

EXPERIMENTAL INVESTIGATION OF VELOCITY DISTRIBUTION INSIDE INVERT TRAP USING 2D PIV METHOD

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In the present study, the velocity distributions inside invert trap of three different shapes with two varying trap depths has been obtained experimentally using 2D Particle Image Velocimetry (PIV). Experiments were performed in a glass-sided rectangular recirculating tilting flume with the trap attached at the bottom of the flume. Two flow depths were selected with a constant channel bed slope. Spherical seeding particles was used for obtaining the flow hydrodynamics and velocity field inside the invert traps. Velocity distribution inside each invert trap configuration obtained through PIV measurements was also plotted by SURFER (Vol. 13.6.618) software. From the above investigation, low-velocity zones have been observed inside each invert trap near the boundary surfaces, corners, and central region. Low-velocity zone decreases at the center region with an increase in flow depth for each depth of traps. With an increase in the depth of each trap, the low-velocity zone increases at the center region at each flow depth. The influence of the low-velocity zone observed in case of the rectangular invert trap with a trapezoidal base was more as compared to other shapes of trap, which predicts more trap efficiency. Average flow velocity in a flume at 0.02 m and 0.04 m depth of flow obtained through PIV measurement were also in good agreement with the velocities measured by Electro Magnetic Flow Meter (EMF).

KEYWORDS: Invert trap, Particle Image Velocimetry (PIV), Trap efficiency, Velocity distribution, Low-velocity zone, Electro Magnetic Flowmeter (EMF).

1. INTRODUCTION

Sediments entering into the sewers and open drains get deposited at the bottom and reduce the discharging capacity which causes spillage of water which leads to the problem of flooding and waterlogging (Buxton et al. 2002; Mohsin and Kaushal 2016). Sediment ejectors, sediment excluders, and sediment trappers are some of the devices used for minimizing the sediment deposition in sewers and open drains for their optimum functioning (Mohsin and Kaushal 2016a, 2016b). Out of the available sediment removal devices, invert trap is a device used to trap the sediment flowing in a sewer or open drains (Chebbo et al. 1996; Kaushal et al. 2012; Mohsin and Kaushal 2016). Trap efficiency of

an invert trap depends on various parameters, namely, the shape of invert trap, slot sizes, flow depth, sediment size, depth of trap, tilt of trap, channel bed slope (Poreh et al. 1970; Gardener et al. 1984; Buxton et al. 2002; Kaushal et al. 2012; Aryanfar et al. 2014; Mohsin and Kaushal 2016a, 2016b).

Out of the factors as mentioned earlier, trap efficiency also depends on the hydrodynamics and velocity distribution inside invert traps, which can be obtained either experimentally or computationally. Particle Image Velocimetry (PIV) and Laser Doppler Velocimetry (LDV) are the techniques, which provide the experimental approach for obtaining the hydrodynamics and velocity field in various fluid flow applications. PIV was introduced first in the 1980s (Adrian 2005). In PIV technique, the flowing fluid is seeded with tracer particles that follow the surrounding fluid. A laser is used as a light source to illuminate the seeding particles. A high-speed digital camera is used to record the pair of photographs with short exposure time delay. The software divides these photographs into small interrogation areas/sub-windows. The cross-correlation method correlates each interrogation areas/sub-windows in the first photograph with the corresponding interrogation areas/sub-windows in the second photograph and yields a unique peak. Location of this peak in the interrogation area/sub window gives the displacement of particles in the interrogation area/sub-window. Dividing the displacement by the exposure time delay provides the velocity (rtCam PIV System Manual 2009). PIV has an advantage that without disturbing the flow, two-dimensional velocity vectors can be determined in a whole plane and on the other hand, it has a disadvantage of low resolution. The downside of LDV is that it can measure the velocity at a point only but has an advantage of high resolution (Deen et al. 2000).

From the available literature, it has been found that some researchers have applied PIV and LDV technique for obtaining the velocity distribution and hydrodynamics of flowing water in an open channel flows. PIV technique can be used in many research fields namely; boundary layer flows, supersonic flows, transonic flows, shock tubes, and shock tunnels, naval hydrodynamics, helicopter aerodynamics and multiphase flows (Jahanmiri 2011). Hyun et al. (2003) carried out an experimental measurement of mean velocity and turbulence in open channel flow over the bed of fixed sand dunes using PIV and LDV. The author concluded that PIV can record the mean velocity and turbulent characteristics in the high shear and high turbulence regions and can provide quantitative data about flow structures that LDV cannot measure. Pechlivanidis et al. (2012) experimentally investigated the velocity field and turbulent characteristics of flow in an open channel with vegetation using the PIV technique. The author observed low velocities above the vegetation region than velocities above an impermeable bed. Zero velocity zones were also observed for 6 cm and 2 cm vegetation. Some of the studies have been conducted on the measurement of the velocity field, and turbulent characteristics of an open channel flow (Wilson et al. 2003; Jarvela 2005; Bigillon et al. 2006). No studies have been carried out to predict the trap efficiency of an invert trap by measuring the velocity distribution inside an invert trap using 2D PIV technique. In this paper, an effort has been made to obtain the velocity field inside invert traps using 2D Particle Image Velocimetry method. This study will help in predicting the trap efficiency of an invert trap by analyzing the obtained velocity field.

2. EXPERIMENTAL SETUP AND PROCEDURE

Experiments were performed in a glass-sided rectangular recirculating tilting flume of 0.15 m width, 0.2 m height and 5 m length. The shape of the invert traps selected for the present study was rectangular, trapezoidal, and rectangular with a trapezoidal base. Width and length of each invert trap were taken as 0.15 m and 0.32 m respectively. Invert traps fabricated by perspex glass sheet were attached at the bottom of the flume at a distance of 3.5 m from an upstream end of the flume.

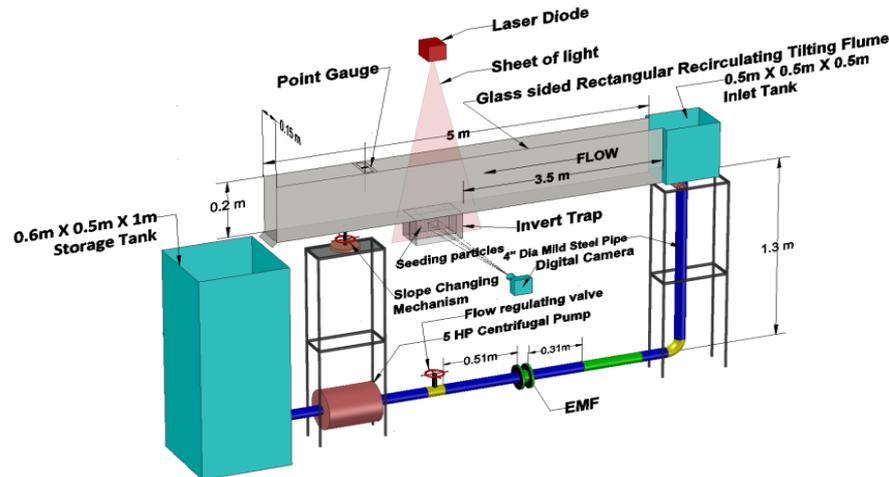
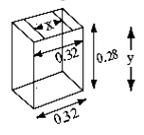
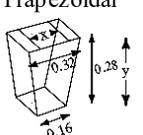


Figure 1. Schematic 3D diagram of experimental Setup

Experiments were conducted under uniform flow conditions and flow depths were taken as 0.02 m and 0.04 m with a constant channel bed slope of 0.005. By keeping the width and length of each invert trap as constant, the depth of each invert trap was varied as 0.28 m and 0.33 m for each flow depths. Flow depth in the flume was measured by a point gauge with an accuracy of ± 1 mm. Centrifugal pump of 5 hp was used to convey the water from the collection tank into the flume. Electromagnetic Flow Meter (EMF) was used to measure the discharge and velocity of water in the flume. For obtaining the flow hydrodynamics and velocity field inside the invert traps and flume, polyamide spherical seeding particles of specific gravity 0.99 g/cm^3 and mean diameter $100 \mu\text{m}$ was mixed with water in the collection tank. A 4 mm beam diameter nanoLase laser diode manufactured by Armfield was used for projecting a thin laser light sheet to illuminate the seeding particles inside the invert trap. For recording the pair of images, the rtCam digital PIV CMOS camera with specifications of $1/3''$ sensor, 8-bit 640×480 video format, $6 \times 6 \mu\text{m}$ pixel size, and frame rate of 6 image pairs/sec was used. rtControl software supplied by Armfield was used for post-processing of recorded images to obtain velocity vector maps inside invert traps. Velocity contour maps were plotted by utilizing the SURFER (Vol. 13.6.618) software for the better representation of the velocity field inside each invert trap configuration obtained by PIV. Experimental set-up and parameters are given in Figure 1 and Table 1 respectively.

Trap shapes, trap parameters and flow parameters

Trap Shapes			Trap parameters and Flow parameters for each trap shape
1. Rectangular 	2. Trapezoidal 	3. Rectangular with trapezoidal base 	Depths of trap, y (m) = 0.28 & 0.33 Slot width, X (m) = 0.15 Flow depths [Discharge], m ³ /s = 0.02[2.03] and 0.04[5.48] Bed slope = 0.005

3. RESULTS AND DISCUSSION

From the experimental study of velocity distribution inside invert traps using PIV and SURFER, the following results were obtained:

3.1 RECTANGULAR INVERT TRAP

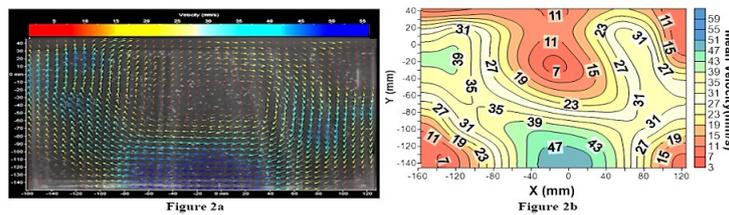


Figure 2. (a) 2D Velocity field vectors by PIV and (b) Velocity contours by SURFER; at 0.02 m flow depth and 0.28 m trap depth.

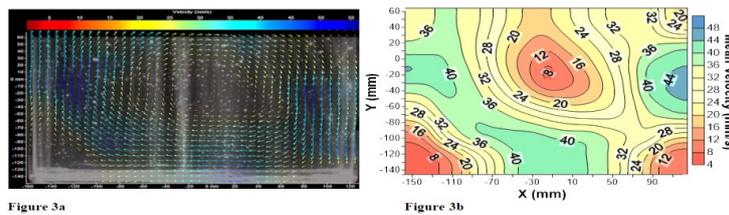


Figure 3. (a) 2D Velocity field vectors by PIV and (b) Velocity contours by SURFER; at 0.02 m flow depth and 0.33 m trap depth.

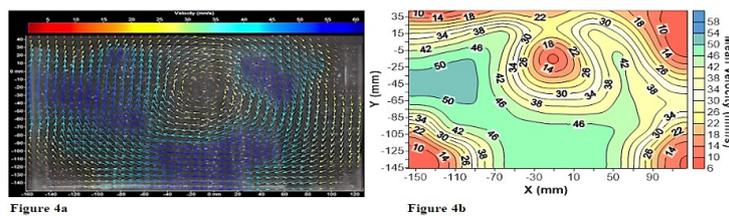


Figure 4. (a) 2D Velocity field vectors by PIV and (b) Velocity contours by SURFER; at 0.04 m flow depth and 0.28 m trap depth.

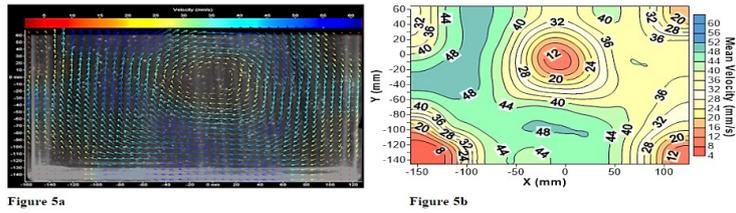


Figure 5. (a) 2D Velocity field vectors by PIV and (b) Velocity contours by SURFER; at 0.04 m flow depth and 0.33 m trap depth.

3.2 TRAPEZOIDAL INVERT TRAP

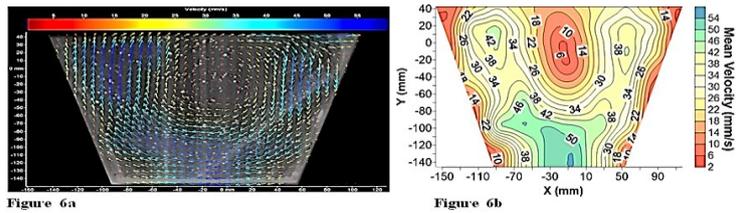


Figure 6. (a) 2D Velocity field vectors by PIV and (b) Velocity contours by SURFER; at 0.02 m flow depth and 0.28 m trap depth.

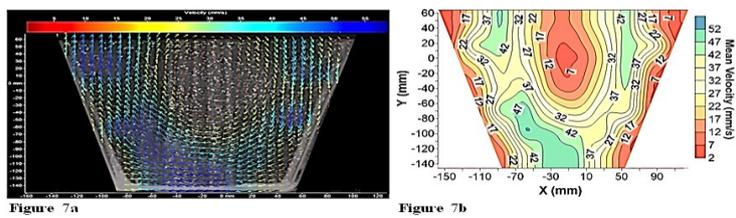


Figure 7. (a) 2D Velocity field vectors by PIV and (b) Velocity contours by SURFER; at 0.02 m flow depth and 0.33 m trap depth.

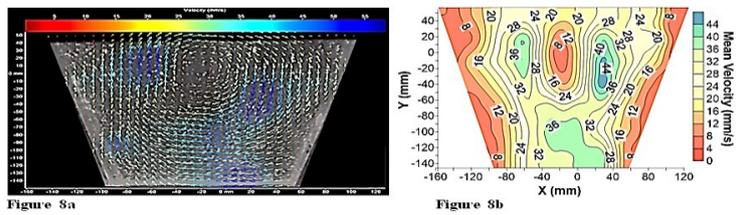


Figure 8. (a) 2D Velocity field vectors by PIV and (b) Velocity contours by SURFER; at 0.04 m flow depth and 0.28 m trap depth.

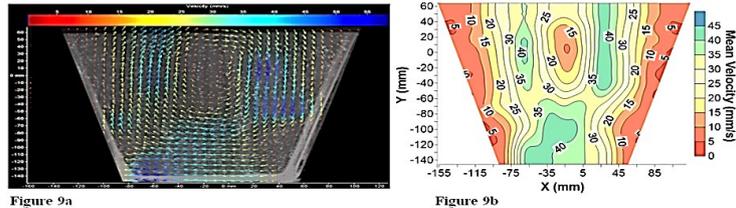


Figure 9. (a) 2D Velocity field vectors by PIV and (b) Velocity contours by SURFER; at 0.04 m flow depth and 0.33 m trap depth.

3.3 RECTANGULAR WITH TRAPEZOIDAL BASE INVERT TRAP

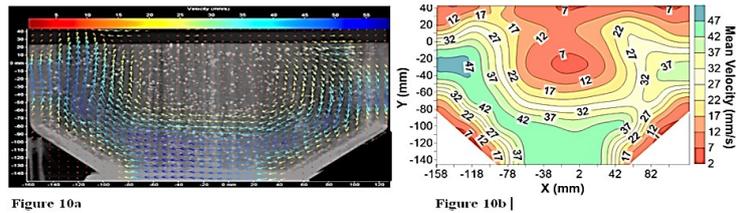


Figure 10. (a) 2D Velocity field vectors by PIV and (b) Velocity contours by SURFER; at 0.02 m flow depth and 0.28 m trap depth.

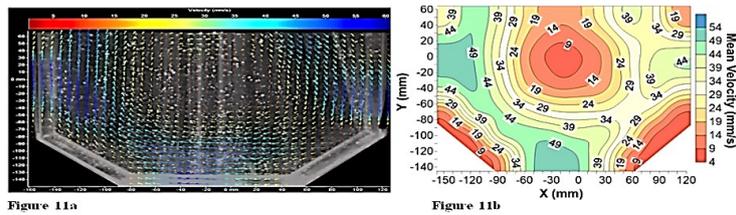


Figure 11. (a) 2D Velocity field vectors by PIV and (b) Velocity contours by SURFER; at 0.02 m flow depth and 0.33 m trap depth.

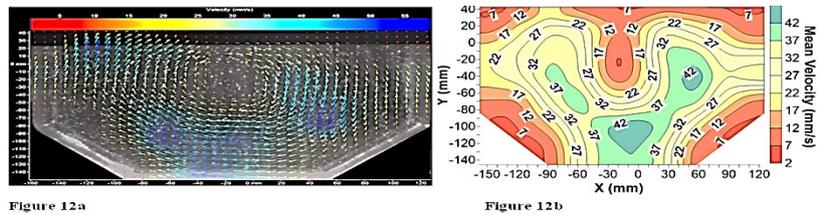


Figure 12. (a) 2D Velocity field vectors by PIV and (b) Velocity contours by SURFER; at 0.04 m flow depth and 0.28 m trap depth.

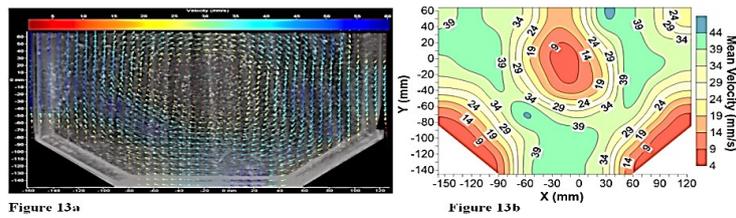


Figure 13. (a) 2D Velocity field vectors by PIV and (b) Velocity contours by SURFER; at 0.04 m flow depth and 0.33 m trap depth.

From the analysis of the results obtained experimentally by PIV, low velocity is observed inside each invert trap near the boundary surfaces, corners, and central region. These low-velocity zones decrease at the center region with an increase in flow depth for each depth of traps. With an increase in the depth of each trap, the low-velocity zone increases at the center region at each flow depth. Influence of low-velocity zones observed in case of the rectangular trap with trapezoidal base is more as compared to other shapes of trap, which predicts more trap efficiency. Mean flow velocity in a flume at 0.02 m, and 0.04 m depth of flow obtained through PIV measurement is in good agreement with the velocities measured by Electro Magnetic Flow Meter (Table 2).

Table 2

Mean velocity in flume measured by PIV and EMF

Flow Depth (m)	Mean Vel. by PIV (m/s)	Mean Vel. by EMF (m/s)
0.02	0.66	0.68
0.04	0.92	0.91

4. CONCLUSIONS

The velocity of water inside each invert trap is less than the average velocity in the flume at each flow depth. Low-velocity zones are observed near the boundary surfaces, corners, and central region in each invert trap. Low-velocity zones decrease with increase in flow depth in case of each shape and depth of invert trap. Low-velocity zones increase at the center region with an increase in the depth of trap at each depth of flow. At each flow depth and depth of trap, the influence of low-velocity zones is more in case of a rectangular trap with a trapezoidal base as compared to other shapes of trap, which predicts more trap efficiency. Average flow velocities in flume measured by EMF are also very close to the velocities measured by PIV. PIV can be a useful and time-saving technique to measure the velocity field in many fluid flow applications.

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