower the amount of sand mass it can contain also gets lower and thus it was not possible to use same range of sand masses for all different nozzles. So, different ranges of masses were used for different nozzle sizes. Details of these distributions are given in the following TABLE 2.

Table 2: Different sand masses for different nozzle sizes

Large Nozzle	Medium Nozzle	Small Nozzle
20g	10g	10g
30g	20g	15g
40g	30g	20g
50g	40g	25g
60g	50g	30g
70g	60g	
80g	80g	
120g	100g	
160g	110g	
200g	120g	

The optical probe was set at six different locations for measuring the frontal velocity of the falling sand clouds. They are given in the following TABLE 3.

Table 3: Different probe positions from free water surface

Position #	Distance from free water surface, cm
1	15
2	25
3	35
4	45
5	60
6	70

III. MECHANISM OF VELOCITY CALCULATION

In this experiment, an optical probe has been used to calculate sand cloud frontal and terminal velocity. The probe cannot give the velocity directly. So it is necessary to explain briefly how sand cloud velocity has been measured from the experiments. The main theme of the velocity calculation is presented in the following Fig. 2. In the following figure, we can see the face of the probe from which two electrical laser beams are emitted. These two beams are separated from each other by a distance, d (m) vertically. When sand mass is released from the nozzle it starts to fall and eventually sand particles pass through probe face. While a sand particle hit the first beam, the probe gets a voltage signal which is registered in to the computer. Similarly, when the same sand particle hits the second beam, again a voltage signal is registered. In a similar manner we get two series of voltage signals. The second series lags from the first one by a definite margin. This lag is the required time for a sand particle to pass through these two laser beams. The distance between the beams is already known. So the velocity can now be easily calculated using the formula shown in the figure.

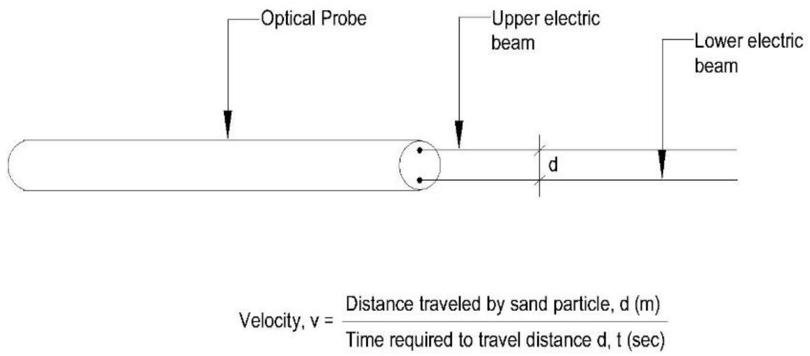

Figure 2: velocity measurement of sand particle using electric probe

3.1 Few samples of voltage signals

In the current study, 6 probe positions were used for each sand mass and nozzle diameter. For the three nozzle sizes, 25 sets of sand masses have been used among them 10 for both large and medium nozzle and 5 for small nozzle (TABLE 2). For each sand mass, 6 probe positions were used which means in total 6 X 25 = 150 experiments have been conducted and thus 150 voltage signals had been registered. All of them cannot be presented here. That is why two of them are presented below just for illustration purpose. The first of them is for large nozzle and 40g sand mass and for the position 15 cm from free water surface which is presented in the following Fig. 3. From the figure, we can see two series of voltage signals namely Series1 (blue) and Series2 (red). The Series1 signal comes when particles hit the first beam (upper beam) and Series2 signal comes when particles hit the second beam (lower beam). As a single particle takes some time to travel the distance between these two beams, the second beam lags from the first one which is clear in the figure and marked with two arrowheads. Now, from the known distance, d and this lag time, t; the velocity can be calculated very easily as v = d/t.

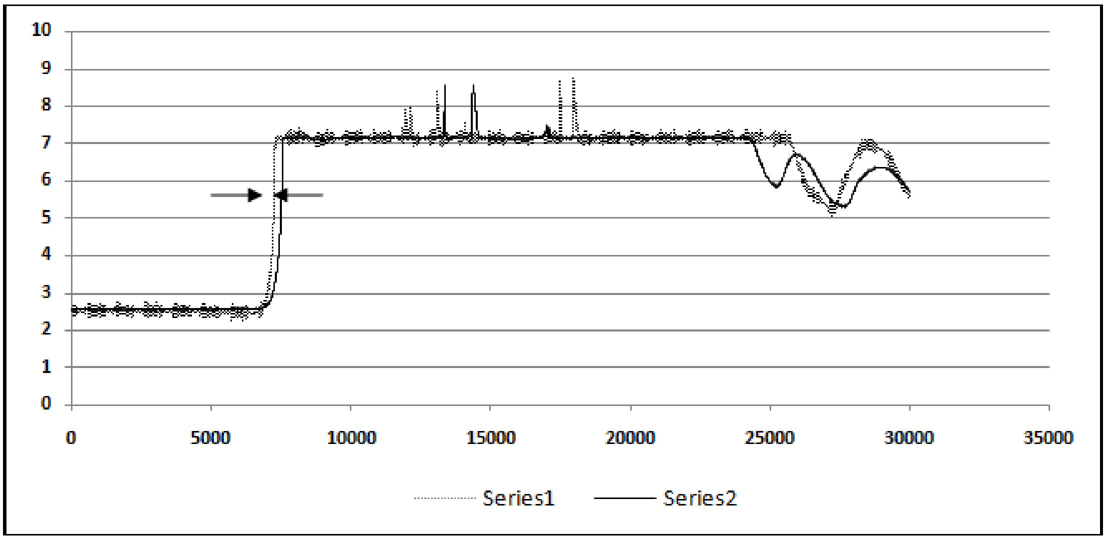

Figure 3: voltage signal for sand mass 40g and large nozzle at position 15 cm.

Similarly, for the same large nozzle and 40g sand mass, voltage data has been registered in a different position which is 45 cm below the free water surface. As the sand cloud falls more distance the frontal velocity reduces because of which the lag time increases between the two voltage signals. This phenomenon is vividly visible in the following Fig. 4 from which we can see that the lag time has been increased as the velocity of the sand cloud decreased at this location. In this way all the voltage data has been analyzed and the frontal velocity for different sand mass and nozzle diameter at different positions has been calculated.

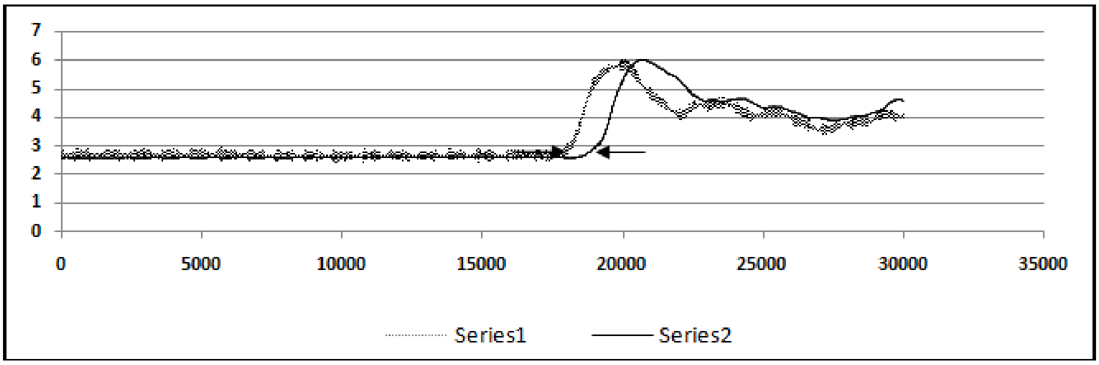

Figure 4: voltage signal for sand mass 40g and large nozzle at position 45 cm.

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1 Effect of Mass

Though several experiments have been conducted for several sand masses, nozzle diameters and probe positions, some selected results among them will be presented here for avoiding clumsiness. As in case of small diameter nozzle, maximum sand mass that could have been used for experiment was 30g and thus it did not provide good results for comparison purposes. So main focus has been devoted to large and medium size nozzles and for each nozzle type, results for 20g, 40g, 60g and 80g sand masses will be presented and discussed here. The extent of probe positions varied from 15 cm to 70 cm vertically. So after 70 cm no measurement was taken and for this reason for larger sand masses, the frontal velocities not necessarily reached to terminal velocity. Now, the first result is shown below for different sand masses for the large diameter nozzle and presented in Fig. 5.

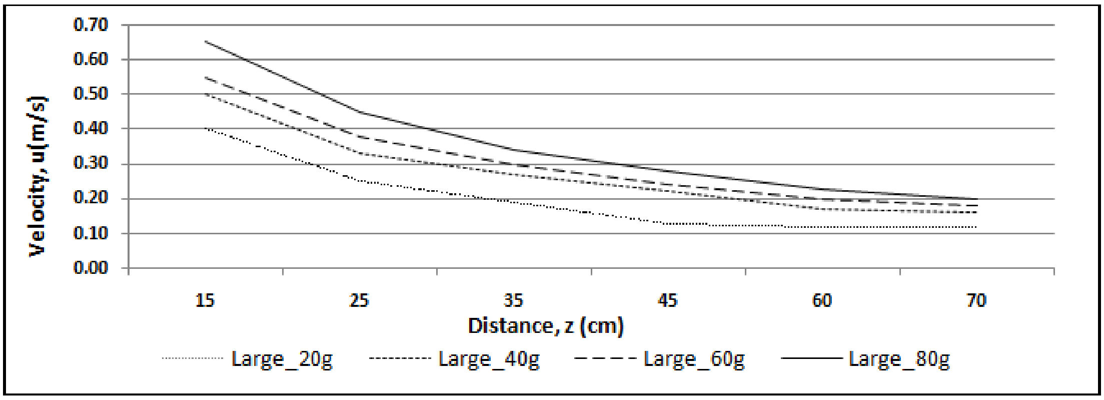

Figure 5: variation of sand frontal velocity with different masses for large nozzle

From the above figure, we can see that for all of the sand masses the sand cloud frontal velocity decelerates and attempts to reach to terminal velocity at different locations. For example, for 20g sand mass it can be seen that the front velocity decelerates quickly and attains terminal velocity around 45 cm depth whereas for the 40g sand mass it appears a little later around 60 cm depth. From the trend of frontal velocity of larger sand masses like 60g and 80g, it can be seen that the frontal velocity is still decelerating up to 70 cm. As no velocity measurement has been conducted after 70 cm, we cannot tell accurately at which depth the terminal velocity is going to be attained. The reason behind it can be thought of as sand mass increases the particle interaction also increases and it takes longer time to separate them from the initial cloud and thus terminal velocity is attained later. Also higher sand mass gets initial momentum very high and they fall very fast initially and the particle-particle interaction starts to get reduced far from the nozzle and thus the terminal velocity occurs at larger depths as at terminal velocity the particle-particle interaction is least and so as the front velocity and at that period the sand cloud gets bigger and bigger and finally it falls with almost round ball shaped cloud with particles dispersed enough to act almost individually rather than acting as a group. This phenomenon of sand cloud dispersing into a large ball shaped dispersed particle group is presented in the following Fig. 6. The photos have been taken with personal digital camera during the experiment in the Stratified Fluid Flow lab of University of Alberta. From the figure we can observe that, initially sand mass falls with a heading front followed by tailing sand mass. This is clear from the 1st part of the Fig. 6 which was taken after 3 sec of sand mass release. From the second part it can be seen that the initial heading and tailing fronts almost disappeared and the whole mass has been converted to a round shaped cloud and the particles are dispersed more and this part of the photo has been taken after 7 sec of release from the nozzle.

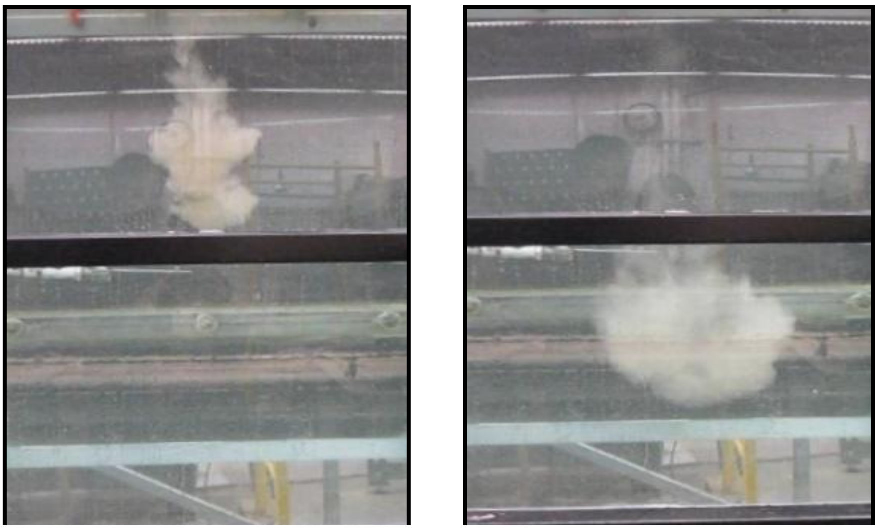

Figure 6: 80g sand mass released from large nozzle and pictures taken at 3 and 7 seconds from the time of releasing

Similarly, for the medium nozzle, the front velocity variation for the same sets (20g, 40g, 60g and 80g) of sand mass has been calculated and plotted which is presented here in Fig. 7. Almost similar trend as for large nozzle has been observed for the medium nozzle for different sand masses.

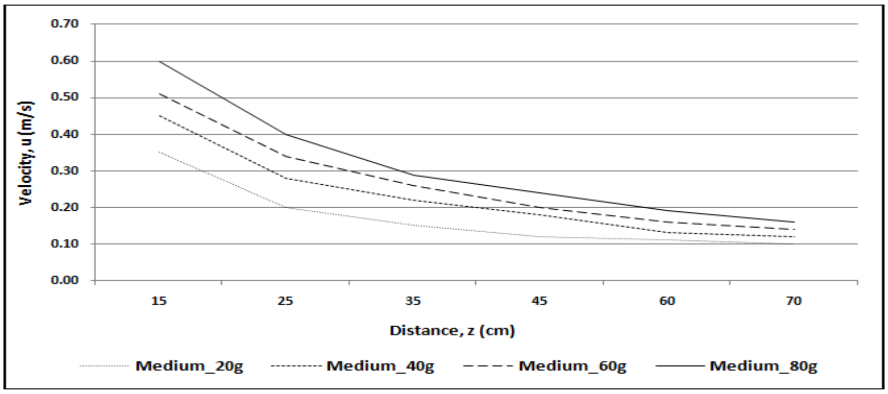

Figure 7: variation of sand frontal velocity with different masses for medium nozzle

4.2 Effect of nozzle diameter

For a definite sand mass, frontal velocity variation for different nozzle diameters have been calculated and plotted in Fig. 8 and 9. In Fig. 8, 20g and 40g sand mass frontal velocities are shown, and in Fig. 9, 60g and 80g sand mass frontal velocities are shown with respect to large and medium nozzles.

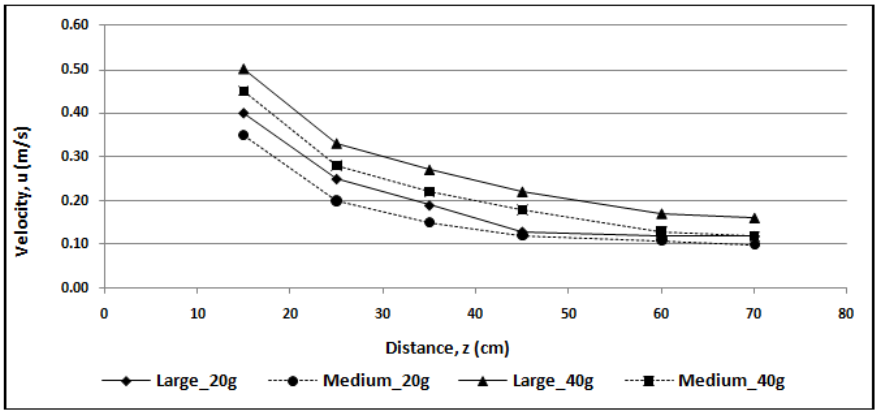

Figure 8: variation of sand frontal velocity with different nozzles (20g and 40g)

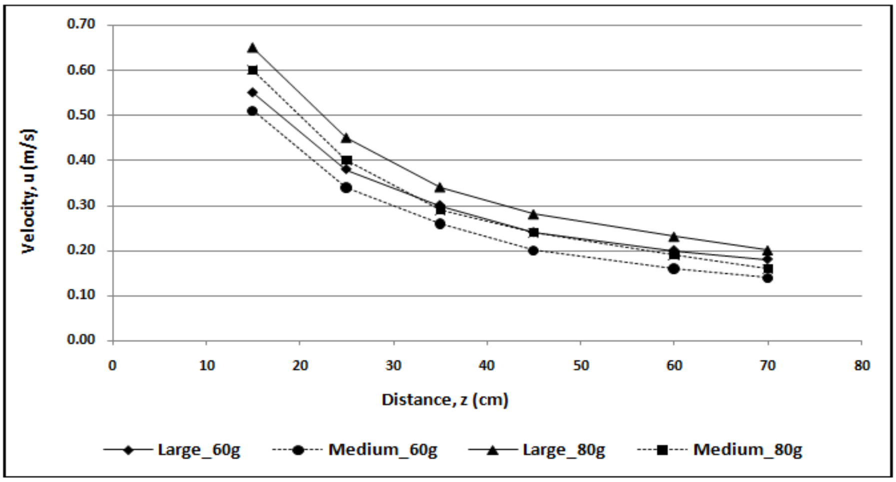

Figure 9: variation of sand frontal velocity with different nozzles (60g and 80g)

In the following Fig. 10, variation of frontal velocity has been plotted in a dimensionless form. The distance z has been normalized with nozzle diameter, d and the frontal velocity (u_f) has been normalized with terminal velocity u_∞. From the normalized result we can see that, for a definite nozzle size, the variation of normalized frontal velocity with different masses fall in a very narrow band.

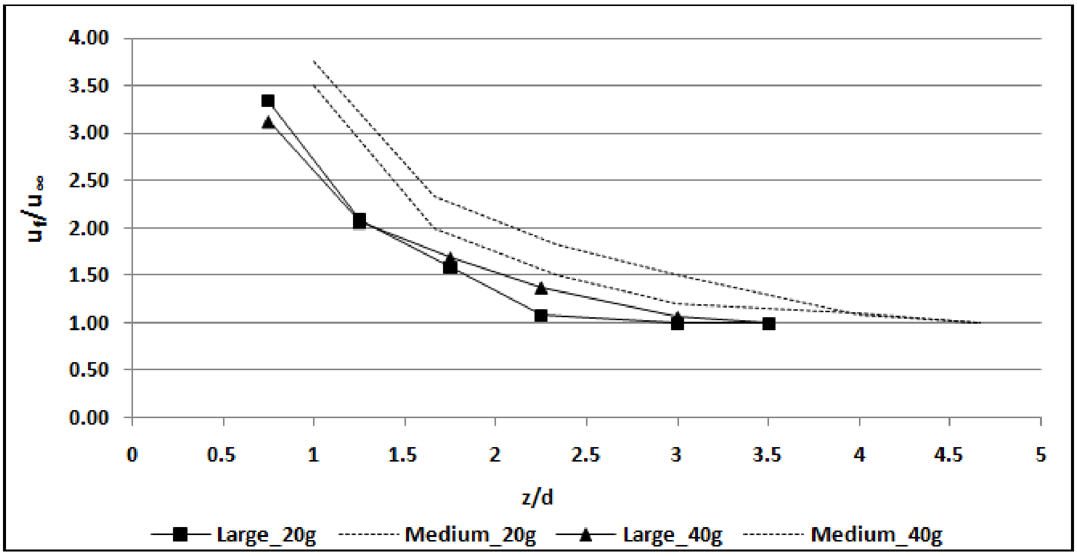

Figure 10: non-dimensional frontal velocity and distance

V. CONCLUSIONS

- Particle-particle interaction is dominant near the nozzle exit point which is apparent from the diverse frontal velocity values as can be seen in the plots.
- As the initial sand mass falls more distance, the frontal velocity decelerates and attains almost a constant value which can be regarded as the terminal velocity and in all cases the terminal velocity is greater than the particle velocity of 5 cm/s.
- After some distance from the nozzle particle starts to disperse and acts almost singly.
- As jet falls, heading front starts to disappear and sand jet falls with settling velocity by forming a sand cloud which is clearly understood from the plot of front velocity values as the terminal velocities for different masses and different nozzle sizes are very close to each other whereas the initial front velocity differs in a quite big margin.

REFERENCES

[1] A.H. Azimi, D.Z. Zhu, and N. Rajaratnam, Effect of particle size on the characteristics of sand jet in water, *Journal of Engineering Mechanics, 137*, 2011, 1-13.
[2] A.H. Azimi, D.Z. Zhu, and N. Rajaratnam, Experimental study of sand jet front in water, *International Journal of Multiphase flow, 40*, 2012, 19-37.
[3] B. Metzger, M. Nicolas, and E. Guazzelli, Falling clouds of particles in viscous fluid, *Journal of Fluid Mechanics, 580*, 2007, 283-301.
[4] J.W.M. Bush, B.A. Thurber, and F. Blanchette, Particle clouds in homogeneous and stratified environments, *Journal of Fluid Mechanics, 489*, 2003, 29-54.
[5] M. Nicolas, Experimental study of gravity-driven dense suspension jets, *Journal of Physical Fluids, 14 (10)*, 2002, 3570-3576.
[6] T. Virdung, and A. Rasmuson, Hydrodynamic properties of a turbulent confined solid–liquid jet evaluated using PIV and CFD, *Chem. Eng. Sci., 62*, 2007, 5963-5979.
[7] N. Hall, M. Elenany, D.Z. Zhu, and N. Rajaratnam, Experimental study of sand and slurry jets in water, *ASCE Journal of Hydraulic Engineering, 136*, 2010, 727-738.