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An experimental study of the flow structure in a rectangular sedimentation open channel in the presence of a baffle

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Acoustic Doppler Velocimeter(ADV) has been successfully utilized to capture the flow pattern in neutral and particle-laden flow and mainly to investigate the effect of a baffle on the flow structure in a rectangular sedimentation open channel. In particle-laden flow a substantial deviation of flow pattern from uniformity was observed. The existence of density-current flow in the presence of particles was confirmed. At higher inlet concentrations the bottom current was observed to be stronger. Also in the presence of the baffle fully developed flow has been noticed in its upstream. In addition, the existence of strong degree of spatiality and high levels of turbulent intensities was identified in downstream of the baffle. Importantly, by using a smoothing method a peak structure has been found in the space averaged power spectra of streamwise and vertical velocities. It was found that baffle causes the peak structure to be alleviated downstream the baffle for the streamwise component and not for the vertical one. As a result the baffle affects on the streamwise energy dissipation and not on the vertical energy dissipation.

Key Words: *Velocimetry, Sedimentation, Baffle, Power spectra, ADV.*

1. Introduction

Sedimentation is an important process to remove inorganic settleable solids from raw water by gravitation[1]. Since efficiency of a settling tank strongly depends on its flow field, investigating the structure and characteristics of the flow field is of great value[2]. The performance is influenced by turbulence levels and hydraulic phenomena such as flow recirculation, existence of dead zones and short circuiting along the tanks [3),4)].

Settling tanks fall into two main categories termed as primary and secondary (final) sedimentation tanks. Primary sedimentation tanks are designed to reduce the particulate flow velocity and provide the settling of organic solids [5]. The sludge in these tanks is not activated [5] and hence the particle concentration is low and there is not a large difference between particle sizes [6),7)]. As a result the flow is not much influenced by concentration distribution [7]. But in a final sedimentation tank the particle concentration in settled sludge is relatively high, resulting in significant density effects [6),7)]. Also a wide range of particles with various sizes can be found [8]. In a prototype test, Anderson compared the flow fields in primary and final settling tanks of similar geometries and hydraulic loadings. In the primary clarifiers, flow was observed to be along the surface from inlet to outlet [8] . On the contrary, the sludge concentration in the secondary-clarifier inlet resulted in a density current along the bottom, causing reverse flow at the surface [6].

Importantly, provision of baffles or solid walls in settling tanks has been considered by several researchers as a simple structural modification to alter the flow field [6),9)] to improve the performance of such tanks.

Basically, flow over a standing baffle (step) can be regarded as a combination of flows over the Backward-Facing Step (BFS) and the Forward-Facing Step (FFS)[10].

It is reminded that the flow characteristics over the Backward- and the Forward-Facing Step were studied by several researchers e.g. Armly *et al.* [11] or Largeau and Moriniere [12]. Regarding the flow over steps in horizontal channels the positive steps(FFS) and negative steps (drops or BFS) have been the focus of various studies [13),14)].

Therefore, although the geometry of a baffle is very simple, flow over it has strong spatial and temporal complexity [10)].

Lyn and Rodi[15)] conducted turbulence measurements by a Laser-Doppler Anemometry system in a rectangular laboratory settling tank to study the flow fields from a plane jet impinging on two types of deflector. Studies of Bretscher *et al.*[9)] on velocity and concentration fields in a rectangular settling tank with a central barrier wall showed the effectiveness of the baffle. Ahmed *et al.*[4)] have investigated the effect of positioning and height of baffles on the flow pattern and on the suspended solid distribution qualitatively in a sedimentation laboratory tank(both for clean and suspension waters) by inserting the baffle from the top at three different positions and with various heights. It was found that the baffle position has a significant effect on the flow patterns and suspended solid concentration by influencing the direction of flow and affecting the size of dead zones. Studies of Taebi-Harandy and Schroeder [16),17)] indicates that effectiveness of the intermediate baffle depends strongly on the predominant flow pattern. This means that baffle can have completely different effect in the presence of a bottom density current compared to the case that a surface density current forms. Tamayol *et al.* [18)] also investigated the effect of positioning of baffle in secondary settling tanks numerically and reported the influence of buoyancy forces in the proper positioning of baffle. Tamayol *et al.*[19)] investigated the effect of baffle configuration on the hydraulic performance of the primary settling tanks and determined its optimal position by computer simulations. Jamshidnia and Takeda[10)] have studied effect of baffle on the spatial and temporal structure of flow in pure water experiments by using UVP(Ultrasound velocity Profiler) and could successfully characterize the multi-dimensional nature of the complex flow structure and the various flow phenomena around a standing baffle such as large recirculation region behind the baffle.

Jamshidnia *et al.* [20)] studied the effect of a standing baffle on the flow structure in along a rectangular open channel in the absence of particles by an ADV. They also showed the existence of a highly spatial flow pattern at downstream portion of the baffle.

It is notable that relatively few detailed measurements of the flow field characteristics of settling tanks are available and thus further investigations are necessary [10)].

Considering the above points, complex flow structure of flow and lack of detailed experimental studies this study is undertaken to obtain a better understanding of the flow field and to investigate experimentally the effect of a standing baffle on the structure of that flow in a quantitative manner. Also a comparison is done on the mean streamwise velocities in particle-laden and neutral flow to capture the difference of streamwise mean flow field in the presence of particles.

To the authors' best knowledge, the effect of a standing baffle on the flow structure, especially on its temporal structure, in a rectangular sedimentation open channel has not been not reported in the literature systematically.

2. Experiments

2.1 Experimental set-up

A specially designed unit (**Fig.1**) at Fluid Mechanics Laboratory of the Mechanical Engineering Department at Sharif University of Technology (Iran) has been utilized for the experiments. Water from the main supply tank was directed by a pump to a storage tank. Then prepared flow was pumped from this tank to the constant head tank to keep the inflow rate unchanged. Fluid travels from this tank to the main channel via a flow meter. A two level damping screen was installed at the inlet to distribute the inflow as uniformly as possible to achieve the uniform flow distribution along the inlet width and consequently to avoid entrance disturbances.

Experiments were conducted in a rectangular open channel $8\text{m}\times0.2\text{m}\times0.4\text{m}$ in length, width and height (x, y, and z, with x=0 at the upstream end, y=0 in center of channel, and z=0 at the bed), respectively, with a smooth bottom. The slope of the channel is zero in these experiments. The Inlet gate is a rectangular feeding slot with the fixed height of h_0 = 0.11 m extending throughout the channel's full width at the bottom. The depth of water was controlled by a sharp-edged weir of height of 32 cm, located at the downstream end of the channel. In the baffle experiments a thin plate with height (h_b) of 8 cm is located at x=4 m (middle of the channel) and is extended across the full width of the channel. A typical photograph of the installed baffle is shown in **Fig. 2**.

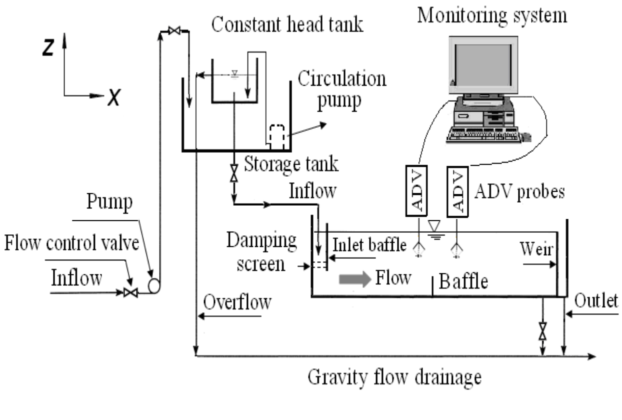


Fig.1 Schematic diagram of the experimental setup

Fig. 2 A photograph of installed baffle

2.2 Experimental Procedures

The streamwise, transversal and vertical velocity components denoted by *u(t), v(t), w(t)* were measured on the vertical longitudinal central plane by a 3D ADV. The corresponding time-averaged velocity components are denoted by *U*, *V*, and *W*, respectively. It is noted that since the experiments have been performed on the vertical central plane the transverse velocity component is less influenced by the sidewalls and 2D flow can be reasonably assumed along this plane.

ADV is based on the principle of Doppler shift of an ultrasonic wave reflected from suspended particles in the fluid flow. ADVs can provide accurate mean values of water velocity in three directions as mentioned by various researchers such as Lohrmann et al. [21]; Kraus et al. [22] ; Anderson and Lohrmann[23] ; Lane et al. [24] ; Lopez and García[25] , and even in low flow velocities as mentioned by Lohrmann et al.[21]. For example, Voulgaris and Trowbridge [26] have evaluated the accuracy of ADV velocity measurements by comparing the results with LDA. They concluded that due to the relatively high accuracy (0.1 mm/s) and the inherently free from drift velocity, ADV can be considered as a suitable and reliable device for accurate measurement of mean flow(with applicability to opaque flows) even at positions close to the boundary(z=0.75 cm) [26),27)]. ADV's small sampling volume is located approximately 5cm away from the probe, which provides noninvasive measurements. The 3-D velocity range is 2.5m/s and the velocity output has no zero-offset [19)].

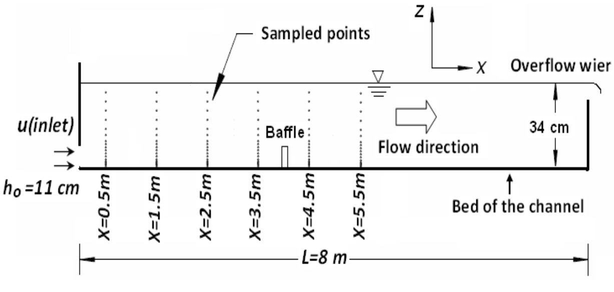


Fig. 3 Schematic of open channel and measurement sections

Two previously calibrated Nortek 10-MHz ADV probes are mounted on a carrier with 1m distance from each other. Since down-looking ADV probes were used measurements performed from the top to the bottom by dipping the probes until all the desired points were measured.

It is noticeable that the data acquisition near the free surface was not possible because if the downward-looking probe of ADV would be out of water, the change of sound velocity in air and water would lead to poor quality data. Thus the measurements could be performed only up to z/H =0.7.

Data at each point collected for about 30-40 sec. at the maximum available sampling frequency of device (25 Hz) which were found to be sufficient and accurate enough to compute average values for such a kind of study. It is noted that prior to each set of experiments the particles should be mixed properly in the storage tank. Therefore, to measure velocity at all spatial points the measurement duration at each point was limited to 30 to 40 s due to the limited capacity of the storage tank.

Fig. 3 illustrates the details of the channel and measured sections. The experimental program was divided into three phases. In the first phase, neutral flow (pure water) was used. Tracer particles were added to tap water to provide adequate return signal strength for better quality measurements. Density of tracers is near density of water and their diameter is 10 µm. In the second phase, a well-mixed slurry of known concentration (namely C = 400 mg/lit and C = 1000 mg/lit) entered the channel at the same inlet and outlet conditions as for the pure water experiments. For particle-laden flow fine kaolin particles (d50, 18µm) were used for preparing the mixture. In the third phase a baffle (thin plate) installed in the middle of the channel resting vertically on its bed.

2.3 Experimental conditions

Inlet flow rate denoted by Q_o was fixed at 35.5 (lit/min) corresponding to the maximum established flow rate in the open channel. This flow rate yielded a total water depth of H=34 cm and an average bulk velocity of $U_{Ave.}= Q_o/A$ = 8.7 mm/s, where A denotes cross-sectional area of water layer. The value of Re numbers, $Re(D_h) = U_{Ave.} D_h / \nu$, based on the hydraulic diameter, D_h) and $Re(H) = U_{Ave.} H / \nu$, (based on the total depth of water, H), are 2690 and 2946, respectively. Similar to experiments of Lyn and Rodi [15)] the traditional hydraulic modeling criteria has been borrowed from pipe studies and thus $Re(D_h)$>2000 is considered as a criterion for turbulent flows in the present experiments. As a result flow in the channel is fully turbulent. The value of the Froude number, $Fr = U_{Ave.} / \sqrt{gH}$ is 0.0259 which corresponds to subcritical flows. Although in this study the Froud number is small and a Froud number model law is usually used in other hydraulic modeling problems, similar to study of Lyn and Rodi[15] the view is that, if $Fr << 1$ and reproducibility was not a problem, it is unnecessary to have strict adherence to the Froude–number similarity. It is noted that in the absence of sediment or density differences, the Froude number has no significant role to play.

This approach was used by Lyn and Rodi[15]. But for particle-laden experiments the value of densimetric Froude number, $F_d = U_o / (\Delta\rho . g . h_0 / \rho_W)^{0.5}$, is 1.63 and 1.03 for C=400 and 1000 mg/lit, respectively. The density difference is given by $\Delta\rho = \rho - \rho_w$ in which ρ is the density of the mixture and ρ_w is the density of pure water respectively.

3. Results and discussions

3.1 Spatial Structure

Since the Doppler signal might cause spikes to appear in ADV time series data [28] despiking has been performed on the velocity components using WinADV™ software and all associated data are removed when a spike is detected. The despiking is based on the Robout Phase-Sapce Despiking Algorithm proposed by Wahl [29]. It was found that, on average, only a small fraction of spikes exist in the data(approximately 5%). Thus, on average, 95 % of data are free from spikes.

Also for removing noise from raw data filtering was performed by WinADV™ software. It was based on removing data points not meeting lower limit for correlation(COR). Thus data points were removed when the COR of ADV data is less than 70 %(for the 3-beam averages). Finally, filtered velocity data were used to calculate the time-averaged velocity profiles.

For our measurements the values of Signal to Noise ratio (SNR) was found to be high enough (40 db on average) providing reasonable quality for reliable velocity measurements.

It is noted that since the ADV measures the velocity of suspended particles it is assumed that the particles and fluid travel at the same velocity. As also mentioned by Hosseini *et al.* [30] this assumption is likely to be valid when dealing with fine sediment, dominantly in suspension which is also the case for our study.

3.1.1 Repeatability of the data

To make sure of quality and accuracy of data each experiment is performed twice under identical conditions. Results indicate that there is a high degree of reproducibility of data. Typical results of velocity profiles of different repeats are shown in **Fig. 4.** The horizontal axis is the time-averaged streamwise velocity (U) which has been made non-dimensional by average bulk velocity ($U_{Ave.}$) and the vertical axis represents the height(z) relative to the total depth of water (H=34 cm). It is reminded that since a downward-looking probe was used, the acquisition of data could not cover the free surface. Thus the measurements could cover only up to z/H=0.7 .

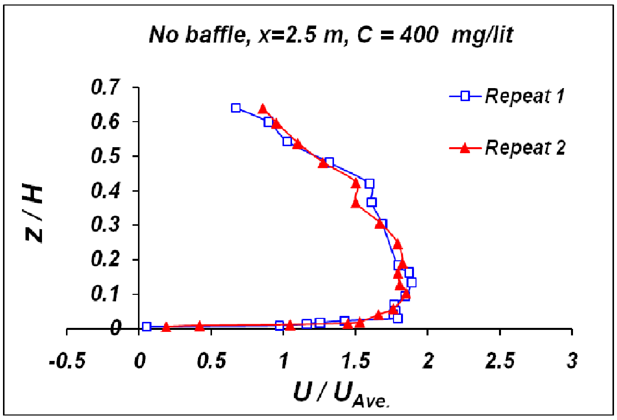


Fig.4 Typical results of two repeats

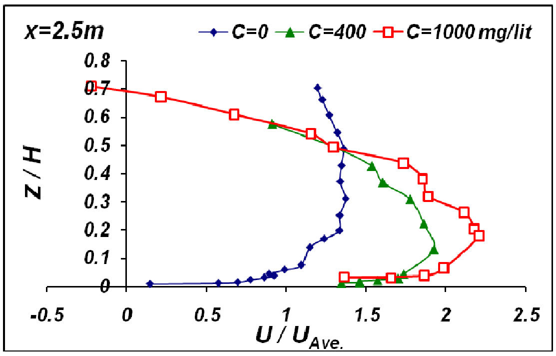
3.1.2. Effect of different concentrations

Fig. 5 represents time-averaged velocity profiles at various sections for the neutral and particle-laden flow at different inlet concentrations. Comparison of time-averaged velocity profiles of neutral and particle laden flow at various sections indicates that a density current flow is induced in the presence of particles while in the absence of the particles the velocity profiles are uniformly distributed in a main part of depth of the channel. Also comparison of velocity profiles at low inlet (C = 400 mg/lit) and high inlet (C = 1000 mg/lit) concentrations reveals that at higher inlet concentrations the bottom current is stronger and its velocity profile has larger maximum near the bed. For higher concentration the hydrodynamic flow pattern deviates substantially from uniformity and a very strong bottom current is observed. When particles exist in the flow the gravitational force acts on them. Thus they move toward the downward direction. For the case of high concentration since the number of particles is larger in the flow, a larger number of particles tend to move downward and thus a strong current appears more significantly near the bottom of the channel which is knows as density-current. In addition, for higher concentrations the magnitude of velocities is near zero or negative at the upper part of the channel. In fact the bottom current is strong enough that causes a strong velocity gradient between fluid layers and generation of a surface return flow. These observations confirm the existence of a density current in the presence of particles.

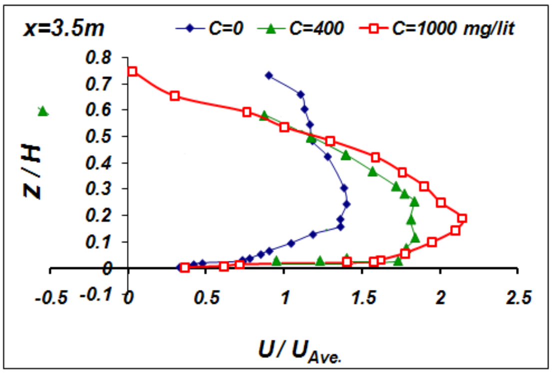
3.1.3 Effect of baffle

Variation of streamwise time-averaged velocity profiles is shown in **Fig. 6.** Near the inlet at x=0.5m (x

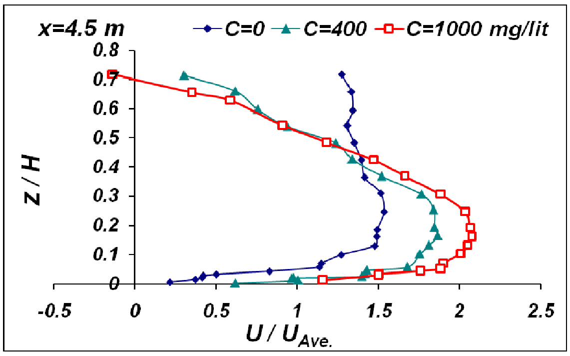
denotes the distance of a measurement section from the inlet) a jet flow is observed near the bed. At *x*=1.5m the density current flow has been induced to some extent. This is reasonable because this section is far away from inlet and is not under the strong influence of inlet jet.



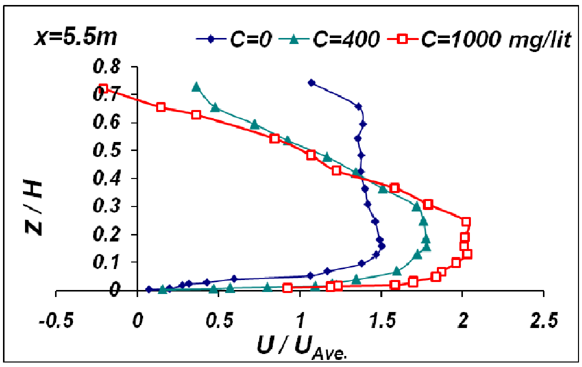
(a) *x*=2.5m



(b) *x*=3.5m



(c) *x*=4.5m



(d) *x*=5.5m

Fig.5 Comparison of flow at different concentrations

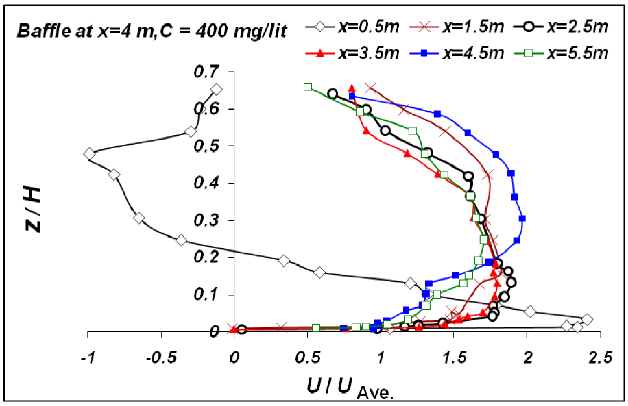


Fig. 6 Time-averaged streamwise velocities (Baffle at x = 4m)

Much downstream of the inlet region (x = 2.5 m and x = 3.5 m) the flow seems to be fully developed to some extend because a small difference of mean velocity profiles along the streamwise direction appears between x =2.5m to x= 3.5m. But at downstream of the baffle (x=4.5m) the flow pattern deviates from upstream ones.

Downstream of the baffle at x = 4.5 m velocity profile has a maximum (at z/H = 0.3), which can be due to an abrupt decrease in cross-sectional area at x = 4 m where the baffle exists. Behind the baffle, a recirculation region exist which can also be the reason of higher average velocity at x = 4.5 m.

Further downstream a density current is again going to be developed near the bed because the maximum of velocity happens to be at lower position ($z/H = 0.25$). Additionally, the value of the maximum velocities near the bed has been decreased for downstream sections which indicate the decrease of the velocity of the bed jet. These observations indicate the influence of the baffle on the flow pattern for the downstream sections.
The time-averaged vertical velocity profiles have been represented in **Fig. 7.** It is noted that since ADV measures velocity of suspended particles it is assumed that particles and fluid travel at the same velocity.
Negative velocities at x = 2.5 m indicate that flow is on average downward, still under the effect of the inlet. But at x = 3.5 m the magnitude of the negative

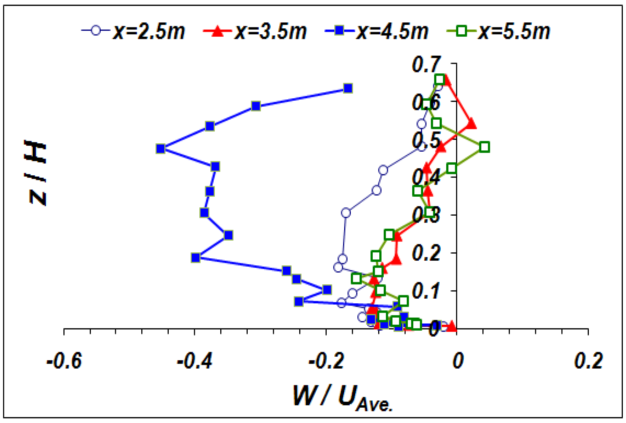


Fig. 7 Time-averaged vertical velocities
(Baffle at x = 4 m)

velocities tends to zero indicating that the flow at x = 3.5 m might be influenced as a result of expected uprising flow at upstream of baffle. It is noted that existence of uprising flow at upstream of a baffle has been quantitatively confirmed by Jamshidnia and Takeda[10].

Negative velocities at x = 4.5 m can be as a result of the recirculation region behind the baffle which causes the fluid to flow toward the bed as a result of change of effective cross-section in downstream of the baffle. Also at the same time the effect of gravity force on particles can be another supportive reason for the existence negative (downward) velocities with relatively high magnitude.

Further downstream of the baffle, because relatively small velocities appear at x = 5.5 m, this section may be under a slight effect of recirculation. It is reminded that measurements were only made up to z/H = 0.7.

It is noted that behind the baffle at x = 4.5 m the values of the mean vertical velocities become much larger than upstream of the baffle at x = 3.5 m. Therefore, a baffle causes a high spatial flow pattern at its downstream portion.

Fig. 8 shows the profiles of streamwise turbulent intensities in the presence of the intermediate standing baffle.

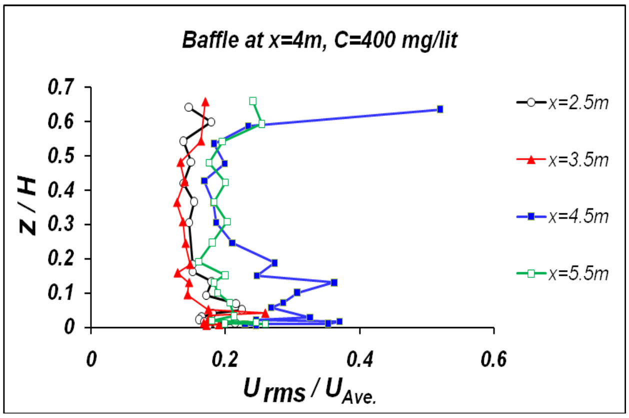


Fig. 8 Turbulent intensities of streamwise velocities (Baffle at x = 4 m)

As it can be observed immediate downstream of the baffle at x = 4.5 m the magnitude of turbulent intensities has been increased compared to the sections at upstream of the baffle(x = 2.5 m and x = 3.5 m). Thus it can be concluded that baffle causes the turbulent intensities to be increased at its downstream. It is observed that streamwise turbulent intensity near the water surface at x = 4.5 m become large. If we compare figures 6 and 8, the reason can be found. At x=4.5 m, the maximum velocity is greater and the location of this maximum is also closer to the free surface. This can cause a higher velocity gradient and consequently higher shear stress. Therefore, the turbulent intensity increases due to higher streamwise velocity gradient.

Further downstream of the baffle as the distance from the baffle increases(x = 5.5 m) the magnitude of turbulent intensities will decrease.

3.1.4. Discussion on two-dimensionality of flow

In order to provide a more detailed picture of spatial variation in flow structure (uniform flows do not vary spatially, whereas non-uniform flows do[31]) and somehow on the degree of two dimensionality of the flow also to investigate the effect of baffle on the structure of flow quantitatively vertical distributions of the ratio of vertical to streamwise time-averaged velocities (W/U) at each spatial point has been plotted in **Fig. 9** for the case of C = 400 mg/lit. A considerable increase in W/U is observed at downstream of the baffle (x = 4.5m) whereas this is not the case for upstream of the baffle.

Thus this illustrates quantitatively the existence of a highly spatial flow pattern as a result of change of flow direction on its pass over the standing baffle. Much downstream of baffle at x = 5.5 m the magnitude of W/U and its variation has been decreased. Hence it can be concluded that flow at x = 4.5 m is strongly influenced by the existence of the baffle than x = 5.5m.

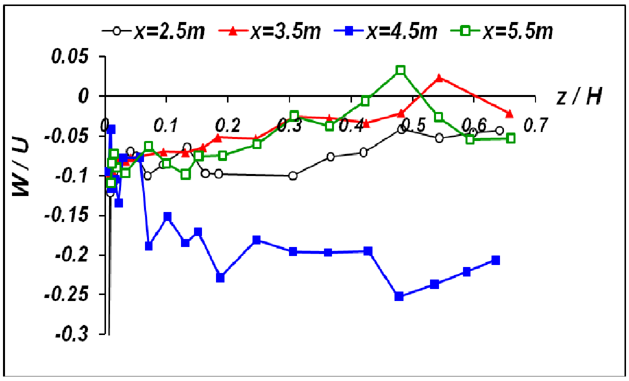


Fig. 9 Ratio of vertical to horizontal time-averaged velocities (Baffle at x = 4 m)

3.2 Temporal structure and power spectra

Discrete Fourier Transform (DFT) has been used to extract the power spectra to understand the temporal structure of the flow and to detect the temporal periodicity in the velocity. By definition, power spectrum gives the portion of velocity signal power falling within a certain frequency range. Its peak corresponds to most commonly occurring frequency [32]. Temporal periodicity refers to the oscillation of flow at that particular frequency as an important physical quantity. Importantly the effect of a baffle on the temporal structure is of great interest.

3.2.1 Methodology

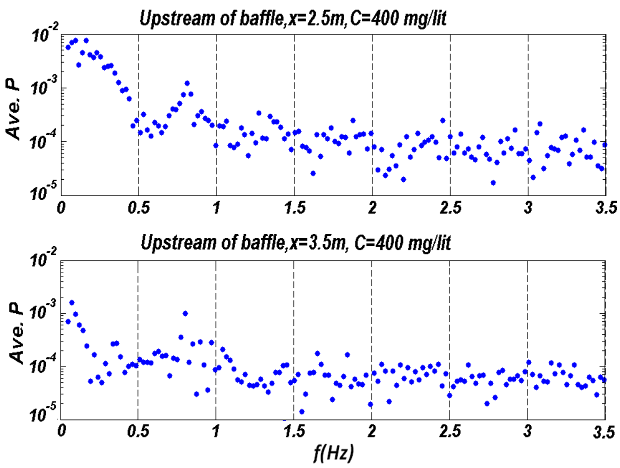
The power spectrum obtained from raw data of velocity time series was found to be quite noisy. For elimination of the noises to some degree and proper observation of peak structures a method has been used for smoothing. We represent velocity time series at each spatial point by $u[n]$ in which $n \in \{1,2,3,...,N\}$ and N is the number of samples. Then $u[n]$ is divided into two time series u_1 and u_2 as follows: $u_1[n]$: $n \in \{1,3,...,N-1\}$, $u_2[n] : n \in \{2,4,...,N\}$.

The DFT is applied separately to each of the subdivided time series to extract their power spectra and then ensemble average of the results is calculated over frequency to obtain the smoothed power spectrum at each point. Although there are special characteristics observed to be space-dependent in the power spectra attention has been focused on the space averages of the power spectra. By taking the space average of power spectra the peak structure could be observed apparently.

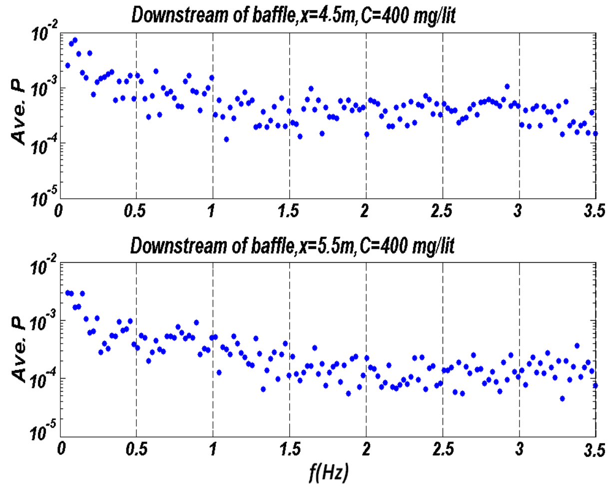
3.2.2 Effect of baffle on power spectra

To investigate the baffle's effect on the temporal structure of the flow space averaged power spectra were investigated over different ranges of heights around the baffle. As it is shown in Figs. 10 and 11 a spatial peak structure exists for $0.08 \text{ m} \le z \le 0.12 \text{ m}$.

Figs. 10 and 11 illustrate the space averaged power spectra of the streamwise and vertical velocity time series for the case of particle-laden flow(C = 400 mg/lit). The ordinate represents the amplitude of space averaged power spectra ($AVE\ P$) and the abscissa is frequency (f). A clear peak structure is observed in low frequencies (around 0.8Hz) upstream of the baffle. This spatial peak structure indicates the existence of a temporal periodicity in the velocity with a specific frequency which exists over a specific range of space. Temporal periodicity refers to the oscillation of flow at that particular frequency which is the most commonly occurring. By taking the average of the spectrum over space the random noise in the spectrum is canceled and a clearer peak structure can be observed. Since this peak structure and periodicity is observed at x = 2.5 m and x = 3.5m it is not sporadic.

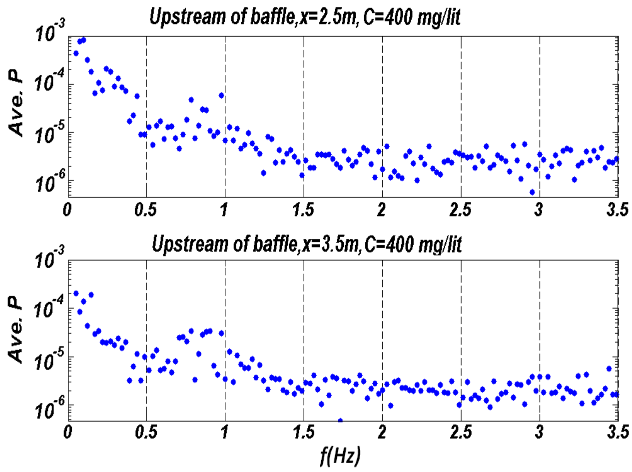


(10a) upstream of baffle: x = 2.5 m, x =3.5 m

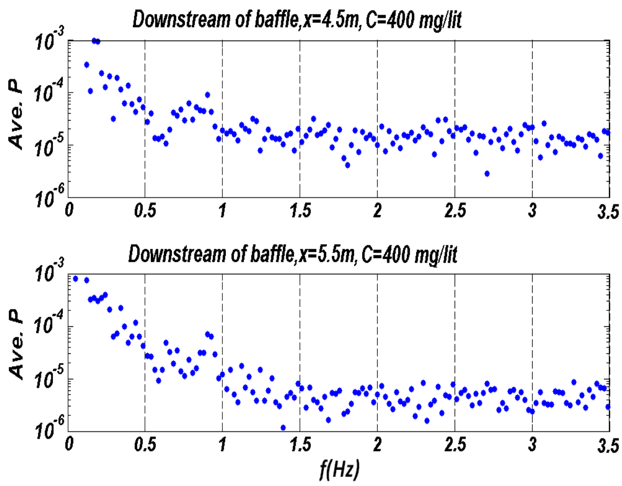


(10b) downstream of baffle: x = 4.5 m, x = 5.5 m

Fig. 10 Space averaged power spectra of the streamwise velocities along the baffled channel(C=400 mg/lit)



(11a) upstream of baffle: x = 2.5 m, x =3.5 m



(11b) downstream of baffle: x = 4.5 m, x = 5.5 m

Fig. 11 Space averaged power spectra of the vertical velocities along the baffled channel(C = 400 mg/lit)

But downstream of the baffle the amplitude of the peak structure is strongly damped out for the streamwise velocity and not for the vertical one.

It is noticeable that the existence of peak structure and the effect of baffle has been discussed and confirmed by Jamshidnia *et al.*[15] for pure water experiments.

The peak structure of the flow is damped downstream the baffle because the baffle works as an obstacle to dissipate the energy of the flow. Since the baffle exerts a horizontal drag force, then, it can be interpreted that the baffle will affect on the streamwise energy dissipation and not affecting the vertical energy dissipation.

4. Conclusions

Effect of the existence of particles on the flow structure as well as effect of a baffle on the flow structure in particle-laden flow has been investigated. Based on the results the following conclusions can be drawn:

1. Existence of density current flow was confirmed in particle-laden experiments.
2. Fully developed flow in the upstream of baffle and far from the inlet has been noticed in the streamwise time-averaged velocity profiles.
3. Baffle causes the levels of streamwise turbulent intensities to be increased significantly downstream of the baffle.
4. A high degree of spatiality is observed at downstream of the baffle in quantitative manner.
5. Space averaged power spectra indicate that there exists a peak structure in the power spectra of streamwise and vertical velocities in the upstream of the baffle. Comparison of the space averaged power spectra of upstream and downstream of the baffle indicates that baffle causes the peak structure in downstream of the baffle to be alleviated for the streamwise component but not for the vertical one. It can be interpreted that the baffle effects on streamwise energy dissipation and not on the vertical energy dissipation.

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REFERENCES

1) Swamee, P.K., Design of flocculating baffled channel, *J. Env'tl Engng,* Vol. 122(11), pp.1046-1048, 1996.
2) Campbell, B.K. and Empie, H.J., Improving fluid flow in clarifiers using a highly porous media, *J. Env'tl Engng.,* Vol. 132(10), pp. 1249-1254, 2006.
3) Shiono, K. and Teixeira, E.C., Turbulent characteristics in a baffled contact tank, *J. Hydr. Res.,* Vol. 38(4), pp. 271-278, 2000.
4) Ahmed, F.H., Kamel, A. and Abdeljavad, S., Experimental determination of the optimal location and contraction of sedimentation tank baffles, *Water, Air and Soil Pollution,* Vol. 92(3-4), pp. 251-271, 1996.
5) American Water Work Association. *Water treatment plant design*, McGraw-Hill, New York (1990).
6) Krebs P., Vischer, D. and Gujer, W.: Inlet-structure design for final Clarifiers, *J. Env'tl Engng.,* Vol. 121(8), pp.558-564, 1995.
7) Tamayol, A., Firoozabadi, B., Ashjari, M.A.: Hydrodynamics of Secondary settling tanks and increasing their performance using baffles, *J. Env. Engng.*, 136(1), pp 32-39 (2010).
8) Anderson, N.E.: Design of settling tanks for activated sludge, *Sewage Works J.*, Vol.17(1), pp. 50–63, 1945.
9) Brescher, U., Krebs P. and Hager, W.H.: Improvement of flow in final settling tanks, *J. Env'tl Engng,* Vol. 118(3), pp.307-321, 1992.
10) Jamshidnia H.R. and Takeda Y.: UVP measurement of flow around a baffle in a rectangular open channel, *J. of Fluid Science and Technology*, Vol. 4, No. 3, pp.758-774, 2009.
11) Armaly, B.F., Durst, F., Pereira, J.C.F.: Schönung, B., Experimental and theoretical investigation of backward-facing step flow. *J. Fluid Mech.* 127, 473-496, 1983.
12) Largeau, J.F., Moriniere, V.: Wall pressure fluctuations and topology in separated flows over a forward-facing step. *Experiments in Fluids* 42(1), 21-40, 2007.
13) Hager, W.H. and Bretz, N.V.: Hydraulic jumps at positive and negative step, *J. Hydr. Res.* 24 (4), pp.237-253, 1986.
14) Hager, W.H. and Singer, R.: Flow characteristics of the hydraulic jump in a stilling basin with an abrupt bottom rise, *J. Hydr. Res.,* Vol. 23(2), pp. 861-866, 1985.
15) Lyn, A. and Rodi, W.: Turbulence measurements in model settling tank. *J. Hydr. Engng.*, Vol. 116(1), pp. 3-21, 1990.
16) Taebi Harandi, A. and Schroeder, E.D.: Analysis of structural features on performance of secondary clarifiers, *J. Env'tl Engng,* Vol.121(12), pp. 911-919, 1995.
17) Taebi Harandi, A. and Schroeder, E.D.: Formation of density currents in secondary clarifiers, *J. Water Res.*, Vol. 34(4), pp. 1225-1232, 2000.
18) Tamayol, A., Firoozabadi, B. and Ahmadi G.,: Increasing performance of final settling tanks by using baffles, *7th Int'l Conf. on Hydroinformatics*, HIC, Nice, France, 2006.
19) Tamayol, A., Firoozabadi, B. and Ahmadi, G.: Determination of settling tanks performance using an Eulerian-Lagrangian method, *J. Applied Fluid Mech.*, Vol.1(1), pp.43-54, 2008.

20) Jamshidnia H.R., Takeda Y. and Firoozabadi B.: Effect of a standing baffle on the flow structure in a rectangular open channel, *J. Hydr. Res.*, Vol. 48(3), pp. 400–404, 2010.
21) Lohrmann, A., Cabrera R., and Kraus, N.: Acoustic Doppler velocimeter (ADV) for laboratory use, *Proc. Symp. on Fundamentals and Advancements in Hydraulic Measurements and Experimentation*, ASCE, New York, pp. 351–365,1994.
22) Kraus, N. C., Lohrmann, A., and Cabrera, R. New acoustic meter for measuring 3D laboratory flows, *J. Hydraul. Eng.*, 120(3),pp. 406–412,1994.
23) Anderson, S., and Lohrmann, A., Open water test of the Sontek acoustic Doppler velocimeter, *Proc., IEEE Fifth Working Conf. onCurrent Measurements*, IEEE Oceanic Engineering Society, St. Petersburg, Fla., pp. 188–192, 1995.
24) Lane, S., et al.: Three-dimensional measurement of river channel flow processes using acoustic Doppler velocimetry." *Earth Surf. Processes Landforms*, Vol. 23, pp. 1247–1267, 1998.
25) Lopez, F., and Garcia, M. H.: Mean flow and turbulence structure of open-channel flow through nonemergent vegetation." *J. Hydraul.Eng.*, Vol.127(5), pp. 392–402, 2001.
26) Voulgaris, G. and Trowbridge, JH.: Evaluation of the Acoustic Doppler Velocimeter(ADV) for Turbulence Measurement, *J. Atmospheric and Oceanic Tech.*, Vol. 15(1), pp.272–289, 1998.
27) Nortek AS.: ADV Operation Manual, 2000.
28) Goring, D.G. and Nikora, V.I.: Despiking Acoustic Doppler Velocimeter data, *J. Hydr. Engng*. Vol. 128(1), pp. 117-126, 2002.
29)Wahl, T.L.: Discussion of Despiking Acoustic Doppler Velocimeter Data. (Goring, D.G., Nikora, V.I.), *J. Hydr. Engng*., Vol. 129 (6), pp.484–487, 2003.
30) Hosseini S.A., Shamsai A., Ataie-Ashtiani B.: Synchronous measurements of the velocity and concentration in low density turbidity currents using an Acoustic Doppler Velocimeter, Flow Measurement and Instrumentation, Vol. 17, pp. 59–68, 2006.
31) McCaffrey W.D.: Chouxa C.M., Baasa J.H. and Haughton P.D.W., Spatio-temporal evolution of velocity structure, concentration and grain size stratification within experimental particulate gravity currents, *J. of Marine and Petroleum Geology*, Vol.20, pp. 851-860, 2003.
32) Lyons, R.G.: *Understanding digital signal processing*. 2nd Edition. Prentice Halle PRT, Upper Saddle River, 2004.

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