Computational Fluid Dynamics Flow through a Wastewater Trap Model A2

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Abstract:
This analysis demonstrates the proposed study of computational fluid dynamics through wastewater trap model A2 (WTA2). The project aims to study the flow performance such as head loss, water level, pressure profile, velocity profile and particle trapping efficiency and validate it with the experimental outcomes. The scale model WTA2 was computationally tested at four different flow rates mainly; 0.5, 1, 1.5 and 2 l/s. The analysis outcomes revealed that the head loss increases in proportion to flow rates. Pressure and velocity profile show high values close to the cylindrical wall and low values at the centre. It has been proved that the smaller particles sizes had lower trap efficiency than bigger particle sizes. The overall trap efficiency decreases as the flow rate increases.
Keywords: *Head Loss, Water Level, Pressure & Velocity Profiles, Trapping Efficiency.*

Introduction:

The wastewater trap type A was designed to remove light and heavy solids and liquid pollutants from wastewater systems by directing wastewater through a simple vortex separator (Ismail, 2020). The hydraulic performance of WTA2 was experimentally tested on 2014 at Edith Cowan University and published by Ismail on 2020. To validate these results, Computational Fluid Dynamics (CFD) investigation was carried out and ANSYS, Workbench - Fluent (V. 2020 R1) was used. ANSYS Fluent module is the relevant software module for CFD as it can simulate fluid flow with high precision and give accurate results. As the free surface is essential, it defines the interface between the water and air which tends to be the critical parameter when simulating the hydrodynamics in the cylindrical chamber (Yan, 2013).

CFD Methodology:

In order to replicate the experimental test procedure, two different software models were selected; Volume of Fluid (VOF) for hydraulic performance and Discrete Phase Model (DPM) for trapping efficiency. As shown in figure 1, three dimensional model (3D) was structured by tetrahedral meshes comprising of 500,000 comutational cells. Using an unstructured grid helps not only to eliminate the occurance of singularities but provides full geometrical facility (Doby et al, 2005) and (Ismail & Nikraz, 2007). Transient model is selected and run for three minutes flow simulation to obtain accurate results. The k - ε (2 eqn) model was used specifically as it has precise mesh refinement features, which helps in providing better results (Yan, 2013). Four different inlet flow rates have been simulated to show a better pattern result. Inlet flow rate was defined by uniform velocities across the inlet plane, outlet was defined as a pressure outlet and vortex separator top was also defined as pressure outlet corresponding to atmospheric pressure. The fluid free surfaces in vortex separation were approximated by fixed friction wall boundaries, the locations of which were derived experimentally. Transient state flow field predictions were obtained, and solutions were converged. Extracted data of pressure and velocity head at inlet and outlet, the head loss was determined by using Bernoulli equation (Ismail & Nikraz, 2007).

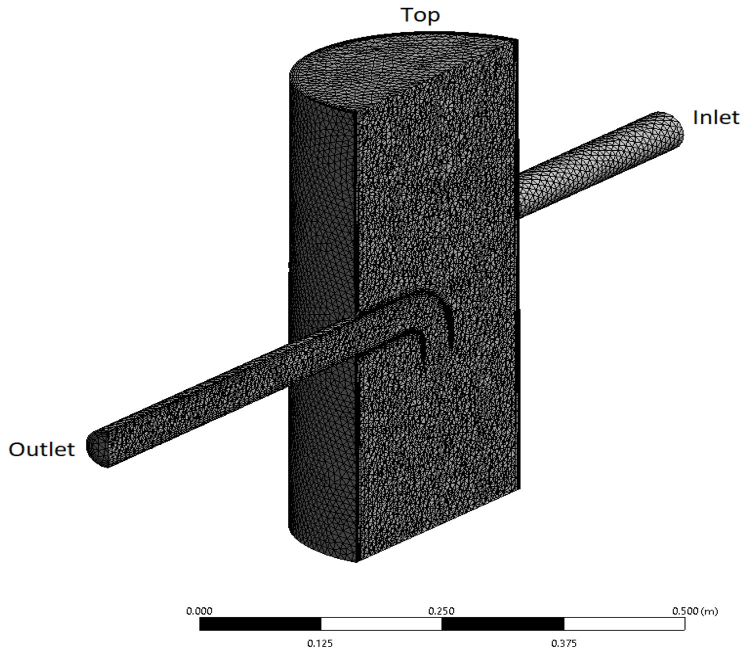


Figure 1: Wastewater Trap Model A2

The DPM was used for particle injections to determine the particle trapping efficiency results which tends to be one of the objectives of this project investigation. Three different granular particles sizes of 100 μ, 200 μ and 300 μ with density of 2500 kg/m^3 are injected to see the variation in trapping efficiency of WTA2. Each simulation was run for 180 seconds to obtain best possible results assuming the system is running for a longer time and allows the chamber to be fully filled with water. The particle trap efficiency depends on inlet velocity, however higher flow rate leads to turbulent flow which results in reducing rates of trapping efficiency (Ismail, Nikraz and Khan, 2009).

Results and Analysis:

The results are described with comparisons in different flow rates while the cylindrical chamber is opened from the top. The hydraulic characteristics such as head loss, water level, pressure and velocity profiles and trapping efficiency are calculated and extracted from the CFD simulations. As WTA2 chamber has height of 600 mm with diameter of 300 mm, it has been decided to extract the results of pressure and velocity profiles at three different levels; 100, 200 and 400 mm as shown in figure 2. The 50 mm diameter pipes, tangential inlet and 'L' 90-degree bend outlet are elevated at the middle of the chamber (300 mm).

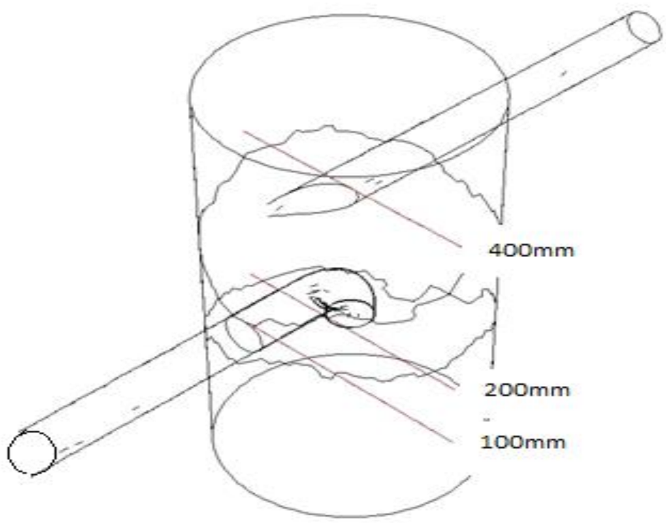


Figure 2: Wastewater Trap Profile Levels

Flow-field Predictions:

The flow field's prediction for WTA2 is shown in figure 3. The swirling behaviour of the flow is dictated by the tangential orientation of inlet pipe (Ismail & Nikraz, 2008). The fluid path-line predictions suggested that the flow is directly entering to the cylindrical chamber and spiral down towards the base then up from the middle to "L" 90-degree downstream. Opposite to VersaTraps, there is a strong evidence of flow short-circuiting for this system thus; such characteristic is unlikely to be conducive to positive performance attributes for fine solids.

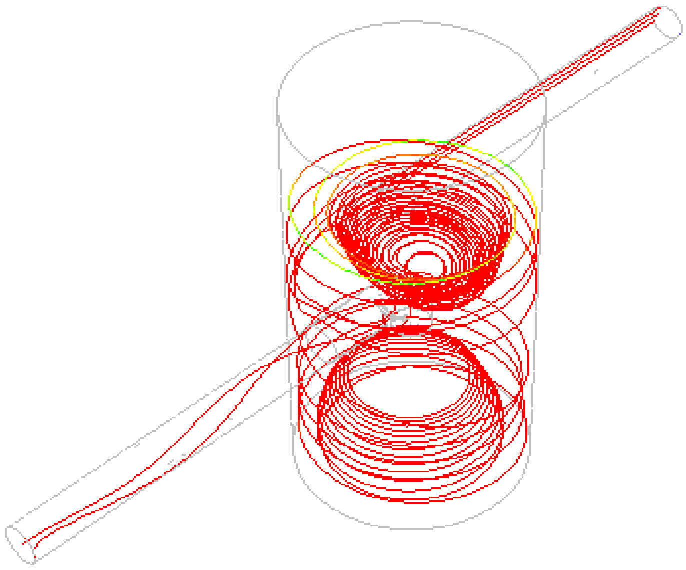


Figure 3. Fluid Path-line at Flow Rate of 1.5 l/s

Hydraulic Analysis:

The hydraulic analysis shows that head loss is proportional to the increase of flow rate (figure 4). This is obvious as the resistance forces generated are higher in increasing flow rate. The head loss has raised from low value of 14 mm at 0.5 l/s to 212 mm at 2 l/s. Comparing the simulation results to experimental outcomes, it is found that both results have similar curve pattern with closed values at low flow rates however, more than a 100 mm difference at the maximum flow rate 2 l/s. This of course due to high friction throughout the downstream elbow.

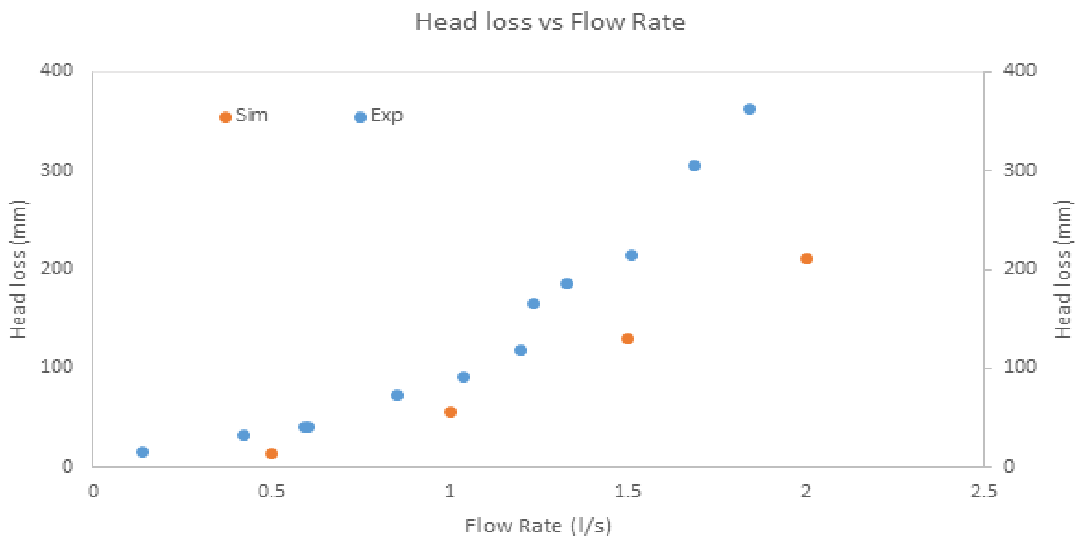


Figure 4: Relationship Between Head Loss & Flow Rate

Water Level Analysis:

Figure 5 shows the five different points where the water levels have been measured inside the chamber (Ismail, 2020). Like experimental outcomes, the first four points around chamber wall have the same water level readings compared to point 5 (centre point) where water level has always lower value and this difference increases with flow rates (figure 6). The highest simulated water level difference between point 5 and the other points is found to be 40 mm at 2 l/s. Figure 7 shows simulation and experimental water levels at two selescted points; 1 and 5.

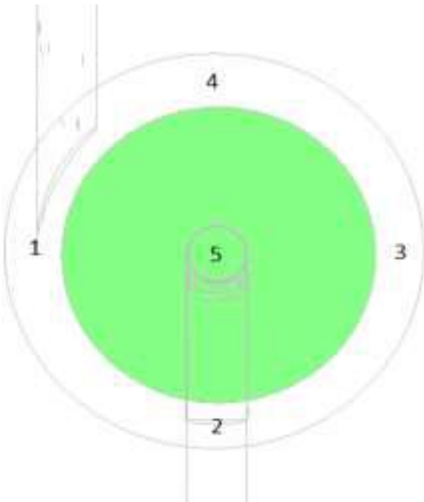


Figure 5: Locations for Water Levels Measurement Points (Ismail, 2020)

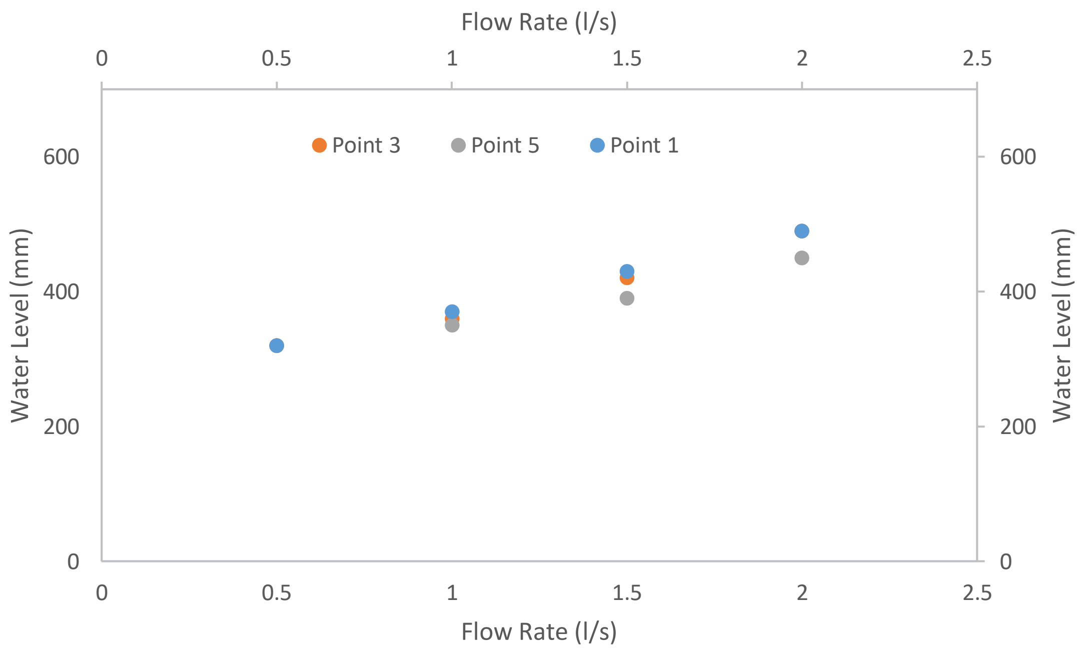


Figure 6: Water Level VS Flow Rate

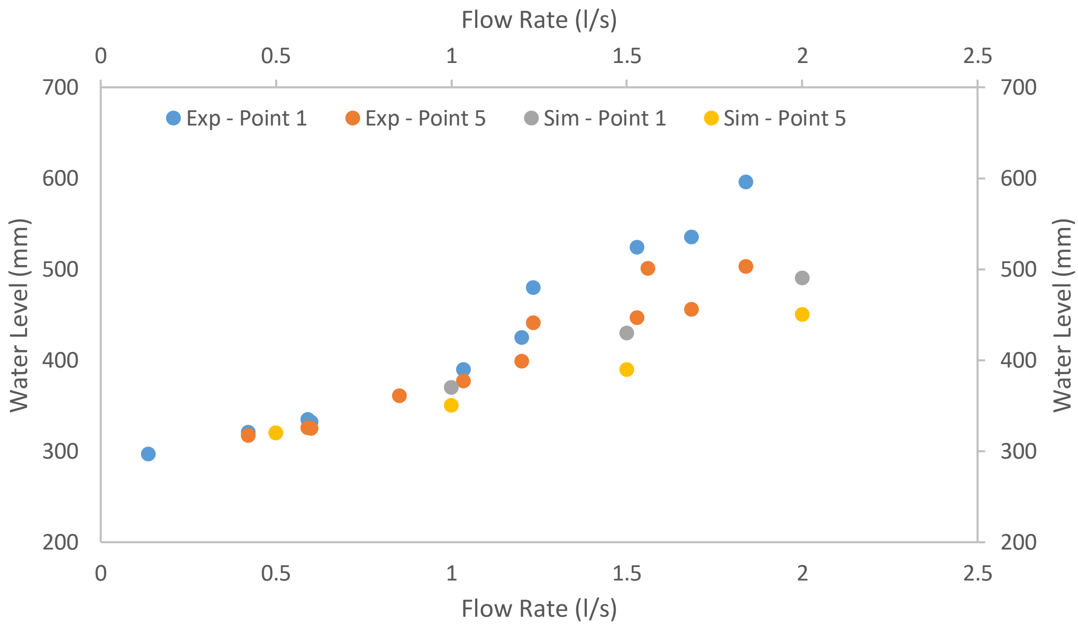


Figure 7: Water Level Validation Inside the Chamber

Pressure Profile:

The static pressure results were decided to be plotted between points 1 and 3 where point 5 is in the middle at three different levels/planes; 100, 200 and 400 mm. Figure 8 presents the pressure at these three selected planes and found the highest readings at 100 mm. Figures 8a and 8b show higher values of static pressure at the cylindrical wall (points 1 and 3) compared to center region (point 5). For instance, at inlet flow rate of 0.5 l/s at 100 mm, pressure was found 2175 pa next the wall compares to 2155 pa at the center point. With the same flow rate of 0.5 l/s at 200 mm, pressure is much less, 1200 pa at the wall and 1175 pa at the center. Pressure at 400 mm level shows zero values in both regains because there is no water reached this height. As inlet flow rate increases, these values are increased. At 2 l/s and 100 mm, the pressure has achieved a value of 3900 pa at the wall and 3300 pa at the center.

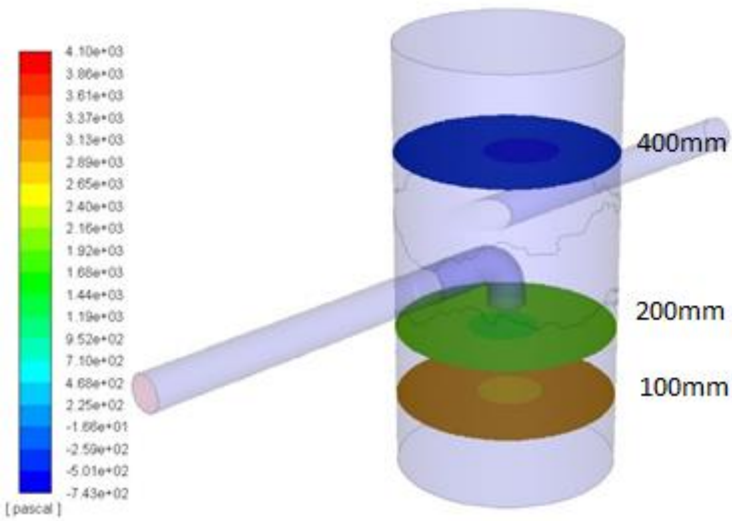


Figure 8: Static Pressure Variation at the Three Selected Planes (Contours)

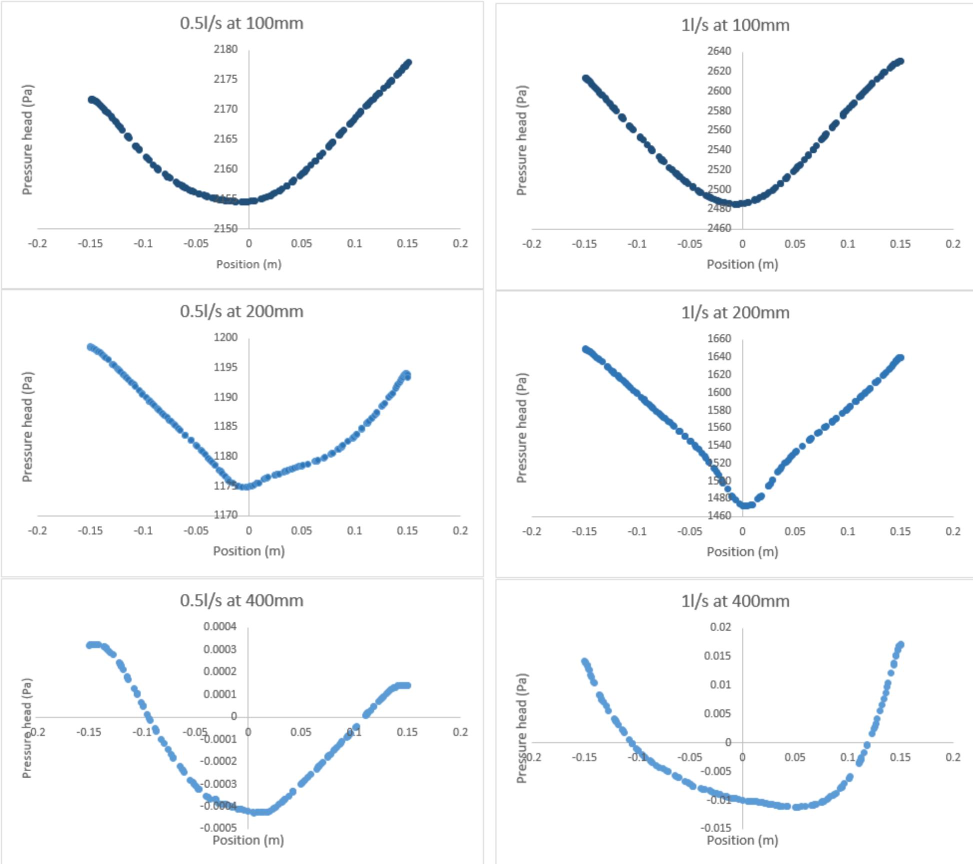


Figure 8a: Pressure Head Profile at all Flowrates

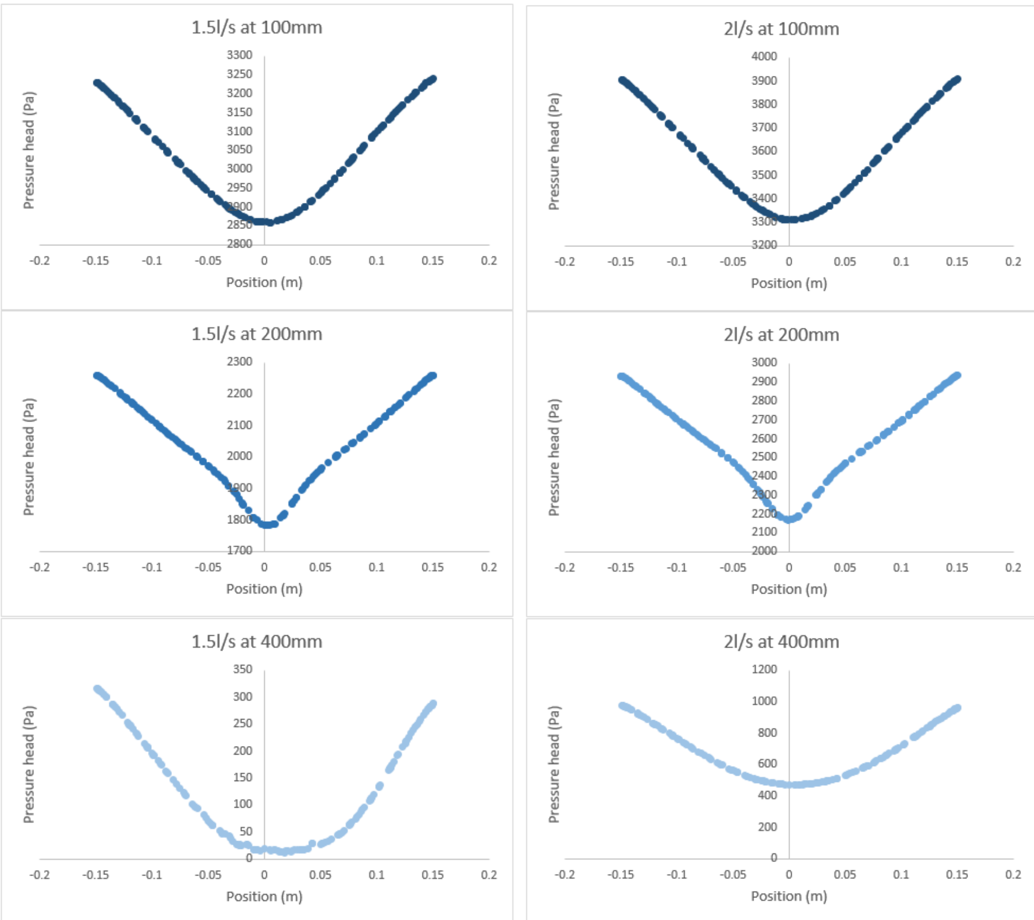


Figure 8b: Pressure Head Profile at all Selected Levels

Velocity Profile:

Figure 9 shows the variation of velocity at three different planes inside the chamber. From the results obtained, velocity is higher at the wall regions compared to swirl region. This is expected due to hydrodynamic or vortex forces generated from tangential inlet. Figures 10a and 10b show magnitude velocity profile at the three selected levels; 100, 200 and 400 mm. At 0.5 l/s, the magnitude velocity at 100 and 200 mm, is found as 0.15 and 0.19 m/s near to wall (i.e. points 1 and 3) and 0.015 m/s and 0.08 m/s at the center (i.e. point 5) respectively. Moreover, at each plane level, the velocity value increases with the increase of inlet flow rate (figure 11). For example, the velocity around the wall at 100 mm is found as 0.15 m/s at 0.5 l/s to reach 0.8 m/s at 2 l/s. Among the three planes, the highest velocity values are found at 200 mm and this of course due to the closeness to inlet pipe elevation.

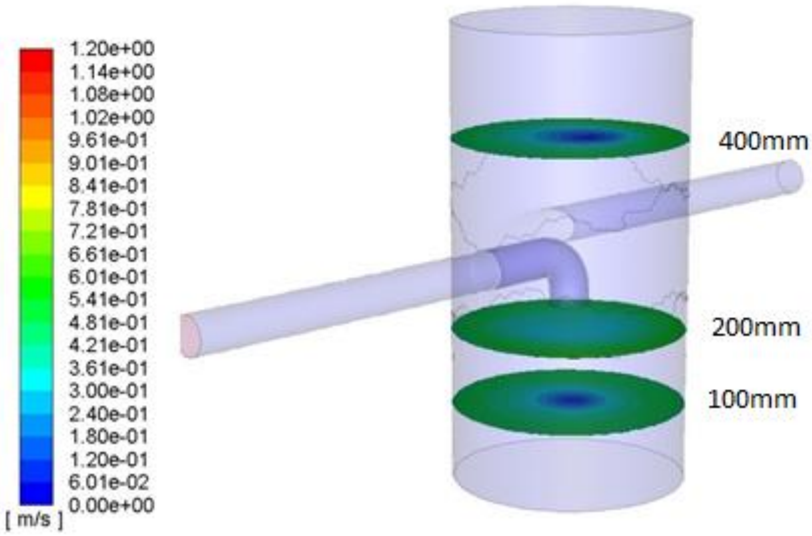


Figure 9: Velocity Variations at the Three Selected Planes (Contours)

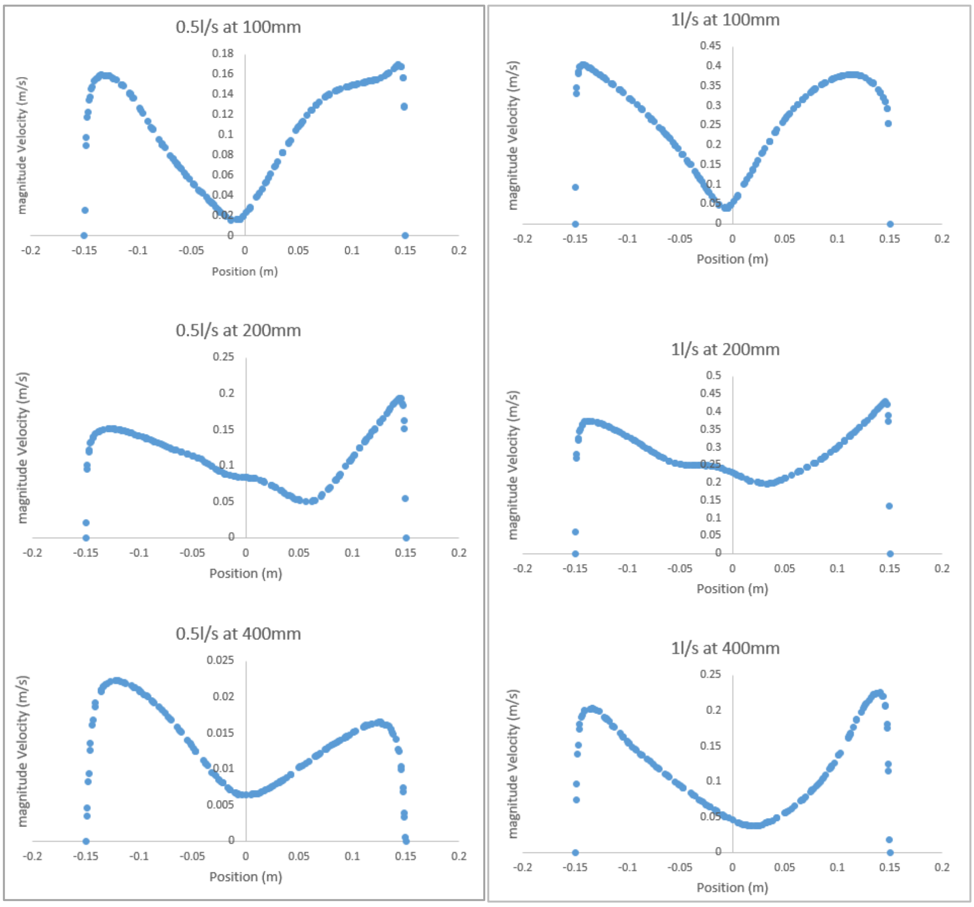


Figure 10a: Velocity Profile at all Flow Rates

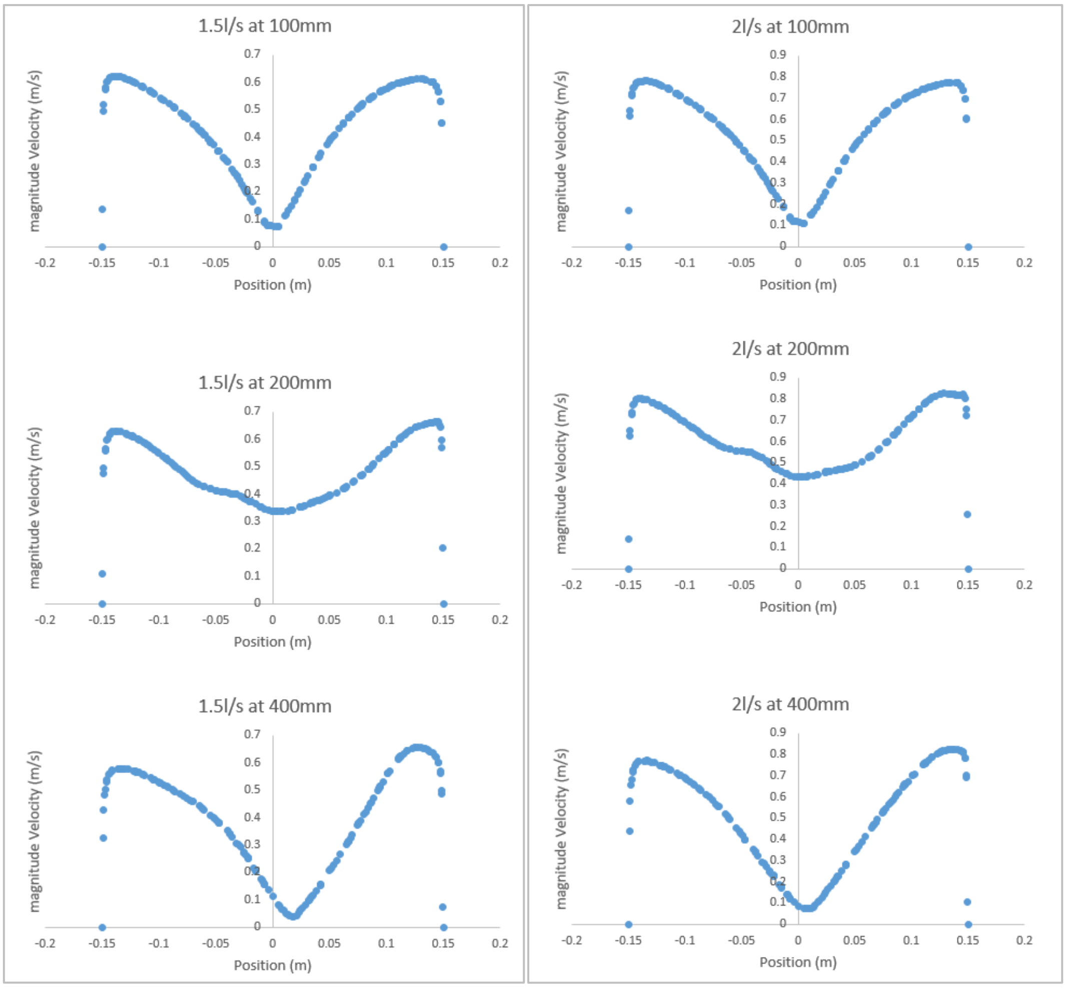
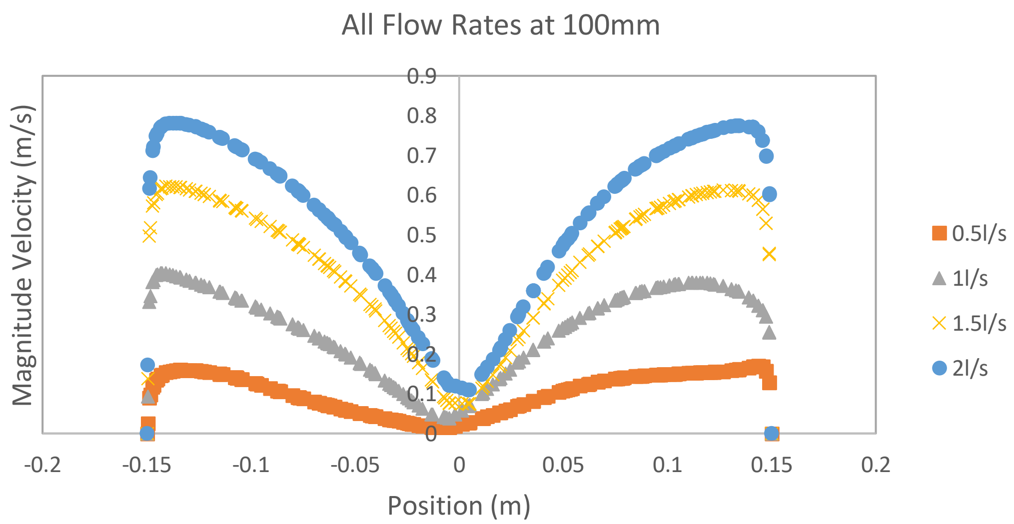


Figure 10b: Velocity Profile at all Flow Rates



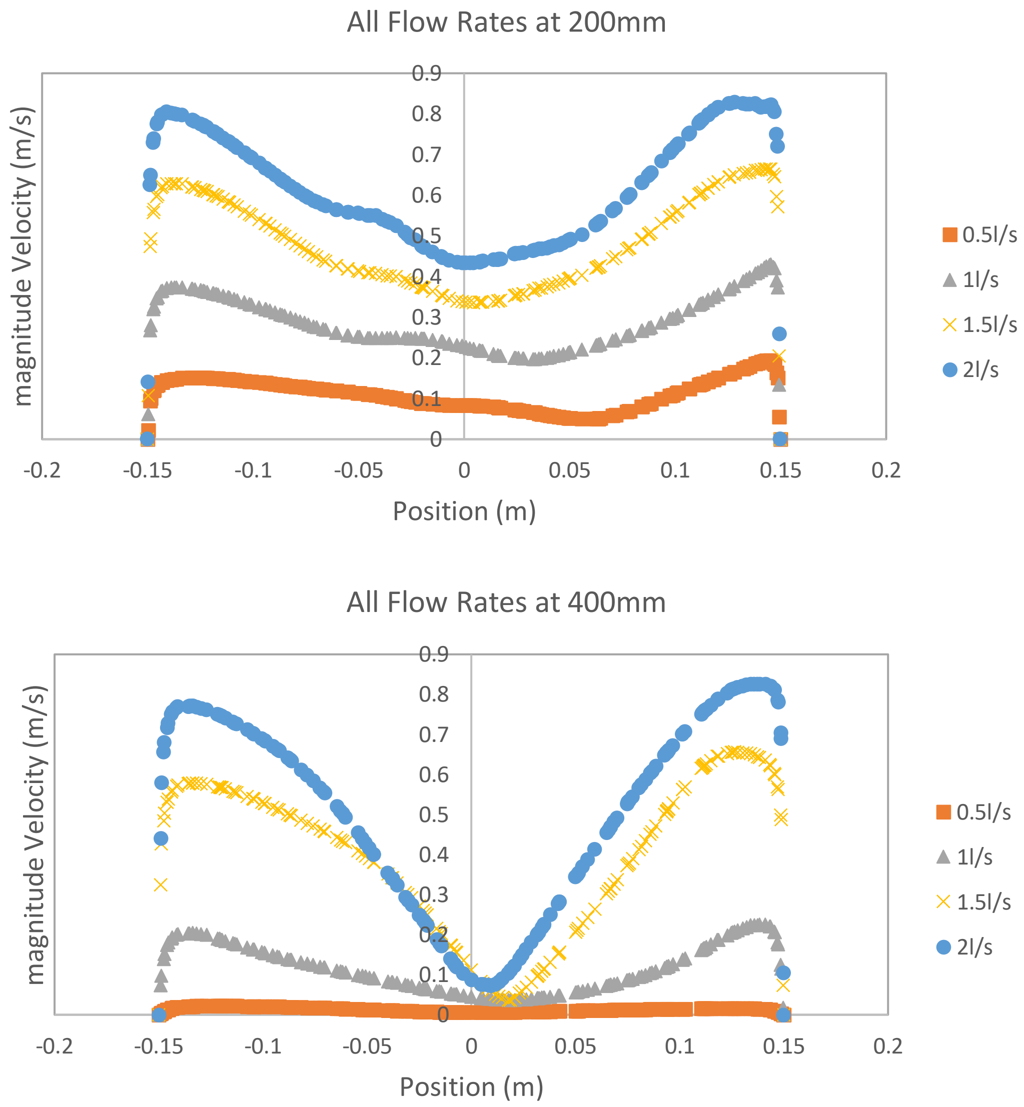


Figure 11: Velocity Profile at all Flow Rates and Levels

Particle Trapping Efficiency:

Discrete phase model (DPM) was used to find out the particle trapping efficiency. The trapping efficiency has been predicted at the maximum selected flow rate (2 l/s) for three different particle sizes, 100 μ, 200 μ and 300 μ. From data obtained, the proportionality of efficiency and particle sizes shows a strong evidence that the trapping efficiency is increasing with the increase of particle sizes. Figure 12 shows the maximum trapping efficiency of 83% for 300 microns particles. Comparing trapping efficiency results from CFD and experimental works, figure 13 shows very similar outcomes. This of course increase the confidence to use and rely on CFD as a technique for this sort of projects.

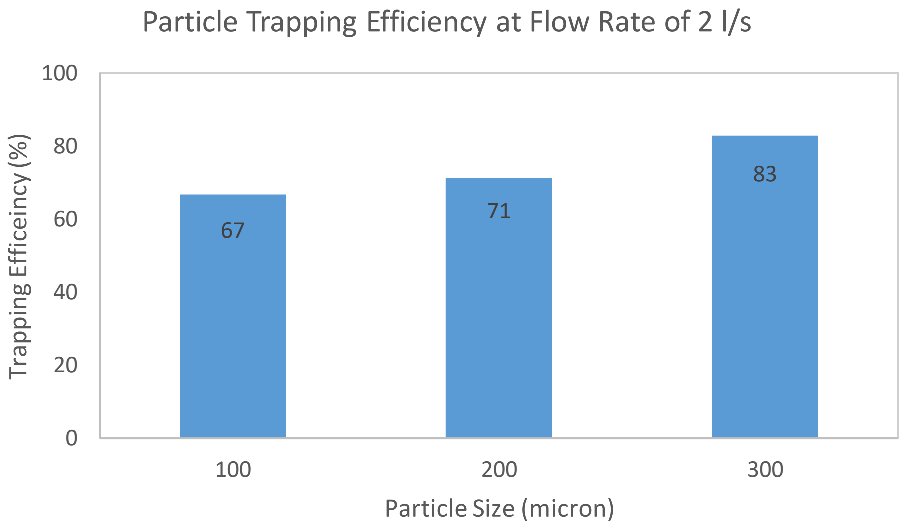


Figure 12: Trapping Efficiency at Flow Rate of 2 l/s

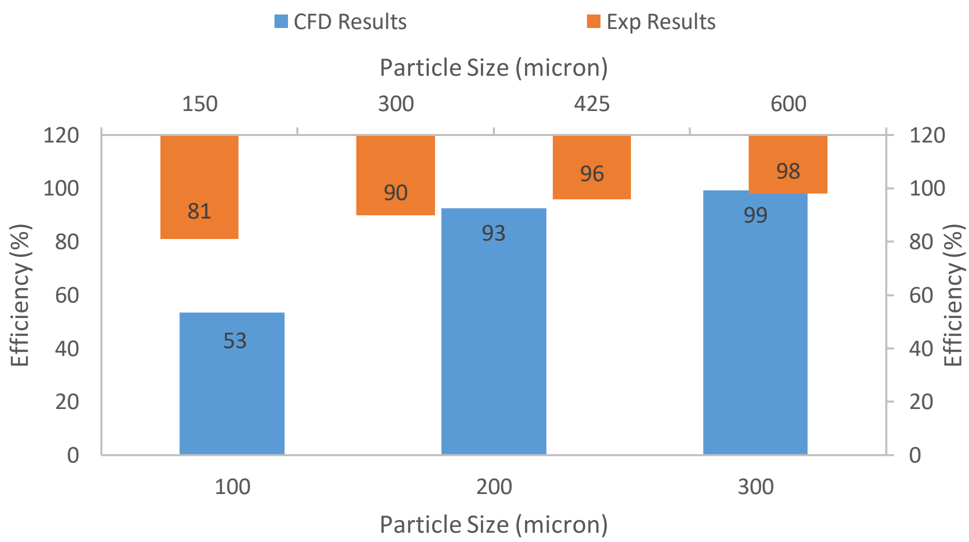


Figure 13: CFD Validation of Trapping Efficiency at Flow Rate of 1.5 l/s

Conclusion:

The primary aim of this project was to perform computational fluid dynamics (CFD) on wastewater trap model A2 (WTA2) to anticipate its flow performance alongside particle trapping efficiency and compare them with experimental outcomes. The results accurately demonstrate that the hydraulic performance and trapping particle efficiency of CFD are very similar to those produced by experimental work. Although WTA2 is designed with a single cylindrical chamber, the investigation proves that WTA2 shows an excellent performance compared to other wastewater traps such as Versa Trap type W.

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