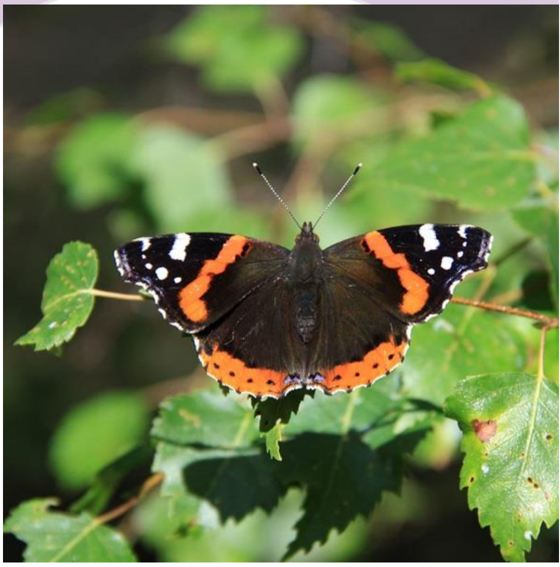
Scottish Water

Seafield Strategic Odour Review – Permanganate Dosing Trials

Final Report



Wood Environment & Infrastructure Solutions UK Limited – December 2018

wood.

Report for

John Telfer
Head of PFI
Scottish Water
Castle House
6 Castle Drive
Carnegie Campus
Dunfermline
KY11 8GG

Main contributors

Lauren Growns (Wood)
Alun McIntyre (Wood)
Rebecca Skuce, Gerry Whelehan (SWH)
Paul Banfield (Veolia)
Craig Carr (SW)

Issued by

....
Alun McIntyre

Approved by

pp ....
Adam Clegg

Wood

Block 2, Level 3
Booths Park
Chelford Road
Knutsford WA16 8QZ
United Kingdom
Tel +44 (0)1565 652100

Doc Ref. 41142 Final Report 18524i1

s:\e&i\projects\41142 nth aq seafield wwtw progress audit\c - client\reports\dosing trial final report & appendices\41142 permanganate dosing trials_final report 18524i1.docx

Copyright and non-disclosure notice

Third party disclaimer

Management systems

This document has been produced by Wood Environment & Infrastructure Solutions UK Limited in full compliance with the management systems, which have been certified to ISO 9001, ISO 14001 and OHSAS 18001 by LRQA.

Document revisions

No.	Details	Date
1	Draft Report for comments	9th November 2018
2	Final Report 18524i1	4th December 2018

Executive summary

Purpose of this report

This report has been compiled by Wood Environment & Infrastructure Solutions UK Ltd ('Wood' - formerly Amec Foster Wheeler) for Scottish Water to provide an independent assessment of raw sewage dosing trials carried out by Scottish Water Horizons. The objective of the trials is to identify the effectiveness of using potassium permanganate to reduce odour emissions from Seafield WwTW by dosing this oxidising chemical into raw sewage. An additional objective is to determine whether the addition of potassium permanganate could potentially bring about an increase in the level of odour emissions from raw wastewater – this need was generated by local residents' experience of a chemical-type odour in Spring 2018, when dosing at the WwTW inlet was taking place. This follows on from recommendations made in the March 2018 report by Amec Foster Wheeler entitled "Seafield Wastewater Treatment Works Strategic Odour Review", a copy of which may be found on the Scottish Water web site[1].

The dosing trials

The approach to and methodology for the dosing trials were formulated jointly by Scottish Water, Scottish Water Horizons, Veolia and Wood E&IS during September 2018 and Appendix A contains a copy of the proposed methodology. The trials were conducted at the Scottish Water Horizons Bo'ness testing facility. Samples of raw wastewater from the inlet of Seafield WwTW were transported to the facility by road tanker and sub-samples (500 litres) were dosed with 1, 5 and 10 mg l^{-1} of potassium permanganate. The trials were performed on fresh raw wastewater, 3-day aged wastewater, 7-day aged wastewater and 7-day aged wastewater with added sea water (20% by volume). The purpose of the ageing process and sea water addition was to simulate the travel times of wastewater in the sewer network serving Seafield WwTW and the potential for saline intrusion into the network to arise.

Findings

The ageing process and the addition of sea water significantly increased the odour and hydrogen sulphide emissions from the non-dosed raw wastewater samples. The addition of potassium permanganate achieved significant reductions in both odour emissions, of up to 65% for fresh wastewater, up to 99% for 3-day aged wastewater, up to 82% for 7-day aged wastewater and up to 70% for 7-day aged wastewater plus 20% sea water. A similar order of reduction was evident for hydrogen sulphide during the trials (Sections 3.2, 3.3 and 4.4). Dosing with potassium permanganate also improved the condition of the wastewater samples, from anaerobic and septic to aerobic and non-septic, as was anticipated (Section 3.1 and 4.2).

Conclusions

Dosing with potassium permanganate of raw Seafield wastewater samples achieved significant reductions in the emissions of odour and hydrogen sulphide and no increases in odour emissions as a result of the dosing were observed. It would therefore appear that this could be a valuable method of reducing the odour emissions from raw wastewater entering Seafield WwTW during extended dry and warm weather periods, such as those experienced during April-May 2017 and July 2018. The aim of this would be to alleviate the disamenity experienced by nearby residents as a result of odour during these periods.

Prior to dosing being carried out at a suitable location just upstream of Seafield WwTW, perhaps at the Siphon House, a full assessment should be conducted of the optimum dosing control system and also of the wider potential environmental effects.

[1] https://www.scottishwater.co.uk/-/media/domestic/files/investment-and-communities/seafieldstrategicodourreviewfinalreport18122i1.pdf?la=en

Contents

1. Introduction

1.1 Purpose of this report

1.1.1 One of the short-term action recommendations contained in Amec Foster Wheeler's (now 'Wood') 2017 Seafield Strategic Odour Review report was for Scottish Water to investigate the use of chemical dosing to alleviate odours arising from odorous incoming raw sewage at Seafield WwTW. This was considered to be of particular relevance during periods of warm, dry weather when wastewater flows are low and retention times of raw sewage in the network serving Seafield WwTW are long, resulting in septicity. This was a recommendation contained in Table 8.1 of that report "*Develop a contingency plan for dosing the network at key locations during periods of low or no rainfall to alleviate septicity, with the objective of having this in place for Spring 2018*". Given that the final report was issued at the end of March 2018, there was little time available to undertake the necessary trials prior to Summer 2018.

1.1.2 Also, during Spring 2018 when potassium permanganate dosing of incoming wastewater was being conducted at Seafield WwTW, local residents reported experiencing a chemical type odour and there were concerns that the addition of permanganate was potentially exacerbating odour emissions from the WwTW.

1.1.3 The purpose of this report, and the experimental work that has been carried out, is to identify whether dosing of raw sewage with potassium permanganate would prove to be effective in reducing odours arising from raw sewage at Seafield WwTW. In addition, it aims to identify if dosing of potassium permanganate gives rise to increases in odour emissions from the raw wastewater. If the efficacy of the permanganate dosing can be established, then the next step in the process is to consider how it can be practicably applied at Seafield.

1.1.4 Potassium permanganate in aqueous solution reacts with sulphide in wastewater as follows:

In neutral or acid pH: $2KMnO4 + 3H2S \rightarrow 3S + 2MnO2$

In alkaline pH: $8KMnO4 + 5H2S \rightarrow 5MnSO4 + 3MnOH2 + 8KOH$

1.2 The dosing trials

1.2.1 The dosing trials were formulated jointly by Scottish Water, Scottish Water Horizons, Veolia, Wood and Cranfield University during September 2018. Appendix A contains a methodology paper which describes the set-up of the trials and the necessary health & safety risk assessments. In essence, samples of raw sewage were taken from the inlet of Seafield WwTW, post screens and detritors, and were transported to the Scottish Water Horizons test facility at Bo'ness WwTW, where they were dosed with varying concentrations of potassium permanganate under controlled conditions. Various analyses were then carried out on the samples, both pre- and post-dosing, to identify the effects of potassium permanganate on odour emissions and other parameters.

1.2.2 The remainder of this report contains:

- The detailed methodology for the trials (Section 2);
- The results of the trials (Section 3);
- A discussion of the results and comparison with other relevant data (Section 4);
- Considerations of a permanent installation at Seafield (Section 5); and

- Conclusions (Section 6).

2. Approach and methodology

2.1 Approach

Raw sewage sampling at Seafield WwTW

2.1.1 With the co-operation of Veolia Outsourcing Seafield Ltd, a 20 m^3 road tanker loaded raw sewage from a point downstream of the screens and detritors at the Seafield site. The sample was then transported to the Scottish Water Horizons testing facility at Bo'ness WwTW. Owing to restrictions upon analytical availability at the olfactometry laboratory (Silsoe Odours Ltd), sample dosing and testing had to be staggered over a period of two weeks, using 2 samples of raw sewage from Seafield.

2.1.2 Upon arrival at Bo'ness, the tanker contents were transferred to IBC 1,000 litre containers

Trial specification

2.1.3 Based upon information from chemical suppliers and the results of earlier trials carried out by WRc in 2005[2], dose rates for potassium permanganate of 1, 5 and 10 mg l^{-1} were used, together with a "zero dose" for blank comparison. As well as utilising "fresh" raw sewage, which is acknowledged not to be a significant source of odours at Seafield, and a potable water "zero blank" case, it was decided to prepare three additional cases, as follows:

- 3-day "aged" sewage to simulate the quality of wastewater arriving at Seafield during periods of no rainfall and low flow;
- 7-day "aged" sewage to simulate an atypical worst-case wastewater quality arriving at Seafield; and
- 7-day "aged" sewage, containing 20% by volume sea water, to simulate atypically high saline ingress into the sewer network and additional sulphide formation under anaerobic conditions from sulphate in the sea water.

2.1.4 The full schedule of tests is summarised in Table 2.1 below.

Table 2.1 Full testing schedule

Sample	0 mg l^{-1} $KMnO_4$	1 mg l^{-1} $KMnO_4$	5 mg l^{-1} $KMnO_4$	10 mg l^{-1} $KMnO_4$
Potable water	●	●	●	●
Raw, screened de-gritted fresh Seafield wastewater	●	●	●	●
Raw, screened de-gritted Seafield wastewater (aged 3 days)	●	●	●	●
Raw, screened de-gritted Seafield wastewater (aged 7 days)	●	●	●	●
Raw, screened de-gritted Seafield wastewater + 20% v/v seawater (aged 7 days)	●	●	●	●

[2] WRc Report Ref: UC6740: Seafield Sewer Network Odour Survey. May 2005

2.2 Detailed methodology

Materials

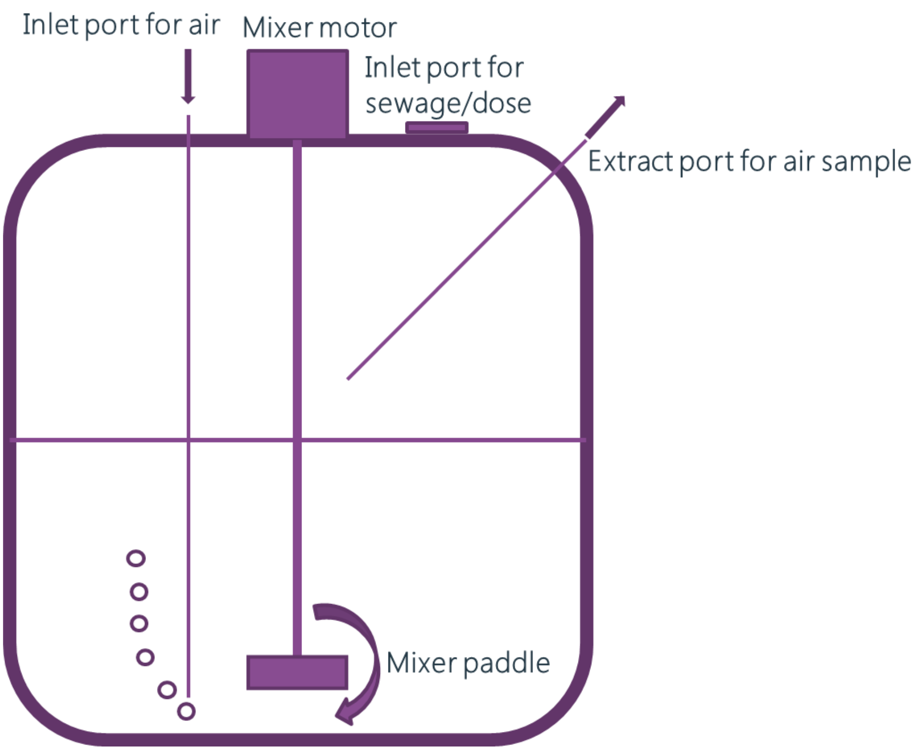
2.2.1 Aliquots of Reagent grade crystalline potassium permanganate ($KMnO_4$) were weighed-out using a Mettler electronic balance, accurate to 4 decimal gramme places. Appropriate quantities were weighed-out into clean aluminium foil trays prior to each set of trials. The quantities required for each of the 1, 5 and 10 mg l-1 dosing rates for 500 litres of liquid were as follows:

- 1 mg l^{-1} - 500 mg
- 5 mg l^{-1} – 2,500 mg
- 10 mg l^{-1} – 5,000 mg

2.2.2 Potable water (for the "zero blank" trial set) was sourced from the towns water supply main at the testing centre in Bo'ness and was directly transferred to the IBC containers by hose. Raw sewage, as described above, was sourced by road tanker from Seafield WwTW and was then either transferred directly into the experimental IBCs or stored in additional IBCs for the 3-7 day "ageing" process at ambient temperature. Sea water was obtained directly from the nearby Firth of Forth (on the flood tide) for use in the 7-day aged plus sea water trail set.

2.2.3 The dosing trials were conducted using 1,000 litre capacity Intermediate Bulk Containers (IBC), equipped with mechanical mixers. A schematic of the IBCs is provided below in Figure 2.1. A Weir 20 l min^{-1} capacity centrifugal pump was used to transfer liquids into and out of the IBCs.

Figure 2.1 Schematic details of IBC for dosing trials



2.2.4 Samples of headspace air from within the IBCs were taken into inert Nalophan A (25 μm thickness) sample bags for subsequent forced-choice olfactometric analysis. Samples of un-dosed and dosed sewage were taken into clean borosilicate sample bottles, supplied by Scottish Water Laboratories, for subsequent analysis, directly from the IBCs.

2.2.5 On-site measurement of pH and REDOX potential of the un-dosed and dosed samples was undertaken using a Hanna Instruments HI-2002 Edge multi-parameter meter, using a HI-3131B ORP electrode and a HI 10430 pH electrode.

Methods

2.2.6 The transfer and dosing of potable water and sewage samples were undertaken as follows:

- The first IBC was half-filled with potable water or wastewater (500 litres) and mixed continuously before adding the required dose of oxidant chemical in solid form;
- Mixing was continued until complete dissolution and mixing of the potassium permanganate was achieved, followed by a further 10 minutes mixing for reactions to proceed;
- At this point, the mixture was transferred by pump to the second IBC and allowed to stand for 10 minutes;
- Two duplicate 40-litre air samples were extracted from the headspace in the second IBC into a Nalophan A inert sample bag (using the "lung" sampling procedure) for subsequent analysis by olfactometry (see below). H_2S measurements were also be made on the air in the bags using an Arizona Instruments Jerome J605 gold leaf monitor. An air inlet port and tube (submerged) was included in the IBC to balance the air extracted for the olfactometry samples (Figure 2.1 above;
- Liquid samples were withdrawn for subsequent pH, REDOX and laboratory analysis;
- After sampling was complete, the contents of the IBC were transferred by pump into a sump, from which the contents were routed to the inlet of Bo'ness WwTW for treatment prior to SEPA licensed discharge into the Firth of Forth;
- The next dosing trial set in the series was then carried out.

2.2.7 The procedures carried out were replicated identically within and between each trial sets, to ensure as far as was practicable, experimental repeatability.

3. Results

3.1 Wastewater quality parameters

REDOX potential (ORP)

The results from measuring the REDOX potential (ORP) in each of the samples are contained in Table 3.1 below.

Table 3.1 REDOX potential measurement results from samples

Sample	REDOX potential, mV			
	0 mgl^{-1} $KMnO_4$	1 mg l^{-1} $KMnO_4$	5 mg l^{-1} $KMnO_4$	10 mg l^{-1} $KMnO_4$
Raw, screened de-gritted fresh Seafield wastewater	-16.3	64.1	169	171
Raw, screened de-gritted Seafield wastewater (aged 3 days)	-46.2	30	141.4	180
Raw, screened de-gritted Seafield wastewater (aged 7 days)	-153.3	-88.4	-96.7	1
Raw, screened de-gritted Seafield wastewater + 20% v/v seawater (aged 7 days)	-136	-42.5	-51.8	-26.7

3.1.1 These results are consistent with the changes in odour and H_2S concentrations recorded in the headspace above the dosed and un-dosed samples. There are depressed REDOX readings from the fresh, 3-day and 7-day aged samples, which are rapidly alleviated by the addition of the oxidising agent ($KMnO_4$), as would be expected.

Biochemical and Chemical Oxygen Demand (BOD_5 & COD)

3.1.2 Results of these analyses on the fresh, 3-day aged, 7-day aged and 7-day aged plus 20% seawater wastewater samples are contained in Table 3.2 below.

Table 3.2 BOD5 and COD results from samples

Sample	Biochemical and chemical oxygen demand				
	Parameter, mg l^{-1}	0 mg l^{-1} $KMnO_4$	1 mg l^{-1} $KMnO_4$	5 mg l^{-1} $KMnO_4$	10 mg l^{-1} $KMnO_4$
Raw, screened de-gritted fresh Seafield wastewater	BOD_5 COD	133 300	112 290	106 272	113 279
Raw, screened de-gritted Seafield wastewater (aged 3 days)	BOD_5 COD	147 354	93 282	101 248	98 236
Raw, screened de-gritted Seafield wastewater (aged 7 days)	BOD5 COD	139 363	155 398	199 468	195 469
Raw, screened de-gritted Seafield wastewater + 20% v/v seawater (aged 7 days)	BOD_5 COD	204 556	206 484	226 592	191 510

3.1.3 There are no clear trends observable in the results of these analyses, other than the usual profile that COD is consistently higher than BOD5 and the results generally display the usual range of values expected of raw wastewaters.

pH, conductivity and soluble sulphide

3.1.4 There was little variation in the pH values of all the samples analysed, with the range lying between 7.0 and 7.4. Electrical conductivity was similarly relatively constant, except for the 7-day aged samples dosed with sea water, which showed a consistently higher conductivity, as a result of the sea water. Soluble sulphide concentrations in all the samples were below the limit of detection at < 0.01 mg l^{-1}. These are summarised in Table 3.3.

Table 3.3 pH, conductivity and soluble sulphide results from samples

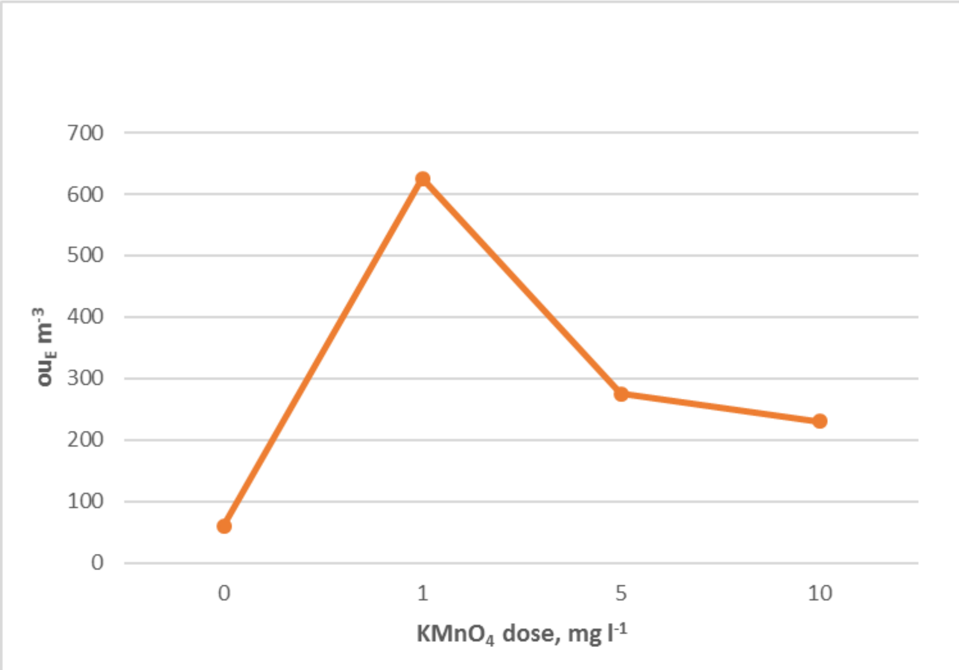
Sample	pH, units*, conductivity, mS cm^{-1}, S^{2-}, mg l^{-1}				
	Parameter, mg l^{-1}	0 mg l^{-1} $KMnO_4$	1 mg l^{-1} $KMnO_4$	5 mg l^{-1} $KMnO_4$	10 mg l^{-1} $KMnO_4$
Raw, screened de-gritted fresh Seafield wastewater	pH conductivity S^{2-}	7.3 4.66 <0.01	7.3 4.8 <0.01	7.4 4.56 <0.01	7.2 4.62 <0.01
Raw, screened de-gritted Seafield wastewater (aged 3 days)	pH conductivity S^{2-}	7.2 4.57 <0.01	7.4 4.51 <0.01	7.3 4.48 <0.01	7.4 4.41 <0.01
Raw, screened de-gritted Seafield wastewater (aged 7 days)	pH conductivity S^{2-}	7.0 4.42 <0.01	7.0 4.56 <0.01	7.1 4.44 <0.01	7.1 4.39 <0.01
Raw, screened de-gritted Seafield wastewater + 20% v/v seawater (aged 7 days)	pH conductivity S^{2-}	7.0 7.15 <0.01	7.0 7.23 <0.01	7.0 7.41 <0.01	7.1 7.4 <0.01

* pH -Log10 molar hydrogen ion concentration, conductivity is microsiemens per centimetre, dissolved sulphide in mg l^{-1}

3.2 Odour

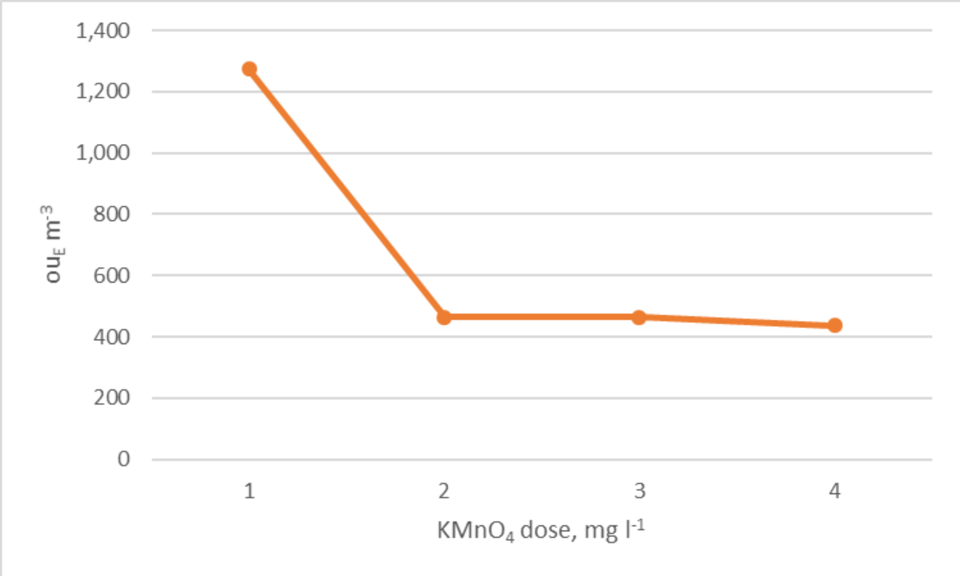
3.2.1 The detailed results from the olfactometric analysis of each of the duplicate odour bag samples are contained in Appendix B to this report. Figures 3.1 to 3.5 contain plots of the changes in odour concentration measured in the headspace air of the IBCs with each of the progressive doses of potassium permanganate (0, 1, 5, 10 mg l^{-1}), starting with potable water and progressing through fresh raw wastewater through to 7-day aged wastewater plus 20% by volume sea water. Values are the geometric means of duplicate samples.

Figure 3.1 Variation in headspace odour concentration with $KMnO_4$ dose – potable water



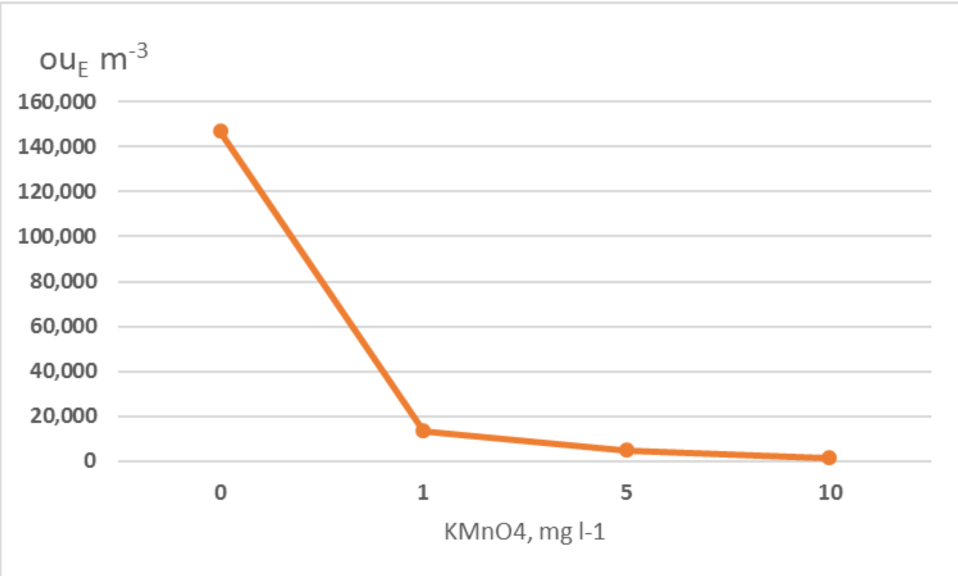
3.2.2 There is a noticeable increase (by approximately a factor of 10) in the headspace odour concentration with the addition of the 1 mg l^{-1} dose of $KMnO_4$ but this decreases with increasing dose. This is possibly as a result of reaction between residual organics and chlorine/chloramines in the potable water and destruction of intermediates with the increasing dose.

Figure 3.2 Variation in headspace odour concentration with $KMnO_4$ dose – fresh wastewater



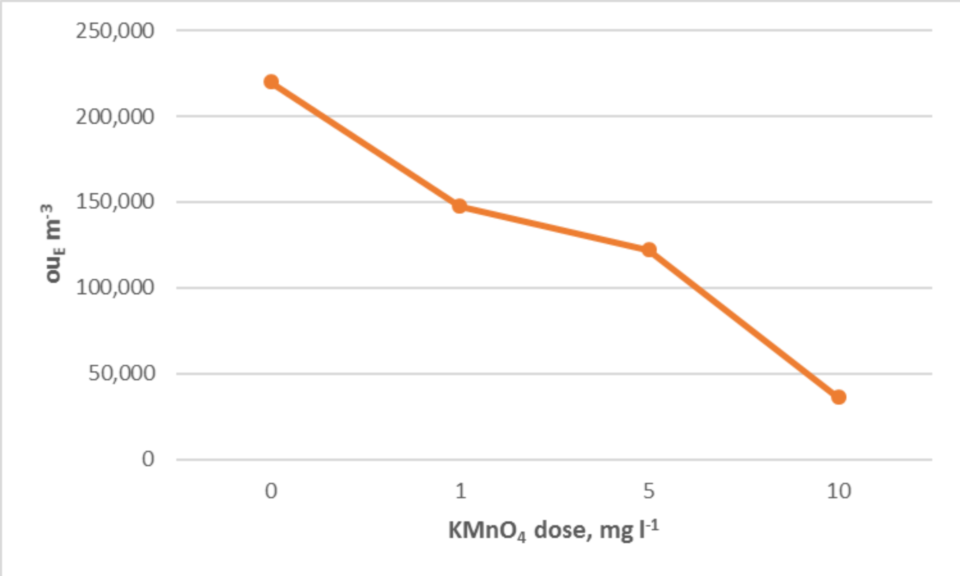
3.2.3 For the fresh raw wastewater, a substantial reduction in the headspace odour concentration is observed with the initial 1 mg l^{-1} dose of $KMnO_4$, reducing the raw odour concentration from around 1,300 ou_E m^{-3} to ~450 ou_E m^{-3}, an approximate 65% reduction. Thereafter, with increasing dose of $KMnO_4$, there is no further reduction in headspace odour concentrations.

Figure 3.3 Variation in headspace odour concentration with $KMnO_4$ dose – 3-day aged wastewater



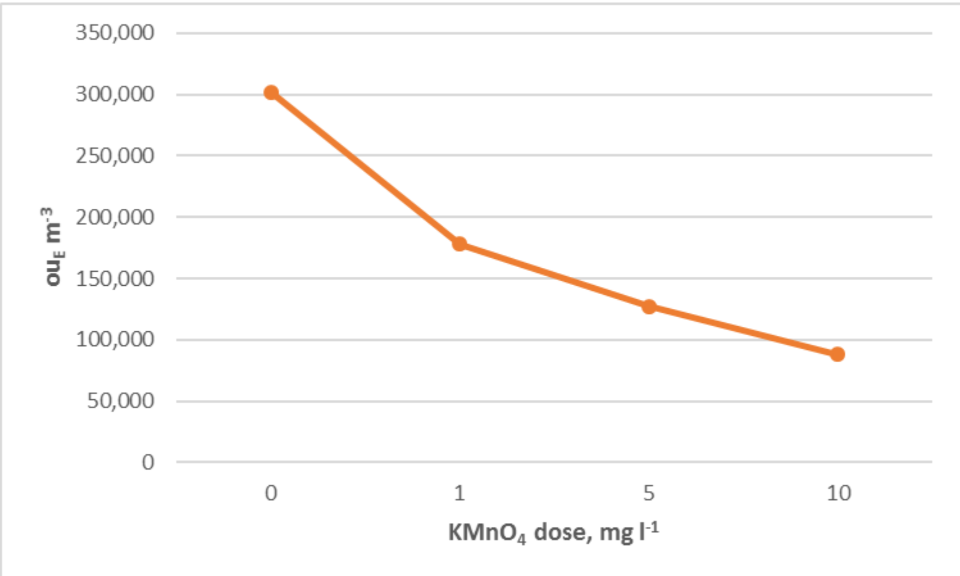
3.2.4 This raw wastewater sample that was allowed to stand for 3 days in IBCs, in an attempt to mimic the possible retention time of wastewater in the sewer network serving Seafield WwTW under dry low flow conditions. There is a clear, substantial and continuing reduction evident in the headspace odour concentrations with increasing $KMnO_4$ dose, with the addition of 1 mg l^{-1} KMnO4 achieving a reduction from 147,000 ou_E m^{-3} to 13,000 ou_E m^{-3}, a 91% reduction. Doses of 5 mg l^{-1} and 10 mg l^{-1} of $KMnO_4$ further reduce the residual headspace odour concentrations to 4,600 ou_E m^{-3} and 1,400 ou_E m^{-3}, respectively, the latter representing a 99% reduction.

Figure 3.4 Variation in headspace odour concentration with $KMnO_4$ dose – 7-day aged wastewater



3.2.5 The 7-day aged raw sewage, having been stored in IBCs at ambient temperature for that period, was noticeably more odorous than previous samples, with a raw headspace odour concentration of around 220,000 ou_E m^{-3}. A dose of 1 mg l^{-1} $KMnO_4$ reduced the headspace odour concentration to just below 150,000 ou_E m^{-3} and the highest dose of 10 mg l^{-1} achieved a reduction to 40,000 ou_E m^{-3}, an overall decrease of approximately 82%. The near exponential reduction rate in odour headspace concentration for the 3-day aged samples is not repeated here and it is clear that additional dosing would be required to reduce odours to a level similar to that of fresh raw wastewater.

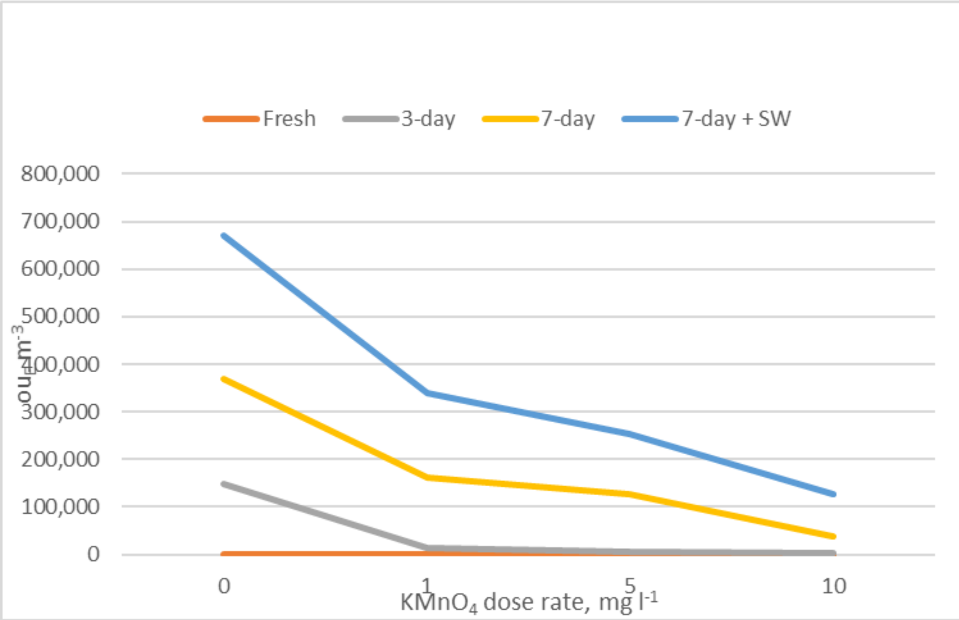
Figure 3.5 Variation in headspace odour concentration with $KMnO_4$ dose – 7-day aged wastewater plus 20% by volume sea water



3.2.6 The addition of 20% by volume sea water to raw wastewater, that was then aged for 7 days at ambient temperatures, generated higher odour levels in the headspace of the IBCs, at around 300,000 ou_E m^{-3} for the blank sample. This was reduced to around 180,000 ou_E m^{-3} by a 1 mg l^{-1} dose of $KMnO_4$ and to below 100,000 ou_E m^{-3} by the highest (10 mg l^{-1}) dose.

3.2.7 Figure 3.6 below contains a comparison of the change in odour headspace concentrations with dose rate for the wastewater samples.

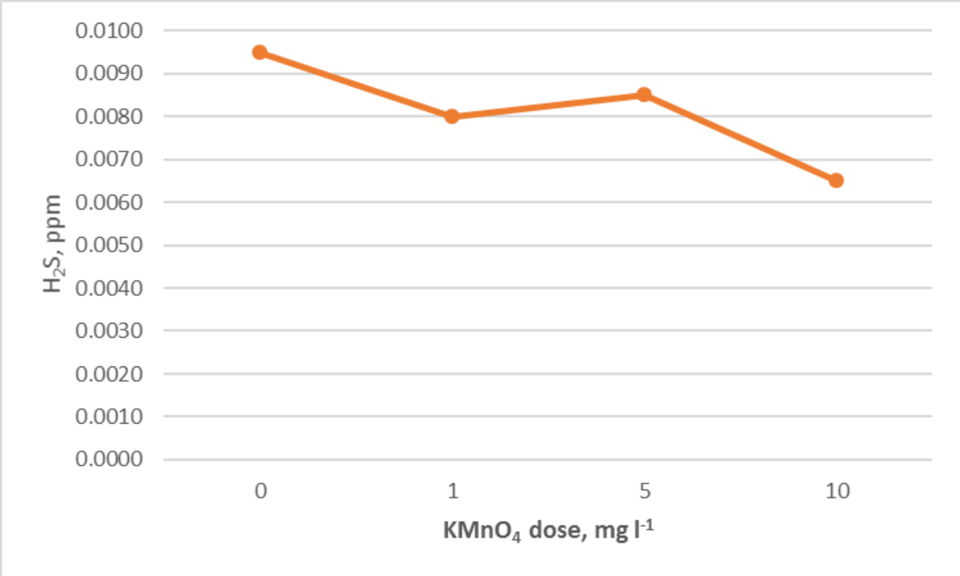
Figure 3.6 Variation in headspace odour concentration with $KMnO_4$ dose - all wastewater samples



3.3 Hydrogen sulphide

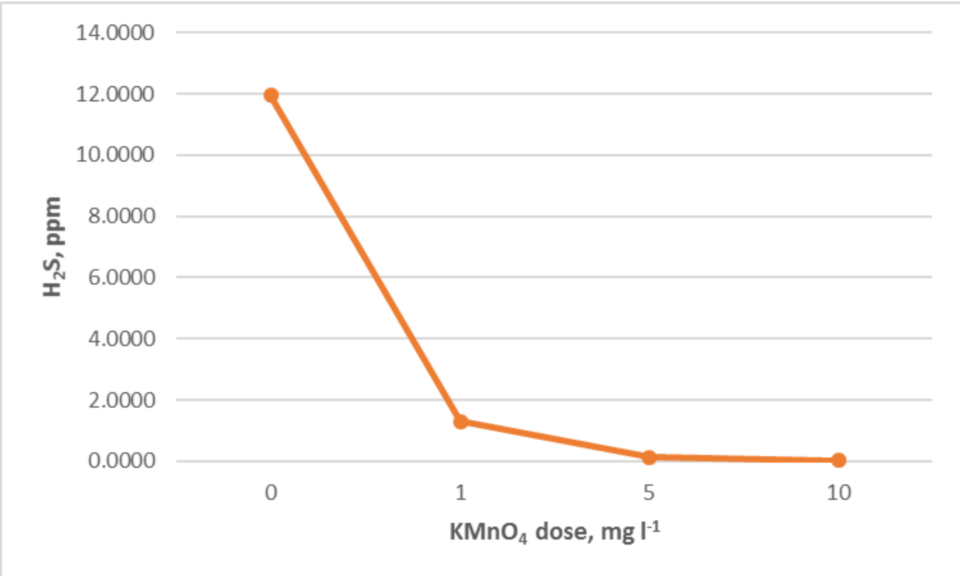
3.3.1 The detailed results from the hydrogen sulphide (H_2S) analysis of each of the duplicate bag samples are contained in Appendix B to this report. Figures 3.7 to 3.10 contain plots of the changes in H_2S concentration measured in the headspace air of the IBCs with each of the progressive doses of potassium permanganate (0, 1, 5, 10 mg l^{-1}), starting with fresh raw wastewater through to 7-day aged wastewater plus 20% by volume sea water. Unsurprisingly, no H_2S was detected in the "zero blank" potable water samples and no results are therefore included for that.

Figure 3.7 Variation in headspace H_2S concentration with $KMnO_4$ dose – fresh raw wastewater



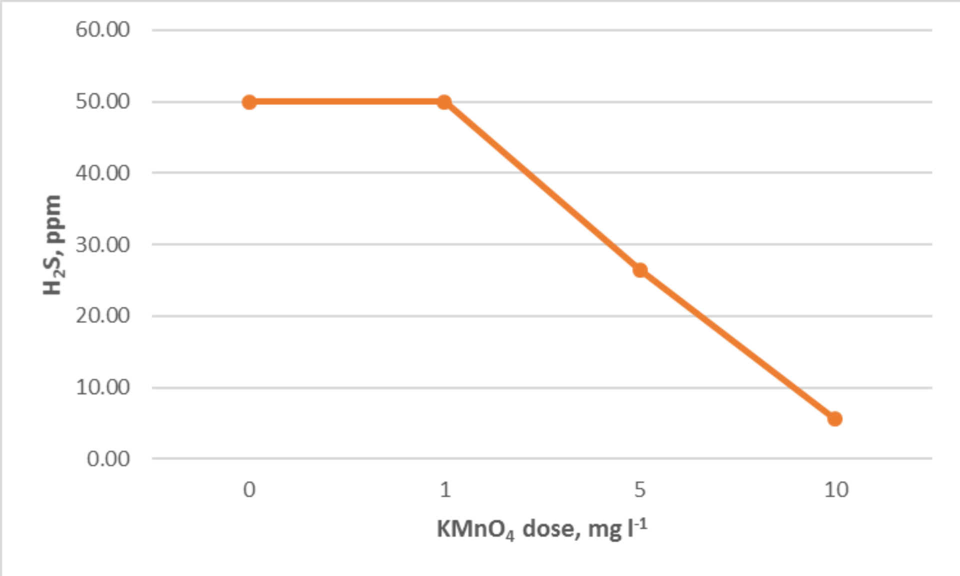
3.3.2 There is a small reduction in H_2S headspace concentration, from 9.5 parts per billion (ppb) to 6.5 ppb and this reduction is less marked than that for total odour (Figure 3.2). This is not surprising, since most of the odour in fresh, well-aerated wastewater will not arise from sulphide sources and the oxidising agent will preferentially target other reduced chemical species.

Figure 3.8 Variation in headspace H_2S concentration with $KMnO_4$ dose – 3-day aged wastewater



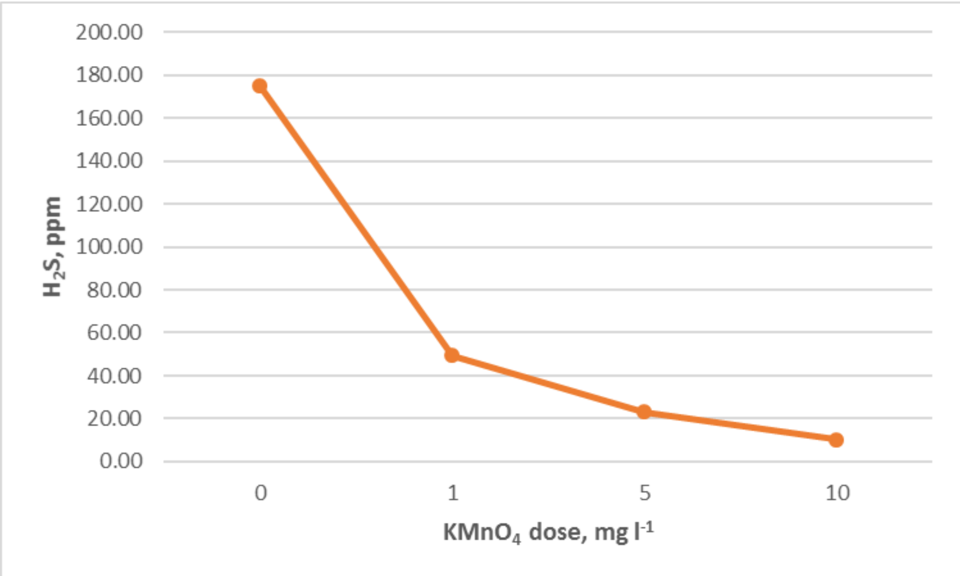
3.3.3 The reduction in headspace H_2S concentration with increasing $KMnO_4$ dosing for the 30-day aged wastewater samples is more effective than for the fresh wastewater and exhibits a similar effect to that upon total odour (Figure 3.3). From an un-dosed starting point of 12 ppm H_2S in the headspace, a 1 mg l^{-1} dose of $KMnO_4$ reduces the concentration to just over 1 ppm, decreasing to 0.035 ppm (35 ppb) with the highest 10 mg l^{-1} dose.

Figure 3.9 Variation in headspace H_2S concentration with $KMnO_4$ dose – 7-day aged wastewater



3.3.4 H_2S headspace concentrations for the 7-day aged wastewater sample were in excess of 50 ppm, above the upper detection limit of the Jerome H_2S analyser, and this was true for both the un-dosed and 1 mg l^{-1} $KMnO_4$ dosed samples. Thereafter, the 5 mg l^{-1} and 10 mg l^{-1} $KMnO_4$ doses reduced H_2S headspace concentrations to 26.5 ppm and 5.6 ppm respectively.

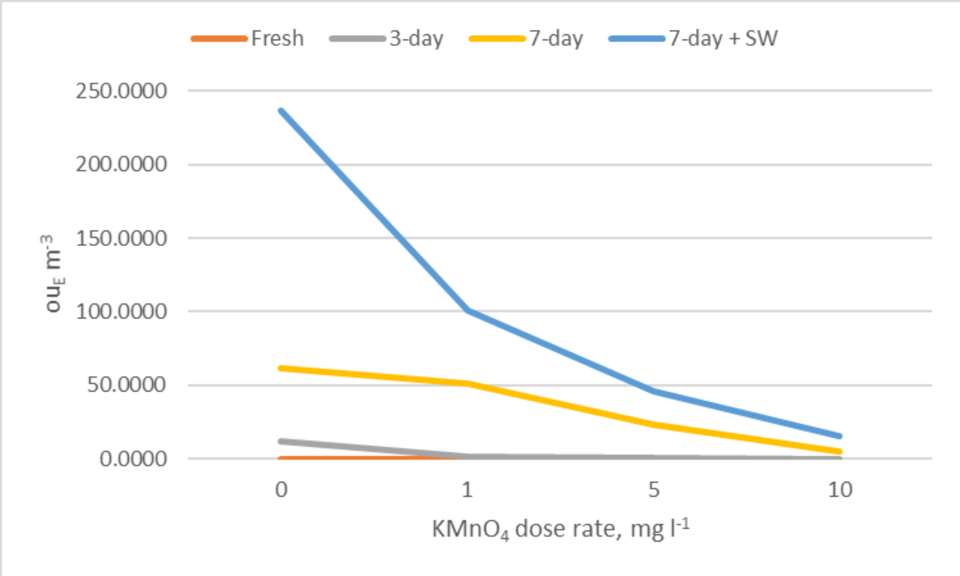
Figure 3.10 Variation in headspace H_2S concentration with $KMnO_4$ dose – 7-day aged wastewater plus 20% by volume sea water



3.3.5 For the 7-day aged wastewater "spiked" with 20% by volume sea water, the bag samples were diluted prior to H_2S measurements and a more expected profile of H_2S concentration reductions in the headspace was obtained. There was a substantial reduction from 180 ppm to 45 ppm by the 1 mg l^{-1} dose of $KMnO_4$, followed by less substantial reductions to 10 ppm by the 10 mg l^{-1} $KMnO_4$ dose.

3.3.6 Figure 3.11 contains a combined plot of the variation in headspace H_2S concentrations with dose rate for all the wastewater samples.

Figure 3.11 Variation in headspace H_2S concentration with $KMnO_4$ dose – all wastewater samples



4. Discussion of results

4.1 Preamble

4.1.1 The use of oxidising agents for control of odours in wastewater conveyance and treatment systems has been widespread for several years and has involved chemicals such as chlorine, hypochlorite, chlorine dioxide, ozone, hydrogen peroxide, peracetic acid and potassium and sodium permanganates. The drawback of using chlorine-based compounds is that a varied suite of chlorinated oxidation by-products can be formed in the wastewater, some of which may be toxic, and storage of such hazardous materials (although chlorine dioxide is produced electrochemically at the point and demand of use).

4.1.2 Ozone is a powerful oxidising agent which, if applied in the correct doses, will ensure complete oxidation of target compounds, whilst avoiding the problems of by-products. However, systems for the generation of ozone are complex and costly and require specific expertise to operate successfully. It is also, with the associated power requirements, expensive to produce.

4.1.3 Hydrogen peroxide and peracetic acid are also powerful oxidising agents which, if applied in the correct doses, will achieve effective oxidation without the generation of potentially harmful by-products. As with the chlorine derivative compounds, there are hazards associated with the transport and storage of these chemicals.

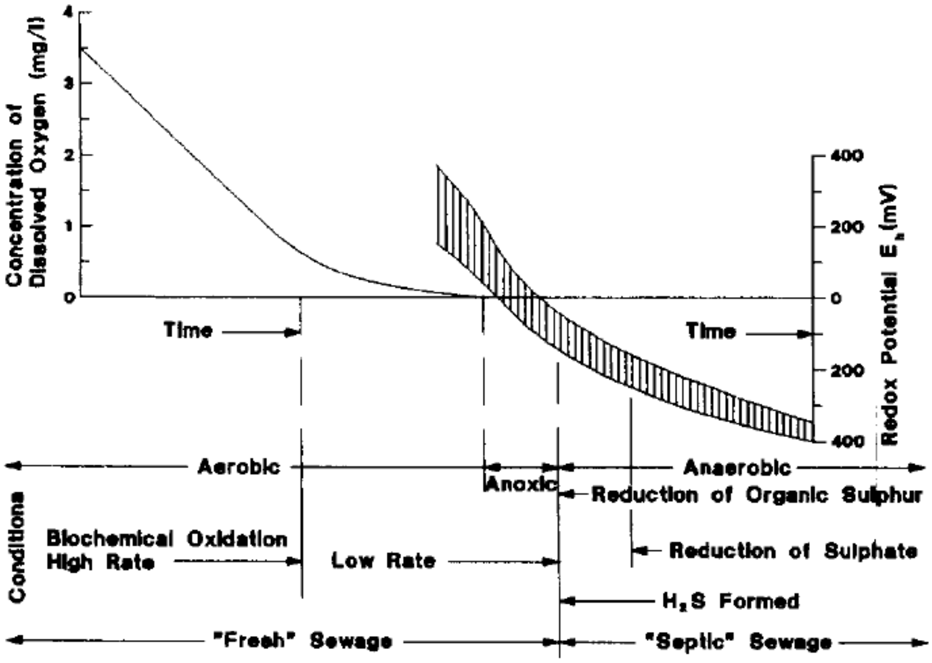
4.1.4 Potassium permanganate can be stored as a crystalline solid or in aqueous solution form (20% or 40%) and is also available in a controlled-release large pellet formulation. It is relatively easy to handle and is widely available on the UK chemicals/commodities market. Its selection for these trials was based upon the joint experience of Scottish Water and Veolia in its use for controlling odours in sludge and wastewater and its relatively benign hazardous properties in comparison to other oxidising agents.

4.2 ORP measurements during the trials

4.2.1 How these recorded values, contained in Table 3.1 on page 9 above, relate to the actual condition of the wastewater, in terms of oxygen, sulphide and degree of septicity is best explained by consideration of the graph below, reproduced from a 1995 publication[3].

[3] A. G. Boon (1995) Septicity in sewers: causes, consequences and containment. Wat. Sci. Tech., 11 (7), 237-253.

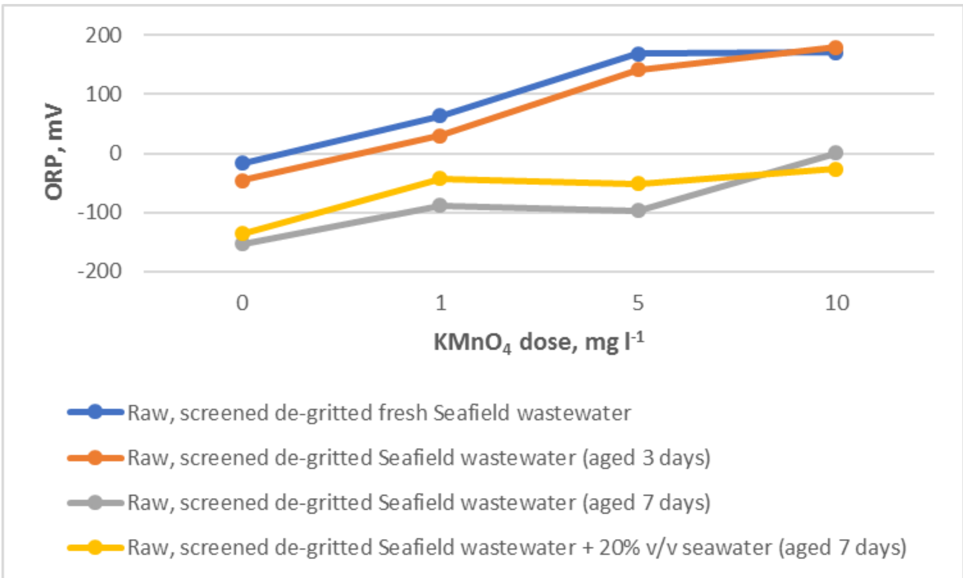
Figure 4.1 Variation in condition of sewage in relation to concentration of dissolved oxygen and redox potential (extracted from Boon (1995).



4.2.2 On the above basis, the fresh sample of raw wastewater would be classified in the "fresh sewage, anoxic" category, whilst the 3-day aged and 7-day aged samples (with and without sea water addition) would be classified in the "septic sewage, anaerobic" category.

4.2.3 The results are conveniently summarised in Figure 4.1 below.

Figure 4.2 Variation in ORP readings with increasing does rate of $KMnO_4$



4.2.4 Clearly, once the $KMnO_4$ oxidising agent is added, even at the lower of the three dose rates, significant changes in the condition of the wastewater are evident. For the 7-day aged sample plus sea water, even the highest dose of $KMnO_4$ does not result in a positive ORP reading. For the 3-day aged sample, which is likely to be most representative of the wastewater arriving at Seafield under extended warm dry conditions in late Spring and Summer, even a 1 mg l^{-1} dose of $KMnO_4$ moved the condition from anoxic to aerobic. It is, though, interesting to consider the results of ORP monitoring at the inlet to Seafield WwTW conducted in April-May 2017 and July 2018. During these periods, ORP readings reached minimum levels of -200 mV over many days, indicative of anaerobic conditions. It is, therefore, likely that, based upon the results of these trials, more substantial doses of $KMnO_4$ may be required in practice.

4.3 Other wastewater analytical parameters

4.3.1 Biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) contents of the wastewater samples were within the ranges typical of UK mainly domestic wastewater. There were no measured concentrations of soluble sulphide above the detection limit of the analytical method (0.01 mg l^{-1}). Conductivity readings on the wastewater samples were relatively constant across the board, apart from those samples containing sea water, which showed an increase in conductivity, as a result of the enhanced salt content.

4.4 Odour and H_2S measurements during the trials

4.4.1 It is clear from the results that $KMnO_4$ dosing of the raw wastewater is effective at reducing emissions of odour and this is most likely to be because of effective reaction with dissolved sulphide and oxidation of odorous organic matter. The reductions effected by successive doses (graphs in Figures 3.1 to 3.5) for the 3-day aged and 7-day aged samples fit to an exponential decay of odour levels in the headspace of the IBCs. It is also noticeable that the effect upon fresh raw wastewater results in a residual odour level (after doses of 5 and 10 mg l^{-1} KMnO4) close to that of the potable water trial. This in itself indicates that there is a final residual odour level that cannot be further reduced in practical terms.

4.4.2 The results for fresh raw wastewater can be compared with results obtained previously by WRc in 2005[4], when fresh wastewater samples form Seafield WwTW were dosed with between 0.1 mg l^{-1} and 1.0 mg l^{-1} potassium permanganate on a jar test apparatus using 20 litre sub-samples of raw wastewater sampled from the Seafield WwTW inlet. Before and after dosing, the samples were analysed using the WRc odour potential stripping rig.

4.4.3 The odour potential concentrations measured during these jar tests were generally low, varying between 500 and 1,000 ou_E m^{-3}. Results of the tests revealed that potassium permanganate dosing removed between 70% and 90% of the H_2S present in the raw wastewater but reductions in odour concentrations were more modest, reducing by up to 40%, similar to the results obtained in this dosing trial using fresh raw wastewater.

4.4.4 The overall conclusions of the WRc jar tests was that it was unclear whether or not chemical dosing of wastewater would reduce odour nuisance but that it could be inferred that at higher wastewater odour levels it could be an effective tool. It was further concluded that, of the chemicals tested (ferric salts and potassium permanganate), addition of potassium permanganate at 1 mg l^{-1} would prove to be the most effective dose and that the dosing should be restricted to those periods when sulphate (and, by implication, sulphide and odour) are elevated in the raw wastewater.

4.4.5 During these current dosing trials, odorous wastewater was generated by artificially "ageing" samples of wastewater, producing headspace odour concentrations in the raw wastewater of between 150,000 and 300,000 ou_E m^{-3}. Dosing of these samples with potassium permanganate at

[4] WRc (2005) Chemical dosing jar tests at Seafield WwTW. Report UC6744.

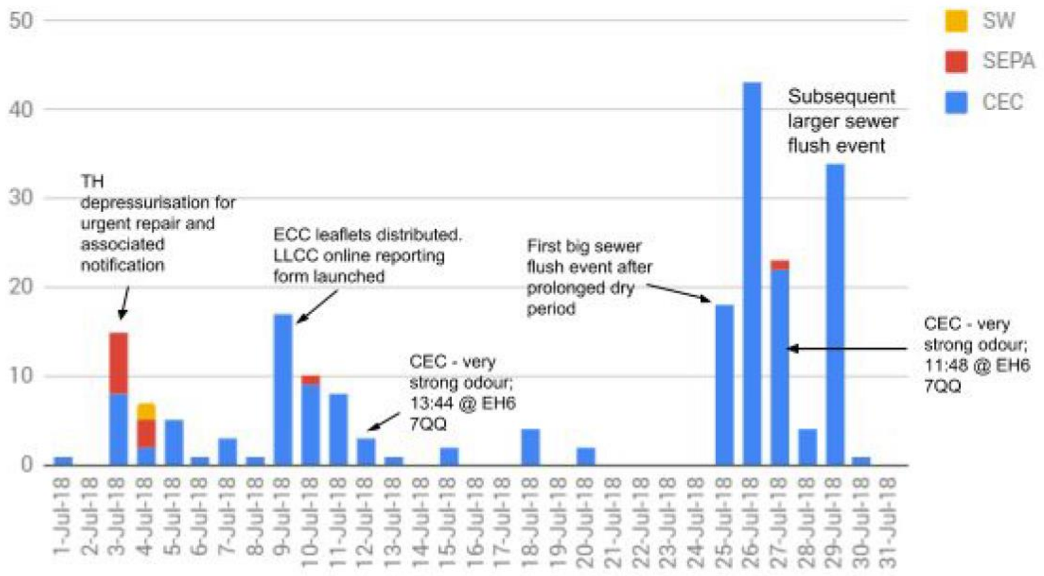
levels of between 1 mg l^{-1} and 10 mg l^{-1} effected good reductions in headspace odour and H_2S concentrations.

5. Full-scale implementation considerations

5.1.1 There is evidence to indicate, from odour complaint records, inlet wastewater monitoring data and ambient air monitoring data that, during extended dry periods and times of low wastewater flows and extended retention times in the sewer network, particularly odorous wastewater enters Seafield WwTW and can give rise to elevated emissions of odour. This also tends to coincide with periods of onshore winds, which disperses emissions in the local community areas of Leith. There is also a suspicion that emissions from manholes and vents in the sewer network feeding the Siphon House could be responsible for generating odours and subsequent complaints from the local community. Examples of times when this has occurred are April and May 2017 and June and July 2018, when common themes were onshore winds, low or no rainfall for extended periods and poor quality incoming wastewater flows.

5.1.2 Figure 5.1 below shows the combination of these effects and the resultant levels of complaints in July 2018[5].

Figure 5.1 Odour complaints in July 2018



5.1.3 The results of these dosing trials revealed that substantial reductions of odour and H_2S emissions from wastewater can be achieved. From a practical standpoint, though, there are logistical issues to be considered, including:

- At what location the chemical dosing should be carried out;
- The exact method of delivery and dosing of the chemical into the wastewater;
- The method by which the dosing can be controlled and managed;
- When the dosing should be initiated; and
- How the effects of the dosing can be measured and monitored.

[5] Extracted from the July 2018 Environmental Performance Report.

5.2 Location

5.2.1 In terms of location, it is considered that dosing into the raw wastewater flows at the Siphon House would be most effective, at the point where the eastern and western interceptor sewers combine before the Seafield WwTW inlet. There would then be sufficient turbulence and mixing time before the flow arrives at Seafield. In addition, flows arriving from the eastern interceptor probably have some of the longest residence times in the network and could well be subject to saline intrusion. Also, from a practical standpoint, there is space in the grounds surrounding the Siphon House for a dosing installation.

5.3 Delivery method

5.3.1 Regarding the method of delivery, $KMnO_4$ is available in solid crystalline form, as concentrated solutions (20% and 40%) and, more recently, in the form of slow-release tablets[6]. During the dosing trials, the 500-litre samples of wastewater were dosed manually with pre-weighed aliquots of crystalline $KMnO_4$, which, given the high solubility of the substance in water, made complete dissolution easy. However, in the dynamic circumstances of a continuously varying incoming wastewater flow through the Siphon House to Seafield, dosing with a solid chemical may not be practical and delivery in a solution form may be more convenient. An Archimedean Screw-type of delivery system could be appropriate, consisting of the following components:

- Bulk dry storage vessel (hopper/silo);
- Gravity delivery to intermediate hopper supply to screw delivery;
- Variable speed motor for screw;
- Pipework for delivery to sump; and
- Building enclosure for weather-proofing.

5.3.2 From information supplied by Scottish Water and Veolia during the 2017 Strategic Review, during extended dry periods, wastewater flows into Seafield WwTW decrease to around 200,000 $m^3\ d^{-1}$[7]. At this flow rate, the daily quantity of $KMnO_4$ required to achieve a dose of 1 mg l^{-1} in the raw wastewater would be 200 kg, equivalent to 8.3 kg h^{-1} or 2.3 g s^{-1}. To deliver the correct dose in liquid form would require the establishment of a rig with the following components:

- A bulk chemical storage tank (for 20%/40% concentrated KMnO4 liquid product);
- A tanker or IBC loading and storage area;
- A mains water dilution system and "day tank";
- A metering pump (duty & standby) for solution delivery; and
- Necessary controls, monitoring and operating software.

5.3.3 A simpler, if less precise, alternative would be to consider the use of controlled-release pelletised $KMnO_4$. The pellets can be contained within a polypropylene mesh bag, suspended in the incoming wastewater flow, and the mass delivery rate can be tailored by the number of pellets contained in the mesh bag. Assuming that a convenient sump can be located within the Siphon House (or immediately upstream) and there are no significant confined space entry issues, then this

---

[6] https://www.youtube.com/watch?v=6Xmm8hJIwf4&feature=youtu.be
[7] Strategic Review Report, Figure 6.6, page 60.

method, if proved to be effective, would offer a simpler, more cost-effective option than both mechanical delivery methods above.

5.4 Monitoring and control

5.4.1 There is already in place at the Seafield WwTW inlet an ORP monitoring probe, the readings from which could be used in real time from the site Control Room to assess the requirement for and the effect of upstream permanganate dosing. However, the important issue here is that of identifying in advance when the dosing will be required. Weather forecasts to assess the occurrence of onshore winds are already monitored by Veolia and Stirling Water, for operational control purposes, and it should be possible to extend these to encompass ambient temperature and rainfall for up to 1 week ahead on a daily basis. It is evident, from examination of weather records over the last 40 years or so, that extended dry and warm periods can occur between the months of March and July, so this 5-month period represents, when combined with onshore winds, the window of risk.

5.5 Wider potential implications

5.5.1 Dosing of chemicals into wastewater should, as a matter of routine and best practice, be subject to careful evaluation, not only in respect of potential effects upon treatment processes within the curtilage of the WwTW site but also with regard to wider effects upon the receiving waters into which the final effluent is discharged and the fate of contaminants in the sludge, which may be disposed to land.

5.5.2 In this particular case, looking at the elemental composition of $KMnO_4$, both potassium and oxygen are unlikely to exert any significant effects, given the existing levels of these elements in the aquatic and terrestrial environments. Manganese, however, a refractory heavy metal, has the potential for effects. The fate of manganese in conventional wastewater treatment has been studied[8], and it was found that approximately 70% of manganese was retained in the primary and secondary sludges. This is unsurprising, given its properties and propensity to precipitate in the oxide and hydroxide forms under alkaline conditions.

5.5.3 If we assume that, worst case, only 50% of the manganese dosed into Seafield WwTW as the 200 kg of potassium permanganate (see 5.3.2 above) is retained in the sludge, then approximately 35 kg would be retained in the sludges and 35 kg would be discharged in the final effluent to the Firth of Forth. The approximate concentration of manganese in the final effluent under dry flow conditions would be 0.175 mg l^{-1}. There is clearly substantial dilution of this available in the Firth of Forth.

5.5.4 There are available environmental quality standards for manganese in fresh and saline waters[9]. The recommended EQS for saline waters is set at 0.05 µg l^{-1}, a factor of some 3,500 below the figure calculated above for the final effluent from Seafield. However, the UK-TAG report referenced below also states, "***The saltwater PNEC of 0.05 µg l^{-1} is an order of magnitude below the low end of concentrations reported in seawater and is therefore not implementable as an EQS***." It is uncertain, therefore, what the current and future status of this theoretical EQS is.

5.5.5 The Sludge (Use in Agriculture) Regulations 1989[10] do not include manganese within their remit and, therefore, no maximum limit is imposed for its content for sludge applied to agricultural land.

---

[8] https://www.ncbi.nlm.nih.gov/pubmed/14550351
[9] https://www.wfduk.org/sites/default/files/Media/Environmental%20standards/Manganese%20EQS%20Report%20-%20UKTAG%20%282%29.pdf
[10] http://www.legislation.gov.uk/uksi/1989/1263/contents/made

6. Conclusions

6.1.1 The dosing trials conducted during October 2018 have indicated strongly that dose rates of $KMnO_4$ of between 1 mg l^{-1} and 10 mg l^{-1} into wastewater can be effective at reducing emissions of odour and H_2S. In particular, dosing of raw wastewater that had been artificially aged for between 3 and 7 days and adulterated with seawater (to simulate saline intrusion into the sewer network) produced substantial odour and H_2S reductions.

6.1.2 There was no indication at ball that dosing of potassium permanganate into raw wastewater resulted in increases in odour emissions.

6.1.3 Incremental doses of $KMnO_4$ also brought about, for the aged wastewater samples, an increase in the REDOX potential of the samples, changing the condition from anoxic and anaerobic to an aerobic condition.

6.1.4 It is, therefore, likely that, with diligent application of this dosing regime at Seafield WwTW at certain critical times of the year, an effective reduction in odour emissions and, hence, complaints, could be achieved.

Appendix A
Proposed methodology for dosing trials

Technical note:
Seafield WwTW: Proposed approach to and methodology for trial chemical dosing of raw wastewater with oxidants

1. Introduction and Background

This technical note has been compiled following initial discussions between Scottish Water and Cranfield University, a tele-conference between Scottish Water, Scottish Water Horizons, Veolia, Cranfield University and Wood E&IS on 21st August and a site visit to the Scottish Water Horizons facility at Bo'ness by personnel from Scottish Water, Veolia and Wood E&IS on Thursday 30th August.

The purpose of this note is to set out, in summary form, the objectives of the trial, the approach to setting-up the experimental equipment, the detailed methodology for conducting the trial and the parameter monitoring requirements.

The background out of which this trial has emerged begins with dosing trials carried out on an experimental basis by WRc in 2004-2006 and recommendations made in the Seafield Strategic Odour Review Final Report, published in March 2018. The key relevant recommendation in that report was for Scottish Water, and the Seafield site operators (Veolia and Stirling Water) to investigate the use of chemical dosing for the alleviation of septicity in the raw wastewater entering Seafield WwTW and a corresponding reduction in odour emissions.

2. Objectives of the trial

The primary objective of the trial is to determine if the addition of a strong oxidising agent, potassium permanganate ($KMnO_4$), to Seafield raw wastewater, at times of low flow and borderline septicity in the raw sewage, would reduce odour levels in the sewage and reduce subsequent emissions of odour to atmosphere, particularly from the surfaces of the primary settlement tanks (PSTs). Secondary objectives include identifying the influence, if any, of the presence of seawater in the sewage and the possible use of alternative oxidising agents to potassium permanganate.

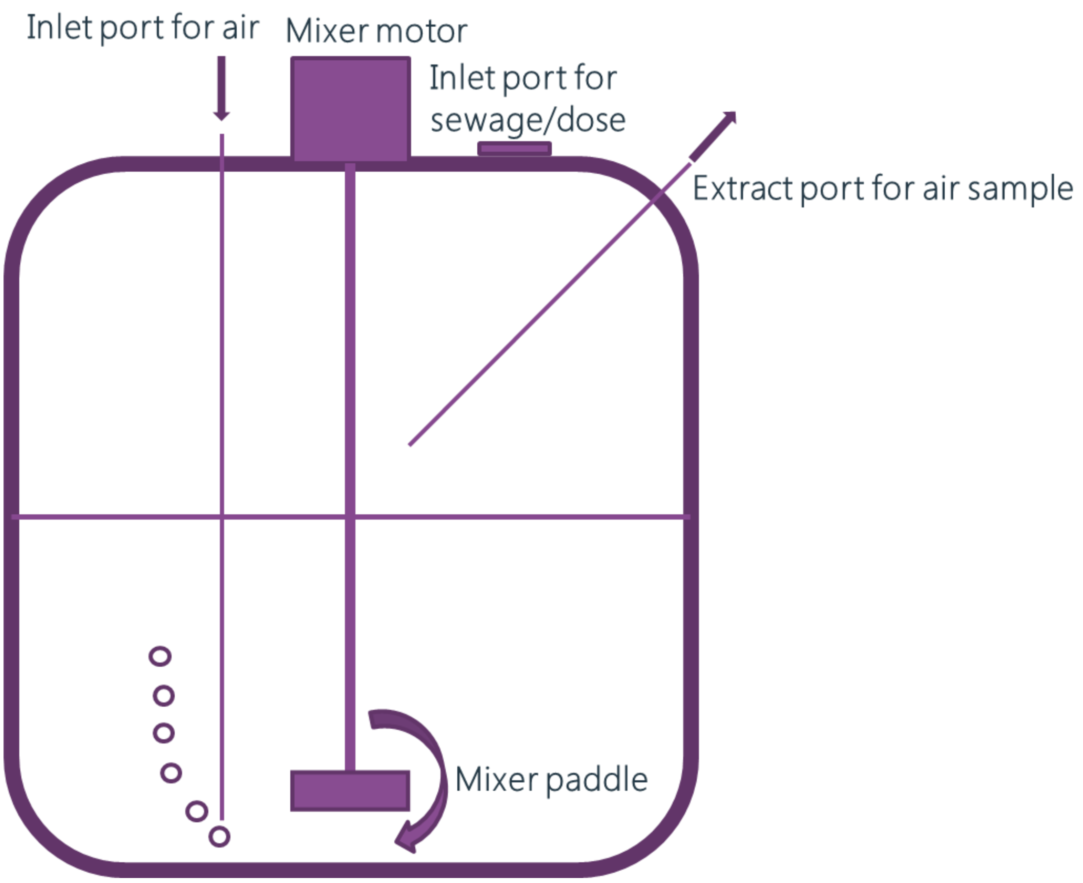
3. Approach

The basic approach agreed between the parties is to make use of the Scottish Water Horizons (SWH) testing facility at Bo'ness and to do a trial run of the dosing using raw screened and de-gritted indigenous wastewater from the Bo'ness WwTW, prior to undertaking trials with imported screened and de-gritted raw wastewater from Seafield. Given that the over-riding objective is to alleviate odour emissions during periods of low flow and borderline septic wastewater at Seafield, it is proposed to store the imported raw wastewater from Seafield for a few days at ambient temperature to generate anoxic/anaerobic conditions before carrying out the dosing trials.

The dosing trials will be conducted using two 1,000 litre capacity Intermediate Bulk Containers (IBC). In simple terms:

- The first IBC will be half-filled with wastewater (500 litres) and stirred continuously before adding the required dose of oxidant chemical in solution form;
- Stirring will continue until complete dissolution and mixing of the oxidant chemical, followed by a further 10 minutes for reactions to proceed;
- At this point, the mixture will be transferred by pump to the second IBC and allowed to stand for 10 minutes;
- Two duplicate 40-litre air samples will be extracted from the headspace in the second IBC into a Nalophan A inert sample bag (using the "lung" sampling procedure) for subsequent analysis by olfactometry at Silsoe Odours Ltd in Bedford in accordance with CEN 13725:2003. H_2S measurements will also be made on the air in the bag. An air inlet port and tube (submerged) is included in the IBC to balance the air extracted for the olfactometry samples (Figure 3.1 below); and
- Liquid samples will also be withdrawn for analysis as per 4.3 below.

Figure 3.1 Schematic details of IBC for dosing trials



4. Trial methodology

4.1 Samples to be dosed

As indicated above, the exact procedures for the dosing trials will be developed on samples of indigenous wastewater from Bo'ness WwTW. Once the protocols are established, the following samples will be used in the dosing trials:

- Potable water – to identify any contribution to odour from the oxidant chemical;
- Raw, screened and de-gritted wastewater from Seafield;
- Raw, screened and de-gritted wastewater from Seafield adulterated with seawater (400 litres wastewater, 100 litres seawater) – to identify any odour issues with reaction of the oxidant chemical with components of seawater;
- Aged (2-3 days) raw, screened and de-gritted wastewater from Seafield – to simulate borderline septic conditions; and
- Aged (1 week) raw, screened and de-gritted wastewater from Seafield – to simulate septic conditions.

4.2 Trial regime

On the basis that a single oxidant chemical ($KMnO_4$) will be used and that the typical dose ranges for wastewaters lie in the range 0.5 to 2 mg/l. Table 4.1 below sets out a potential schedule of trial dosing experiments.

Table 4.1 Potential schedule for trial dosing experiments

Sample	0 mg/l $KMnO_4$	1 mg/l $KMnO_4$	5 mg/l $KMnO_4$	10 mg/l $KMnO_4$
Potable water	•	•	•	•
Raw, screened de-gritted Seafield wastewater	•	•	•	•
Raw, screened de-gritted Seafield wastewater + 20% v/v seawater	•	•	•	•
Raw, screened de-gritted Seafield wastewater (aged 2-3 days)	•	•	•	•
Raw, screened de-gritted Seafield wastewater (aged 1 week)	•	•	•	•

For introduction of the oxidant chemical into the samples to be tested, a mass of between 500 mg and 5,000 mg $KMnO_4$ will be required per test. It is recommended that these small quantities of solid should be dissolved in 5,000 ml of distilled, deionised water prior to adding to the IBC to facilitate mixing.

4.3 Measurements

It is recommended that the following measurements are made on each sample batch prior to testing and repeated post dosing and testing:

- pH;
- Conductivity;
- Oxidation reduction potential (ORP);
- Dissolved sulphide; and
- BOD_5/COD (from routine daily Seafield influent analyses).

For each of the individual dosing tests (24 elements from Table 4.1 above), duplicate bag samples will be taken for H_2S and olfactometric analysis. With regard to the tests using seawater, it is also recommended that a sub-sample of the post-test sample is taken (1-2 litres) and is subject to Grob-type stripping and GC-MS analysis. Standard water Industry "Blue Book" analytical methods should be followed.

5. Time scales

Figure 5.1 below lays out the time scale for the trials.

Activity	M	T	W	Th	F	S	S	M	T	W	Th	F	S	S	M	T	W
Potable water																	
Raw, screened de-gritted Seafield wastewater																	
Raw, screened de-gritted Seafield wastewater + 10% v/v seawater																	
Raw, screened de-gritted Seafield wastewater (aged 2-3 days)																	
Raw, screened de-gritted Seafield wastewater (aged 1 week)																	

6. Deliverables

The output of this dosing trial will be in the form of a summary report, detailing the materials and methods, results, interpretation thereof and conclusions, followed by recommendations for additional work.

7. Health, safety & environmental issues

It is recommended that a specific health, safety and environment plan is compiled for this set of tests, on a "cradle to grave" basis, covering the following:

- Sampling of raw wastewater at Seafield and transportation to Bo'ness;
- Discharge and interim storage at Bo'ness (particularly for aged samples);
- Transfer into IBCs for testing, stirring and dosing;
- Handling, transfer, dissolution and dosing of $KMnO_4$;
- Sampling and measurements on dosed samples;

- Disposal of tested samples and materials; and
- Appropriate PPE for each of the steps above.

8. Future community demonstration trial

Depending upon the results of these dosing trials, consideration will be given to staging a subsequent community demonstration trial at Seafield, on a smaller scale (in terms of sample volumes), concentrating upon the most effective permanganate dosing levels and taking small odour bag samples for examination by a residents' panel.

Issued by	Approved by
[signature]	[signature]
Alun McIntyre	**Chris Haigh**

Management systems

This document has been produced by Wood Environment & Infrastructure Solutions UK Limited in full compliance with the management systems, which have been certified to ISO 9001, ISO 14001 and OHSAS 18001 by LRQA.

Appendix B
Olfactometric analysis of odour bag samples

Olfactometric measurements

Silsoe Odours Limited

Client: Wood Environment
Location: Bo'ness
Measurement Date: 18, 19, 23 & 25 October 2018

01525 860222
info@silsoeodours.co.uk
www.silsoeodours.com

Contract report number:	CR/SO1864/18/WE009
Customer reference:	
Measurements carried out by:	J. R. Sneath; G. A. Liddle
1. Contact:	Alun McIntyre Wood Environment & Infrastructure Solutions UK Ltd Floor 12, 25 Canada Square Canary Wharf, London E14 5LB Mobile +44 (0) 758 300 3631 Office +44 (0) 203 215 1650
2. Odour source:	Waste Water
3. Sampler: *	unknown
4. Sampling date: *	17, 18, 22 & 24 October 2018
5. Laboratory temperature and CO_2	23.5°C; 1,007 ppm; 23.3°C; 1,126 ppm 22.4°C; 998 ppm; 24.4°C; 1,296 ppm
6. Measurement date	18, 19, 23 & 25 October 2018
7. Presentation mode:	Forced choice
8. Olfactometer:	PRA Odournet B.V. Serial number OLFACTON-E
9. Pre-Dilution Gas Meter:	Kimmon Model SK25 Ser No 0003171
10. Reference odorant/accepted reference value	n-butanol. 60 ppm / 40ppb
11. Calibration Status of Laboratory	A_{od} = 0.076; r = 0.343; A_{od} = 0.076; r = 0.353 A_{od} = 0.076; r = 0.354; A_{od} = 0.64; r = 0.384
12. Method:	Following Odour Lab Procedure OL2 which incorporates BSEN13725 "Air quality – Determination of odour concentration measurement by dynamic olfactometry".
13. Special remarks:	Nalophan NA bags 25µm thick
14. Approved by	Compiled by

R W Sneath J.R. Sneath

R. W. Sneath, Head of Laboratory. J. R. Sneath, Deputy Laboratory Manager

"This laboratory is accredited in accordance with the recognised International Standard ISO/IEC 17025:2005. This accreditation demonstrates technical competence for a defined scope and the operation of a laboratory quality management system (refer joint ISO-ILAC-IAF communiqué dated April 2017)"

*Sampling is outside the scope of UKAS Accreditation

Silsoe Odours Limited
Building 42,
Wrest Park, Silsoe,
Bedfordshire MK45 4HP

Olfactometric measurements

Silsoe Odours Limited

01525 860222
info@silsoeodours.co.uk
www.silsoeodours.com

Client: Wood Environment
Location: Bo'ness
Measurement Date: 18, 19, 23 & 25 October 2018

Results:

Table 1: Results for Bo'ness odour samples analysed on 18 October 2018

Samples collected 17/10/18 at:	Samples analysed 18/10/18 at:	Sample No.	Sample Source and Position	S. O. H_2S ppm	Odour Panel Threshold, $ou_E\ m^{-3}$	Lab. Pre-dilution factor	Odour concentration of sample, $ou_E\ m^{-3}$ (including laboratory pre-dilution)
09:10	09:14	20181018 BON1	P.W. 01	0.002	54	None	54
11:30	10:36	20181018 BON2	P.W. 0. 5.1	0.004	724	None	724
12:45	10:08	20181018 BON3	P.W. 2.5.1	0.000	266	None	266
13:45	09:41	20181018 BON4	P.W. 5.0.1	0.000	207	None	207
09:25	09:30	20181018 BON5	P.W. 02	0.000	68	None	68
12:00	10:26	20181018 BON6	P.W. 0. 5.2	0.000	540	None	540
13:00	10:21	20181018 BON7	P.W. 2.5.2	0.000	284	None	284
14:00	09:57	20181018 BON8	P.W. 5.0.2	0.000	255	None	255

Table 2: Results for Bo'ness odour samples analysed on 19 October 2018

Samples collected 18/10/18 at:	Samples analysed 19/10/18 at:	Sample No.	Sample Source and Position	S. O. H_2S ppm	Odour Panel Threshold, $ou_E\ m^{-3}$	Lab. Pre-dilution factor	Odour concentration of sample, $ou_E\ m^{-3}$ (including laboratory pre-dilution)
10:00	10:37	20181019 BON1	A3.01	12.4	1,598	100:1	161,398
10:18	10:16	20181019 BON2	A3.02	11.5	1,326	100:1	133,926
10:40	11:36	20181019 BON3	A3.051	1.4	928	13:1	12,992
11:00	11:20	20181019 BON4	A3.052	1.2	976	13:1	13,664
11:30	11:02	20181019 BON5	A3.251	0.14	6,182	None	6,182
12:01	10:52	20181019 BON6	A3.252	0.139	3,541	None	3,541
12:20	10:03	20181019 BON7	A3.51	0.040	1,289	None	1,289
12:45	09:55	20181019 BON8	A3.52	0.030	1,543	None	1,543

Silsoe Odours Limited
Building 42,
Wrest Park, Silsoe,
Bedfordshire MK45 4HP

Olfactometric measurements

Silsoe Odours Limited

Client: Wood Environment
Location: Bo'ness
Measurement Date: 18, 19, 23 & 25 October 2018

SILSOE ODOURS

UKAS TESTING 0609

01525 860222
info@silsoeodours.co.uk
www.silsoeodours.com

Table 3: Results for Bo'ness odour samples analysed on 23 October 2018

Samples collected 22/10/18 at:	Samples analysed 23/10/18 at:	Sample No.	Sample Source and Position	S. O. H_2S ppm	Odour Panel Threshold, $ou_E\ m^{-3}$	Lab. Pre-dilution factor	Odour concentration of sample, $ou_E\ m^{-3}$ (including laboratory pre-dilution)
07:00	11:17	20181023 BON1	A7 0.1	50	240	1000:1	240,240
07:30	11:32	20181023 BON2	A7 0.2	50	201	1000:1	201,201
08:00	11:47	20181023 BON3	A7 0.5.1	50	175	1000:1	175,175
08:20	11:56	20181023 BON4	A7 0.5.2	50	124	1000:1	124,124
09:00	13:12	20181023 BON5	A7 2.5.1	30	1,592	100:1	160,792
09:20	13:02	20181023 BON6	A7 2.5.2	23	919	100:1	92,819
09:15	13:37	20181023 BON7	A7 5.0.1	5.9	2,995	13:1	41,930
09:30	13:26	20181023 BON8	A7 5.0.2	5.2	2,239	13:1	31,346
10:00	11:04	20181023 BON9	ASW 7.0.1	150	339	1000:1	339,339
10:20	10:50	20181023 BON10	ASW 7.02	200	268	1000:1	268,268
10:30	10:40	20181023 BON11	ASW 7.0.5.1	50	187	1000:1	187,187
10:45	10:22	20181023 BON12	ASW 7.0.5.2	49	113	1000:1	113,113
10:55	10:05	20181023 BON13	ASW 7.2.5.1	25	143	1000:1	143,143
11:30	09:54	20181023 BON14	ASW 7.0.5.2	21	169	1000:1	169,169
11:20	09:40	20181023 BON15	ASW 7.5.1	11	207	500:1	103,707
11:35	09:25	20181023 BON16	ASW 7.5.2	9.2	75	1000:1	75,075

*Sampling is outside the scope of UKAS Accreditation

Odour measurement & consultancy services

Silsoe Odours Limited
Building 42,
Wrest Park, Silsoe,
Bedfordshire MK45 4HP

Olfactometric measurements

Silsoe Odours Limited

Client: Wood Environment
Location: Bo'ness
Measurement Date: 18, 19, 23 & 25 October 2018

01525 860222
info@silsoeodours.co.uk
www.silsoeodours.com

Table 4: Results for Bo'ness odour samples analysed on 25 October 2018

Samples collected 24/10/18 at:	Samples analysed 25/10/18 at:	Sample No.	Sample Source and Position	S. O. H_2S ppm	Odour Panel Threshold, $ou_E\ m^{-3}$	Lab. Pre-dilution factor	Odour concentration of sample, $ou_E\ m^{-3}$ (including laboratory pre-dilution)
11:10	16:12	20181025 BON1	R.0.1	0.010	1,970	None	1,970
11:20	16:00	20181025 BON2	R.0.2	0.009	824	None	824
11:45	15:52	20181025 BON3	R.0.5.1	0.008	500	None	500
12:00	15:36	20181025 BON4	R.0.5.2	0.008	430	None	430
12:16	15:20	20181025 BON5	R.2.5.1	0.009	426	None	426
13:35	15:04	20181025 BON6	R.2.5.2	0.008	504	None	504
13:00	14:53	20181025 BON7	R.5.0.1	0.007	379	None	379
13:10	14:36	20181025 BON8	R.5.0.2	0.006	503	None	503

Deviation from the standard:
None
The following data is not covered by our UKAS Accreditation:
S. O. H_2S measurements in Table1,2,3 & 4 not accredited

Contract report form issued 8 November 2017 *Sampling is outside the scope of UKAS Accreditation

Silsoe Odours Limited
Building 42,
Wrest Park, Silsoe,
Bedfordshire MK45 4HP