Modelling the Impact of Drop Structure Design on Odour and Gas

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Abstract

A key aim of Water Corporation's statewide wastewater conveyance operations is the reduction of odour and gases released into the surrounding environment. A particular access chamber has been identified as a major source of odour and gas release, with noticeable odour issues impacting nearby residential areas. Odours continued despite previous interventions. Physical modelling of the current access chamber plunge design, a vortex design and a long radius bend design is being conducted to determine mass transfer rates. Oxygen mass transfer will be used as a proxy for hydrogen sulfide transfer, with dissolved oxygen content being measured upstream and downstream of the drop structures. A cost benefit analysis will be conducted to evaluate the business case for adopting a different design.

1. Introduction

Wastewater odour issues have long plagued metropolitan water utilities. A key access chamber (Drop Chamber 1), which acts as the junction between two sewer mains, has been identified as a major odour source. The drop acts as the point of mass transfer for malodourous compounds to leave the wastewater into the sewer atmosphere and disperse throughout the network and into the local atmosphere. Odour complaints have been recorded from the developing residential community surrounding the site over the last 5 years, and odour control units were implemented to mitigate this. The odour control units were not able to adequately reduce the odour release and were decommissioned, and the access chamber was sealed to decrease the odour release. Odour issues are also an indicator of corrosion issues, driven by sulfuric acid formation from high hydrogen sulfide concentrations, impacting the lifespan of assets such as the pumping station located downstream from Drop Chamber 1. A redesign of the drop structure contained in Drop Chamber 1 was identified as a potential control measure, which would reduce the rate the dissolved malodourous compounds transfer from the wastewater to the sewer atmosphere.

1.1 Literature Review

Wastewater naturally contains dissolved sulfides and sulfates, which can lead to hydrogen sulfide (H_2S) gas releases into the sewer atmosphere. Hydrogen sulfide is a colourless, toxic, and flammable gas and is recognised as the compound primarily responsible for odours associated with wastewater, with a distinctive rotten egg smell (US EPA, 1985) (TMMBW, 1989). Other known malodourous compounds in wastewater include methyl mercaptans, indoles, and skatoles (US EPA, 1985).

Drop structures are used in sewer networks to navigate elevation differences. These drops also increase liquid to gas mass transfer of dissolved malodourous compounds (Yang, et al., 2020). Increased mass transfer is driven by increased interfacial transfer area (Williamson, 1998) and lowered mass transfer resistance by thinning of the hydrodynamic film (Lahav, Lu, Shavit, & Loewenthal, 2004). Two main drop structure designs were identified in Williamson, 1998. Plunge drops are the simpler design where a pipe joins into an open space or a drop shaft, allowing a waterfall to form. Vortex drops use centripetal force to create an annular flow against the drop shaft, minimising interfacial area and air entrainment by creating a stable air core.

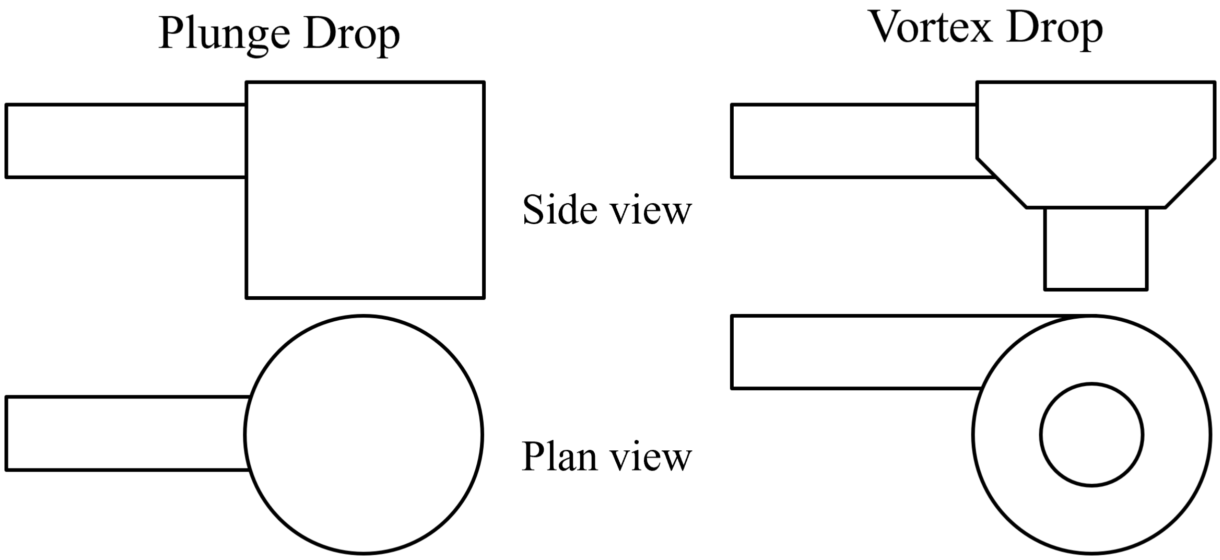

Figure 1 Two classifications of drop structures identified in Williamson, 1998

The recommended design criteria for drop structures are provided in the H_2S Control Manual (TMMBW, 1989). The generic recommendations, which cover all drop structure designs for Australia, recommend a bell mouth inlet and water cushion outlet. Western Australia is identified as having more acute odour issues and uses state specific recommendations. For the dimensions of Drop Chamber 1, the Western Australian guidelines recommend a vortex chamber inlet with stilling basin outlet (TMMBW, 1989).

1.2 Project Objectives

The project focuses around providing additional evidence, in the form of a cost-benefit analysis, to aid in the decision-making process for determining the future designs for Drop Chamber 1, such that the odour issues can be minimised. The results will also allow future access chambers to be designed in a way that minimises the odour and gas released by providing additional information regarding the relative reaeration and odour generation abilities of different drop structures, as both high and low reaeration abilities are required over the length of major sewers, to ensure high dissolved oxygen (DO) content upstream and prevent the release of malodourous gases downstream.

2. Process

2.1 Experimental Process

The experimental process was based on the combination of the Froude scaling performed in Keller & Winston, 2006 and reaeration method outlined in Carrera, Springer, Lipeme-Kouyi, & Buffiere, 2017. The reaeration method is recommended for testing the mass transfer rates of oxygen addition to wastewater. A variation of this method has been used for estimating the hydrogen sulfide transfer out of the wastewater, as the transfer behaviour of both species is governed by resistance in the liquid side hydrodynamic film.

The experimental setup used is displayed in Figure 2. The pump is submerged in a deoxygenation tank with Na_2SO_3 as an oxygen scavenger, and drives water to the inlet of the drop structure chamber, where gravitational flow takes over. A globe valve installed shortly after the pump allows flow control. Access points are placed such that a dissolved oxygen meter can measure the upstream and downstream oxygen concentrations.

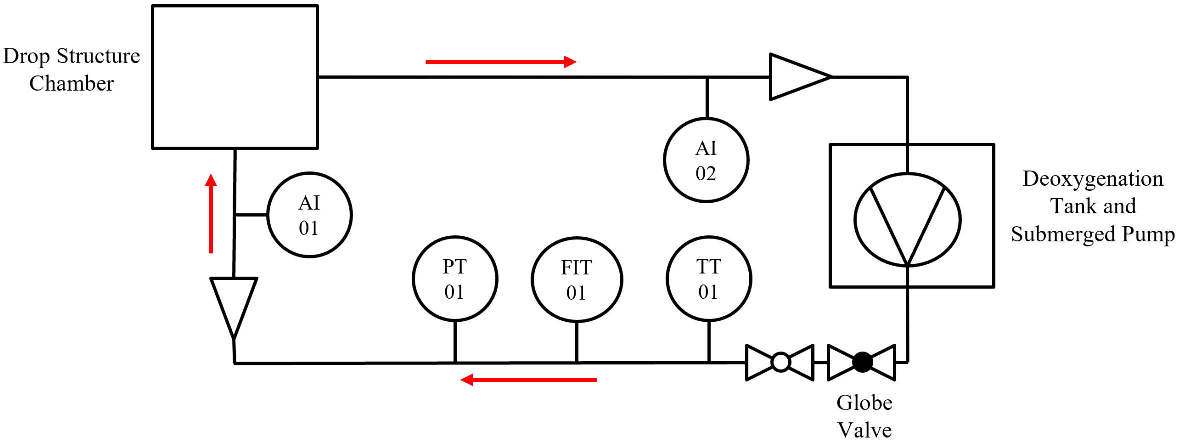

Figure 2 Experimental Test Rig Schematic

A 1:15 length scale is used, and scaling was done to ensure Froude number similarity between the on-site and experimental length scales, which required several other parameters be adjusted according to the table below, where λ represents the scale factor.

Parameter	Equation	Scaling Factor
Length	λL	1 / 15
Flowrate	$\lambda Q = \lambda L^{2.5}$	1 / 871
Velocity	$\lambda U = \lambda L^{0.5}$	1 / 3.8
Time	$\lambda t = \lambda L^{0.5}$	1 / 3.8
Reynolds Number	$\lambda Re = \lambda L^{1.5}$	1 / 58
Weber Number	$\lambda We = \lambda L^{2}$	1 / 225

Table 1 Parameter scaling factors based on the conducted Froude scaling. Adapted from Keller & Winston, 2006

Using the experimental rig in Figure 2, the following process will be followed.

1. Install the desired drop chamber geometry into the drop structure chamber.
2. Remove dissolved oxygen from water in the deoxygenation tank using sodium sulfite (Na_2SO_3), with cobalt sulfate ($CuSO_4$) as a catalyst. A dissolved oxygen meter is used to determine when the DO concentration is reduced.
3. Switch on the pump and pump the anoxic water through the test rig.
4. Record the temperature, pressure, and flowrate upstream of the drop structure. Record the DO concentration upstream and downstream of the drop structure chamber using a DO meter at the access points.
5. Switch off the pump.
6. Perform 3 trials for each design

Equations 1, 2 and 3 are used to estimate the overall oxygen mass transfer over a drop structure, based on the dissolved oxygen concentrations and drop height (Yang, et al., 2020). Equation 4 is used to compare the oxygen and hydrogen sulfide overall mass transfer rates (Yongsiri, Hvitved-Jacobsen, Vollertsen, & Tanaka, 2003).

$$K_L a_{O2} = \frac{C_u - C_d}{\left(t_f + t_w\right)(C_u - C_{sat})} \tag{1}$$

$$t_f = \sqrt{2H/g}\,/3600 \tag{2}$$

$$t_w = 10D/U \tag{3}$$

$$K_L a_{H2S} = (1.736 - 0.196\,pH)\;K_L a_{O2}\;\; for\; 4.5 < pH < 8 \tag{4}$$

Where $K_L a$ is the overall mass transfer coefficient (h^{-1}), C_u is the concentration of oxygen upstream of the drop (g/m^3), C_d is the concentration of oxygen downstream of the drop (g/m^3), H is the drop height (m), g is the gravitational acceleration constant 9.81 m/s^2, D is pipe diameter (m) and U is mean flow velocity (m/s).

2.2 Design Process

Three key designs were generated for testing. These designs were selected based on proven odour reducing drop structure designs. The three designs selected are the plunge drop structure that is currently installed at the site, a vortex drop structure based on another operational drop structure, and a long radius bend designed to maximise bend radius.

The plunge drop structure is shown below in Figure 3. It was constructed out of Perspex, based on the drawings for Drop Chamber 1. The vortex drop structure is shown below in Figure 4. The vortex spiral was constructed from 3D printed PLA, with a Perspex chamber and stilling basin connected, and was designed based on another vortex drop structure operated by the Water Corporation. A drowned discharge was added to reduce the air entrainment and odour generation. The long radius bend, shown in Figure 5, was designed to maximise the bend radius, and therefore minimise turbulence induced by sudden direction change. The bend was adjusted to avoid intersecting the nearby roadway and was limited in size to fit on the test rig. This corresponded to a maximum radius of 1.6m on the test rig, or 25m radius on site.

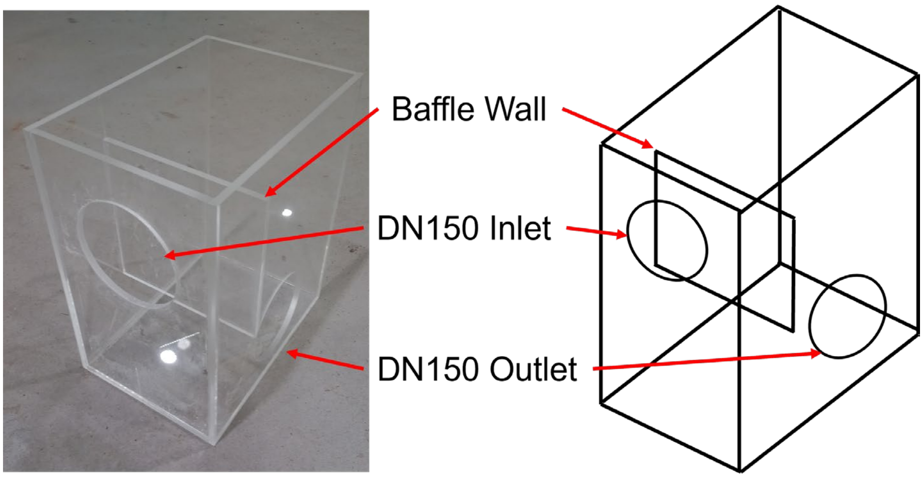

Figure 3 Picture and schematic diagram of the plunge drop structure design used in the experiments.

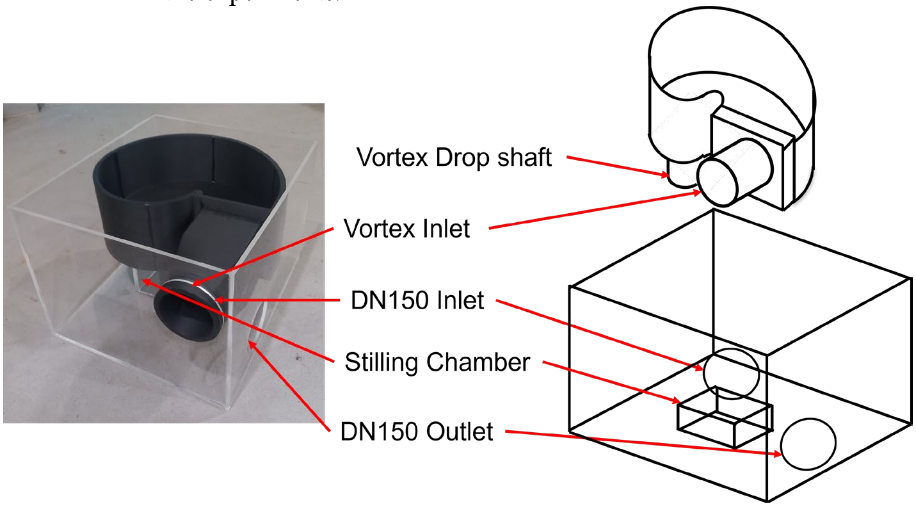

Figure 4 Picture and schematic diagram of the vortex drop structure design used in the experiments.

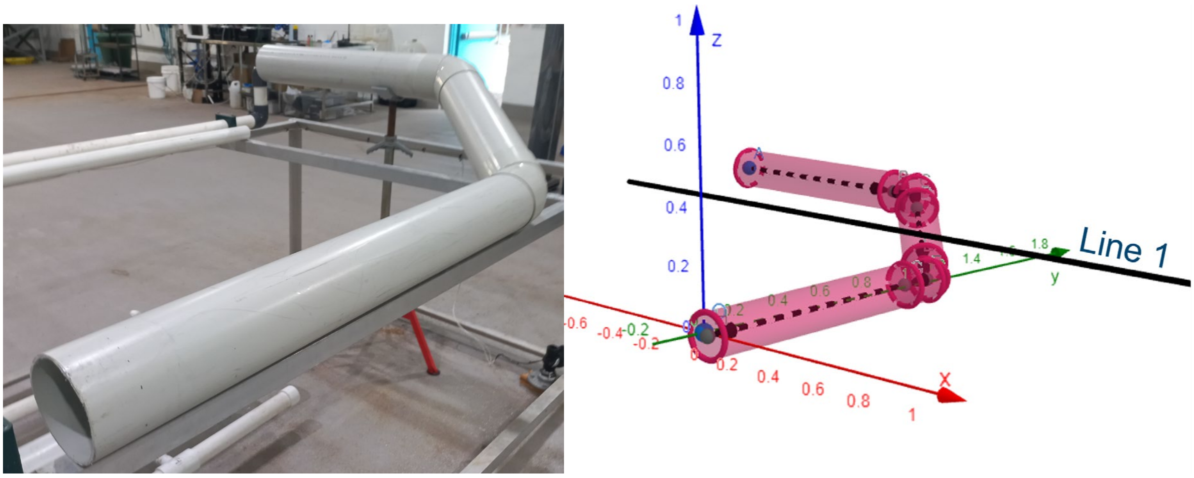

Figure 5 Picture and model of the long radius bend design used in the experiments. Line 1 on the right image shows the edge of the road nearby passes cleanly over the piping without intersection.

3. Results and Discussion

This project is ongoing work, and results will soon be obtained from the testing rig, which is still under calibration. Preliminary trials of the drop assemblies have shown similar flow behaviour to monitoring carried out at the access chamber. Batch tests have shown the vortex drop chamber exhibits clear helical flow into a drowned discharge, with falling film behaviour down the sides of the stilling chamber. The plunge drop chamber exhibited some channelling between the zone where the inlet falls and the outlet pipe.

4. Conclusions and Future Work

By project completion, all experimental data will have been collected and converted to mass transfer coefficients. This data will underpin a cost benefit analysis which weighs decreased odour and corrosion against the costs of replacing the access chamber and necessary connected piping. If a clear reduction in gas release is indicated by this project, additional work will be required to determine the effects of increased hydrogen sulfide levels and biofilm levels entering the downstream pumping station. As there is no release at Drop Chamber 1, increased odour and corrosion would be expected on or around the pumps.

5. Acknowledgements

I would like to thank my client mentors Mustafa Nabi and John Nazimek, as well as my academic supervisor Jeremy Leggoe, for their support and advice throughout this project. I would like to thank Des McEwan for his advice and assistance with the development of the test rig. I would like to thank Lyn Dawkins and Andrew Hatley, for their assistance with coordinating with procurement and operations. Finally, I would like to thank the Water Corporation Research and Development program for funding and supporting this project.

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