final report

Project code: P.PIP.0557
Prepared by: Greg Ibbotson
Churchill Abattoir Pty Ltd

Date published: 2 November 2017

PUBLISHED BY
Meat and Livestock Australia Limited
Locked Bag 1961
NORTH SYDNEY NSW 2059

Rendering Plant Biofilter Design and Demonstration

This is an MLA Donor Company funded project.
Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government and contributions from the Australian Meat Processor Corporation to support the research and development detailed in this publication.

Executive summary

This project involved an investigation into the design criteria of odorous gas biofiltration and LECA™ and other material as suitable biofilter media.

Physical properties, pressure and flow testing were undertaken on wood chip, LECA™, bark, coal ash, and Hebel™ block (a likely LECA™ alternative). A setup up using separation of layers of media was constructed and nine separate test cells were used to determine odour removal efficiency from three rendering plant exhaust streams: non-condensables, a combined non-condensables/by-products building exhaust stream, and a blood furnace line.

44 – 67% removal efficiency was obtained over the nine test cells with various media at 900 mm depth in several arrangements with some being separated into layers. Water spray nozzles were believed to have aided in odour removal. Seeding of the media with bacteria from an existing biofilter was seen as an imperative for early efficient operation of the biofilter.

From the results of the research project, it was proposed that two 40-foot shipping containers were sufficient with a bed depth of about 1500 mm of wood chip the same as the previous biofilter would effectively treat all three exhaust air streams.

It is suggested that the lower media layer of rock or Hebel™ be separated from the above media layers and water sprays installed to act as a scrubber and add moisture to the air stream.

The aim was to build a biofilter based on the research. This was not to be because of external factors but the design using 2 x 40-foot shipping containers with wood chip media is considered to be a good result. Using the 40-foot containers (total bed area of 56 m^2) results in a design parameter of about 2700 OU/m^2 and about 16000 OU/s emission rate for a bed depth of 1200 – 1800 mm.

Table of contents

1 Background

1.1 Original Concept - Overview

The intent of the project was to replace the rendering plant biofilter at Churchill Abattoir Pty Ltd (CA) using manufactured media. Essential design criteria for rendering plant biofilters was not readily available and/or non-existent. To this end a Plant Initiated Project (PIP) was proposed and accepted to investigate and build a demonstration biofilter. Investigation was to determine performance criteria to enhance biofilter performance, examine biofilter media, minimise costs, increase biofilter longevity, and minimise maintenance costs. A major component of the proposal was to investigate and compare LECA™ (light expanded clay aggregate) to wood chip and bark as the primary media.

The overarching aim was to provide industry with data and design guidelines/criteria to build a better biofilter.

It became apparent that LECA™ would not be a practical media and hence the direction of the project was modified and is explained later. The following sections describe existing conditions and issues to be investigated and how the project was modified based on the Literature Review and pre-existing conditions.

1.1.1 Pre-existing Conditions

Up until September 2017 Churchill Abattoir (CA) was one of Australia's largest domestic-only beef abattoirs, processing approximately 600 head of cattle per day (3,000 head per week), with a possible extension that could lead to an increased operational throughput of 1,200 head per day (6,000 head per week). Rendering operations were undertaken from approximately 0600 to 2000 hrs daily (5 days/week). Subject to an expansion this would have increased to 24 hrs operation.

Until about 2001 CA had a small (5m x 6 m) in-ground biofilter consisting of a series of 150 mm slotted pipes under a bark media; wetting was haphazard. This biofilter was extended in 2001 to about 20 m x 30 m and a sprinkler system installed. This system was not effective as measured by community odour complaints. While fine tuning of this system made some improvement, short-circuiting of gases occurred; it proved unsatisfactory.

In Dec 2012, a system using two standard 6 m shipping containers was installed as per Figure 1 below.

Fig 1: Shipping Containers being placed on-site

The lower container was empty as shown in Figure 2 and 3. Stone was placed on a mesh reinforced structure as shown in Figure 2. The empty space was lined with plastic sheet to catch water that drained to a pump (Figure 3).

Fig 2: Looking at the underneath of the floor of the top container showing rock fill and supports

Fig 3: Empty space in lower container with con-condensables inlet (left) and By-products building inlet (far end) with air flap.

The upper container was filled with bark and sprinklers installed (Fig. 4).

Fig 4: Bark fill and sprayers

The internal dimensions of the shipping containers are:

Internal Length	5898 mm
Internal Width	2352 mm
Internal Height	2392 mm

Table 1: Standard 6 m shipping container (approx. internal volume 32 cu m allowing for intrusions)

No air volume or pressure drop was measured for the Biofilter or the data has been lost. The previous 'Open Bed' in ground Biofilter suffered due to small inlets and back pressure from the non-condensables fan did not allow efficient air extraction from the Rendering/By-products building (cooker, presses, centrifuges, hammer mill, blood cooking/bagging and meal storage).

The larger void in the lower container seems to have stabilised the pressure drop from two separate sources. The container arrangement was very successful. However, the container Biofilter was commissioned in Jan 2013 and the filter media was effective for about 3 years. Bark replacement is a time consuming and potentially unsafe operation. Significant rusting of the containers has allowed fugitive emissions.

The disadvantages of the container system are:

a. The metal container will 'rust out' and pose an injury risk at some stage (leaks are now evident)
b. The door openings become rusted
c. Removal of the bark media is cumbersome and can pose an injury risk
d. Has a large 'footprint'
e. It has a relatively small operational life.

The advantages of the container system are:

a. It is highly effective
b. It is relatively very cheap
c. Has less a 'footprint' than open biofilters
d. Minimal maintenance ('set and forget') although monitoring moisture content (MC) is an ongoing requirement for any system

Although the current system works very well, the long-term viability is low with a media life of about 3 years. The operating parameters are unknown and the potential to handle any future rendering exhaust gas increase is also unknown. There appears to be no known Australian design and/or performance criteria available in the public domain related to rendering plant biofilter design.

1.1.2 Conceptual Framework

The initial concept to replace the biofilter was based upon using LECA™ as the biofilter media as it is commonly used in Europe but use for that purpose in Australia (it is available, bagged, for aquaculture and small-scale hydroponics). Preliminary investigation has shown that while LECA™ is suitable and has longevity, there may be several practical reasons to seek alternate media.

The following initial investigations raised the following issues – both general issues, and as they relate to CA:

1. **Roof**. Biofilters can be open to the atmosphere, have exhaust stacks/funnels, or be roofed. Sawtell meat works has a low roofed structure that condenses the exhaust gases and allows greater control of MC. A roofed structure is preferred for simplicity although the existing open biofilter works well.
2. **Depth of Bed**. Advice is that 1 – 2 m of LECA™® is sufficient for a rendering plant (pers. comm. Tom Curran, UCD). This can be calculated from the various references and from model testing. Factors such as volume, air flow, EBRT etc to be determined.
3. **Bed Width/Length**. As per 2 above
4. **Plenum**. This is similar to 2 and 3 above except that there are two air flow inputs: by-products building and non-condensables fan. The by-products is high volume/low speed; the non-condensables is low volume (comparative to the by-products) but high pressure. The existing plenum is approx. 32 m^3 and performs as a pressure equalisation chamber (Figure 3). Previous experience is that the non-condensables' airflow creates a back pressure to by-products if not equalised.
5. **Dust and Fatty Material**. It is noted that most LECA™ referenced is related to pig housing air extraction where dust is an important consideration. The by-products building can contain a lot of meal and blood dust if the extraction were operating at higher fan extraction speeds. The air from the by-products may contain some fatty material from the presses. Meat meal dust does have some fatty residue in the meat meal itself. Most blood meal process dust is extracted to the boiler. The non-condensables air stream is from the cooker exhaust gases at 135^oC that has been passed through a heat exchanger. The temperature of the air stream is between about 50 – 70^oC. This air stream is fatty and has a high odour level. However:
    a. the existing biofilter had no problem with the air mix and operated well for several years until the media biologically degraded.
    b. It is assumed that the fatty material is not of concern either because of the bacteria on the bark media or the dust and fats are condensed in the waste stream in the plenum.
    c. It is unknown if LECA™ will have the same response as wood chip/bark for rendering plant air flows or the plenum is the prime operative to remove fats and dust if that is what occurs.
6. **Maintenance**. Assuming that the media needs to be maintained as has been mentioned in some instances, what level of maintenance is required, how does it occur, how is it cleaned, what disposal is required for either cleaning materials and/or LECA™.
7. **Containers for LECA™**. An issue with the bark media and the arrangement within the container system biofilter is the replacement of the media that is required now. LECA™ has an end life of about 7 years but the media may need cleaning (unknown at this stage but it

has been indicated that in some circumstances this may be required). Removing the media, no matter the type, is therefore problematic. It is believed that a container system for the media may be possible (this is a new idea not seen anywhere but a search may prove its existence).

8. **Location**. The present location works but limits further work. Options for location to be examined (see (9) below).
9. **Dual or Single Biofilters**. The two air streams, although proximate, are separate and easily defined. An option is to treat each air stream separately; this will allow a smaller footprint for each stream. What is unknown is the treatment requirements for each stream and if the combined streams are mutually beneficial. Having two biofilters is slightly more expensive (an assumption) than one but if smaller then the location is better able to be placed and maintenance should be easier. Twice the monitoring equipment is also needed. This does not include the third Blood Furnace air stream discussed later.
10. **Drainage**. The location should, where possible, be naturally drained rather than pumped; hence located to the main wastewater stream is beneficial. Reduces the risk of pump failure and overflow.
11. **Building Materials**. The existing biofilter uses two shipping containers, the longevity is not known due to rust potential. Maintenance and replacing the media is difficult and may be an injury risk.
12. **Time to Operate Fully**. An unknown is commissioning time for the bacteria to work effectively. If a new location is used, then the old biofilter can be maintained until full commissioning is successful.
13. **Seeding with Waste Water**. A passing reference to seeding with wastewater was noted as a commissioning process. Wastewater is not suitable for wetting the media due the need for fine filtration to avoid clogging of the spray jets. The existing bark filled biofilter was seeded with a compost layer.
14. **Blood Dust**. Currently CA exhaust gases from the blood ring-dryer are sent to an inducted air input in the coal fired boiler. While this works, it is not an optimal solution. Blood exhaust dust and its effect on a biofilter need to be examined.

CA undertook an investigation that resulted in the shipping container concept as an interim measure. This was a temporary measure to alleviate an immediate need for a biofilter pending investigation for a permanent solution. The issues described above are the result of this initial investigation.

1.2 Modified Concept

1.2.1 LECA™

LECA™ appears to be used extensively in Europe but primarily for intensive animal industries. While there appears to be little information related to the use of LECA™ in biofilters for rendering, work by Fogarty and Curran (2008) shows it is a useful media.

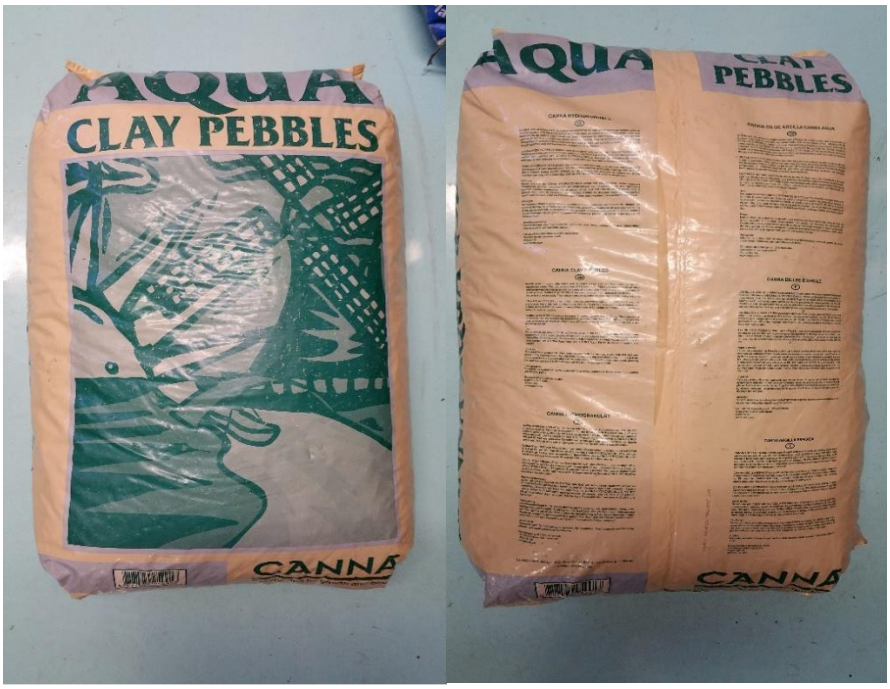

Fig 5: Source and Type of LECA™

Figure 5 shows the typically available source of LECA™ in Australia where it is predominantly used in aquaponics and hydroponics. Overseas sources were investigated; it become clear that the supply of LECA™ would be difficult and costly. Advice from Dr. Micheal Fogarty, Katestone Scientific Pty Ltd (pers. comm.) was that the sources of LECA™ varied in Europe and that selection of a supplier was critical to obtaining a quality product.

A decision was taken by the investigative team to discount LECA™ as a potential media and seek a replacement although the available LECA™ would be examined for comparative performance.

2 Project objectives

The project objectives and milestones are shown in Table 2.

Serial	Objective	Relevant Milestone and Timeline
1	Literature review of odour removal biofilters	**1** - Lit Rev & Feasibility Study
2	Characterisation of physical characteristics and odour units from 3 x sources – rendering plant building, non-condensables fan, and blood dryer exhaust	**1** - Lit Rev & Feasibility Study (1 Jun 17 – 15 Jul 17)
3	Pilot scale test of odour removal efficiencies using bark, LECA™ , and coal ash media.	**2** - Build and test model biofilters (16 Jul 17 – 30 Aug 17)
4	Identification of potential prime odour monitoring chemical species – chemical compound indicators of performance (if feasible)	**2** - Build and test model biofilters
5	Design of biofilter for CA	**2** - Design Biofilter and develop generic design model (31 Aug 17 - 14 Sep 17)
6	Identification of maintenance issues and media replacement mechanisms	**2** - Design Biofilter and develop generic design model

7	Model biofilter design methodology	**2** - Design Biofilter and develop generic design model
8	Demonstration working biofilter	**3** - Build biofilter (15 Sep 17 - 15 Oct 17) **3** - Commission and validate biofilter (16 Sep 17 - 30 Oct 17)
	N/A	**4** - Report submission (16 Sep 17 - 30 Oct 17)

Table 2: Objectives and Milestones

Note that Serial 6 and 7 were incorporated into Milestone 2 at the contract signing stage. Milestone 1, Literature Review and Feasibility Study, was completed in August 2017 and a report submitted to MLA. Milestone 2 was extended to 28 Oct 2017. Due to the closure of CA in September 2017 Milestones 3 and 4 ceased by agreement with MLA.

3 Methodology

3.1 Milestone 1 Literature Review and Feasibility Study

There were several elements to Milestone 1: Literature Review, Establish Sampling Ports, Prepare Test Sites, Measure Basic Operational Parameters, and Experimental Design/Feasibility Study. The milestone ran from 1 June – 15 July 17.

3.1.1 Literature Review (Lit Rev)

The Literature Review (Lit Rev) has been submitted separately to MLA and an extract from the Lit Rev is attached as Appendix 1. The Lit Rev is comprehensive and was peer reviewed by Mr Geordie Galvin of Pacific Environment Ltd. The primary author was Dr Ihsan Hamawand. The Lit Rev is further discussed in Section 6.

3.1.2 Establish Sampling Port

Three sampling ports were established on the Non-condensables ducting, By-products exhaust fan, and Blood ring-dryer (also referred to as the Blood Furnace) exhaust ducting. These areas are shown below:

Fig 6: Non-condensables ducting

Fig 6 shows odour unit sampling by Mr Aaron Dobson from Assured Monitoring Group Pty Ltd. A known volume of the air stream is collected in a special propylene bag for later analysis (dual samples are taken). Two sampling ports of 75 mm were installed in each of the three locations (Figures 6-8).

Fig 7: By-products Exhaust Fan

Sample ports should be installed 6 x diameter of the pipe from any fan, valve or other connection that may create turbulence and interfere with the sampling. This could not be achieved for the By-Products exhaust (Fig 2) where the ports were inserted prior to the fan.

Fig 8: Blood ring-dryer exhaust duct: access can sometimes be an issue.

3.1.3 Prepare Test Sites

The initial concept was to test each of the 3 air steams identified in Section 1.1.2 as the existing biofilter is known to be capable of dealing with the combined by-products/con-condensables air streams. Some discussion of this concept queried if individual streams was warranted. The logic was that measuring individual streams would allow flexibility of biofilter installation for individual streams if installation space was limited; individual air stream testing was confirmed.

The only test site not suitable is the by-products (Fig 7). A new port was not installed for testing waiting on the design of the test apparatus and to be installed prior to Milestone 2. The other two sites are suitable and to be confirmed when the test apparatus is constructed in Milestone 2.

3.1.4 Measure Basic Operational Parameters

Assured Monitoring Group (AMG) conducted basic testing of the three main exhausts from the rendering plant: Non-condensables post heat exchanger, By-products building exhaust, and exhaust gases from the blood furnace ring dryer (Figures 6 - 8). The Executive Summary of the findings are presented in Appendix 2: Performance Data. The full report has been submitted separately to MLA.

An overview of sampling apparatus was provided at Appendix 3: General Sampling Devices and Measurement, of the Milestone 1 Report.

3.1.5 Experimental Design

The project concept was based on several precepts that:

a. a thin-layer, open, in-ground biofilter was barely acceptable and was high maintenance;
b. dual 20-foot shipping containers, filled with rock - wood chip – bark - compost layers, achieved exceptional odour reduction within a week of installation;
c. the shipping container solution had about a 3-year life span;
d. good results had been achieved overseas using LECA™ extending the life of the biofilter, and
e. the fall-back position was that shipping containers, better modified and rust-proofed, would be an expedient solution.

The underlying design aim was that a biofilter should be cost-effective and 'low-tech' as possible requiring low maintenance. Initial review of several papers indicated the factors to consider in biofilter design although 'replace as is' was strongly considered but this did not overcome the relatively short life span of the 'container' biofilter. To design a biofilter using other than wood chip brought unknow design factors into play; hence this project.

The design steps involved measuring the operational output parameters (1.1.2 above), identifying key design elements vide the Lit Rev, analysing media based on Lit Rev findings, and conducting basic performance tests using selected media prior to building in-line bench test apparatus.

Two of the primary design parameters are: a. Air Flow and Pressure Drop, and b. Media Characteristics. Air Flow and Pressure Drop is discussed in Section 4.1.2 and the Milestone 1 Report. The purpose of these two investigations is to determine how the media responds to air flow that can be scaled against the operational characteristics conducted by AMG on the three air exhaust lines.

A test apparatus was built to conduct the air flow and pressure drop analysis. The test apparatus is shown in Figures 9 -14. The measurements were taken at several depths of the media and in both wet and dry conditions.

Four media types were tested: Wood chip, LECA™, sieved coal ash, and Hebel™ lightweight concrete. The Hebel™ blocks were cut to a reasonably uniform size. This raises issues for supply and size uniformity should the Hebel™ prove successful (the blocks are sold in varying sizes but generally 600 mm (L) x 300 mm (W) and from 100 – 400 mm (D)).

Air was passed into the plenum Figure 11; the bed was initially empty and then layers of dry media was placed on the perforated plate. Air flow and pressure drop measurements were taken at varying media depths and repeated for wet media (Milestone 1 Report).

Based on this model, three units with three chambers were constructed to test each media at the three air exhaust locations to measure odour removal efficiency.

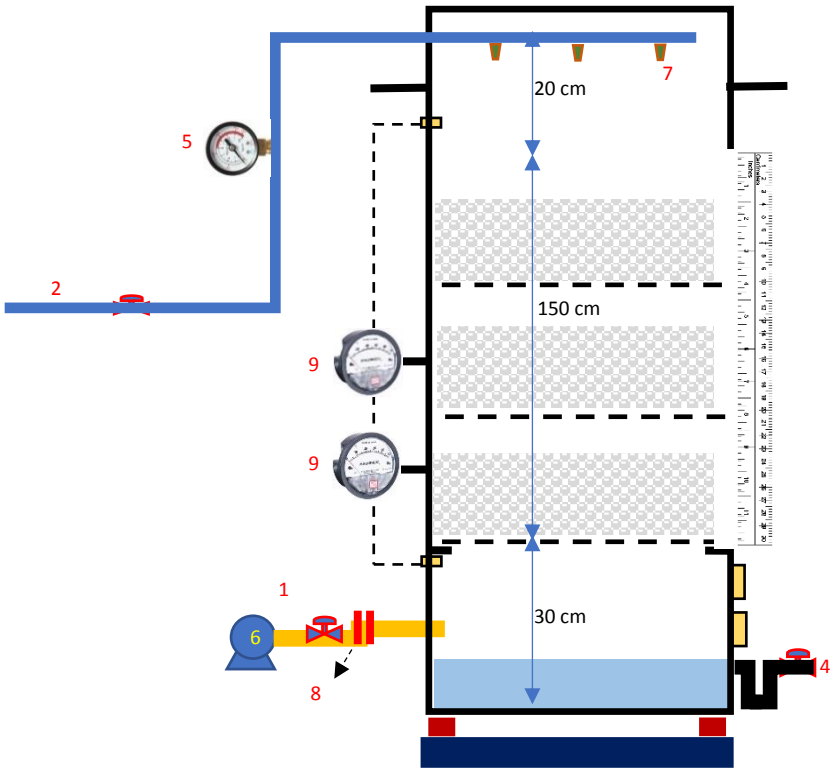

Fig 9: A Schematic diagram of the pilot-scale biofilter

(1) Inlet gas (2) Inlet water (3) Packed bed (4) U-shape drain (5) water pressure gage (6) air compressor (7) sparkling nozzle (8) flexible connecting pipe (9) pressure drop gage

Fig 10: Test apparatus 2 m (H) x 500 x 500 mm (Internal dimensions) showing air pump, drain, pressure gauges and test port

Fig 11: Internal space showing inlets, plenum and perforated plate to hold media

Fig 12: LECA™

Fig 13: Wood Chip

Fig 14: Hebel™ blocks

3.2 Milestone 2: Build and Test Model Biofilters

Based on the findings from Milestone 1, a selection of media types and model methodology was made.

3.2.1 Pilot Scale Biofilters

Three pilot-scale biofilters were constructed using recycled 50 mm thick Cold Room Panel (CRP) for each of the exhaust gas outlets. Each pilot-scale biofilter (Figure 15 - 16) has three cells: two cells at 500 mm wide, 500 mm length and 1700 mm height and one at 500 x 500 x 1100 mm high. Two of the three cells contain three trays (cartridges) of 330 mm height. The third cell has only one deep tray (1100 mm). Each tray is irrigated with two water pipes and four nozzles. The cartridges were made of rigid galvanised plate for the sides and perforated plated at the base. The base was made of stainless steel mesh with 10 mm square openings.

Media was placed into each cartridge (300 mm deep for the small cartridges and 900 mm deep for the large one). The placement of media to each cartridge is shown diagrammatically in Figures 16 – 17. A gap of 120 mm was left between the trays (or 150 mm between the top of the media and the base of the next cartridge). Each biofilter was fitted with a door that attached to the biofilter using Tie Down Straps and sealed using insulating foam (Figures 17 - 18).

The non-condensables and the blood furnace scale model biofilters each had separate plenums while the combined by-products/non-condensable test box had a common plenum. Each test box was fitted with a U-bend pipe water outlet to maintain a water seal to prevent air leakage from the test apparatus.

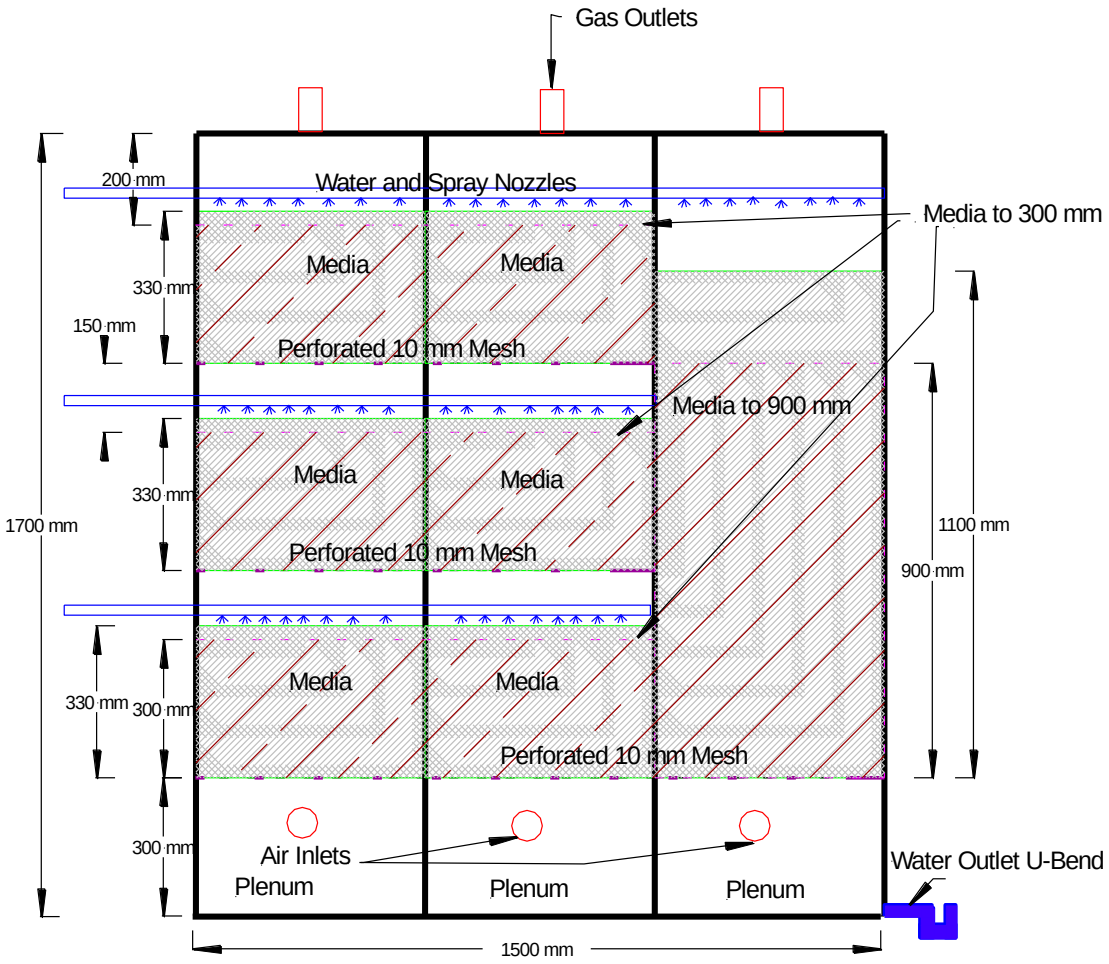

Fig 15: Schematic of 3-Cell Pilot Biofilter

Figure 15 represents the test Biofilters for the Non-condensables and Blood Furnace exhaust lines. The combined By-products/Non-condensables exhaust has a common plenum.

The original plan was to connect to the three distinct air stream outlets based on a scaling down from the existing shipping container biofilter matched against air flow; that is, the cross-sectional area of the biofilter was to match a scaled reduction in air flow. For example, the exhaust velocity from the by-products/non-condensables air lines is 7.2 + 12.2 = 19.4 m/s and the existing biofilter is approximately 12 m^2, the scaled velocity required is approximately 0.04 m/s. Because the abattoir was closing, testing of air flow variations as per the original intent was not able to pursued and hence the in-situ air flow from the 75 mm outlets was used unaltered.

For ease of construction and handling, and to maintain compatibility with other research, a size of 500 x 500 mm cross section was decided. From the literature review a bed depth of 900 mm appeared adequate compared to the original 2 m bed depth in the existing shipping container biofilter; hence the height determination of the test units.

From the literature review, air flow testing in Milestone 1, and bed compaction in the existing biofilter, separate 300 mm (in 330 mm high containers) was considered as the novel concept for bed handling and analysis. A primary issue as mentioned previously was the effort to replace media efficiently.

The test units were sealed with concreter's expansion foam and weights placed upon the top panel to hold it down to minimise air leakage.

Fig 16: View of empty pilot scale biofilter showing aluminium angle to support cartridges

Fig 17: View of pilot Scale biofilter with cartridges (non-condensables in this image)

(Note: Cell A, Tray 1, bottom left is not marked and contains 300 Hebel ™)

Fig 18: View of pilot Scale biofilter showing door and gas exhaust pipes

3.2.2 Media Selection

One of the prime reasons for this project was to identify a suitable media to replace wood chips and/or bark as the wood chip/bark media has a limited life span, about 3 years, before breaking down and needing to be replaced. LECA™ was identified during initial investigation as a suitable long-life product that achieved good odour reduction results.

During Milestone 1 it proved that the supply of LECA™ was problematic in terms of the right properties, supplier, and cost. A suitable material was sought in place of LECA™ and, to this end, HEBEL™ block, and coal ash were identified as discussed previously (section3.1.5 above). The testing of the media was critical to biofilter performance. Even though LECA™ was discounted as the most likely media to be used it was important that a comparative analysis of the material be undertaken.

The various media types selected were placed in the cartridges as shown in Tables 3 and 4:

Cells	Tray 1	Tray 2	Tray 3, top
Non-Condensable			
A	300 Hebel	300 Ash	200 WC+100B
B	100R+200 Hebel	300 WC	300 B
C	---	---	100 R+800 WC
By-Products/non-condensables combined			
A	300 Hebel	300 Ash	200 WC+100 B
B	300 WC	300 WC	300 WC
C	---	---	800 WC*
Blood-line			
Scrubber	Onion bags and irrigation		
A	300 Hebel	300 Ash	200 WC+100 B
B	300 Ash	300 Ash	300 Ash
C	---	---	900 LECA™

Table 3: Media combination in the cells and cartridges

R: rock (30-70 mm), WC: wood chips, B: bark; *wood chips from the old biofilter

	Non-condensables	Combined By-products/non-condensables	Blood Furnace
Cell A			
Tray **1**	300 Hebel	300 Hebel	300 Hebel
Tray **2**	300 Ash	300 Ash	300 Ash
Tray **3**	200 WC + 100 B	200 WC + 100 B	200 WC + 100 B
Cell B			
Tray **1**	100R+200 Hebel™	300 WC	300 Ash
Tray **2**	300 WC	300 W	300 Ash
Tray **3**	300 B	300 WC	300 Ash
Cell C			
Tray **1**	---	---	---
Tray **2**	---	---	---
Tray **3**	100 R+800 WC	800 WC*	900 LECA™

Table 4: Media comparison by cell and input gases

(Note: Cell A, across all three test boxes, has the same media arrangement)

3.2.3 Media Sources

Most media is readily obtainable as per Table 5:

Symbol used	Media	Supplier/s	Cost $ (approx.)	Comment
LECA™	LECA™	(1) Bulk	GBP £6 - £7 per 50L bag (quoted) (allow £120 - £140 /m^3)	No local manufacturer identified. Sources are India, Dubai, Europe and UK. China possibly has a supply but not identified
		(2) -Bagged	$30-$40 per 45L bag (allow $500/$m^3$)	Local aquaculture shops
Hebel™	Hebel™	CSR manufacture the product and available at most hardware stores	$5-$8 each individually subject to size. CSR likely to supply in bulk	The issue is reducing the building block to small, approx. 10-20 mm pieces, without too much wastage. A Hogger or pre-breaker works well without damage to the machine
WC	Wood Chip	Local bulk garden suppliers/landscapers	$35-45 per metre	Preferable to get washed WC but may be more expensive
WC*	Wood Chip	Taken from the old biofilter	N/A	Existing material. Used only in one test cell (see Fig 24)
B	Bark	Local bulk garden suppliers/landscapers	$35-45 per metre	May vary in price
R	Rock	As above	Varies	Relatively cheap, not a large volume is required to act as a base for the media above
Ash	Ash	Coal fired boilers	free	Needs to be sieved and washed

Table 5: Media availability and cost

3.2.4 Exhaust Gas Connection Points

The following sections briefly describe the location and setup for the three, pilot scale biofilters, namely: combined by-products/non-condensables, non-condensables, and blood furnace exhausts.

3.2.3.1 Combined By-products and Non-condensables

The original plan was to connect to each of the three exhaust lines. The by-products exhaust (Figure 7) proved not suitable for testing due to practical issues such as accessibility, air flow, and water supply. It was decided to compare performance of the combined by-products/non-condensables exhaust lines that already existed by inserting an offtake in the exiting biofilter.

Fig 15: Combined by-products/non-condensables pilot scale apparatus

The connection was via a 250 mm PVC pipe from the existing biofilter that received both the by-products and non-condensable exhaust lines. This test box had a common plenum.

3.2.3.2 Non-condensables

The non-condensables line was connected via two 50 mm offtakes that were joined into a single 50 mm line and introduced via a manifold to each of the test cells A – C. Both offtakes were above the condensed element (water) in the exhaust ducting. The volume of water in the 200 mm exhaust line was not able to be measured effectively but was observed as 'substantial'.

Fig 16: Non-condensables exhaust ducting and offtakes

3.2.3.3 Blood Furnace

The blood furnace exhaust location for the offtakes was about 5 m off the ground. The ducting closer to the boiler was not suitable for measurement or connection to the test box. The arrangement shown in Fig 17 shows two steel threaded pipe connected to a 63 mm 100^{o}C resistant

flexible tubing. The flexible tubing was connected into a scrubber to remove blood dust prior to the air stream entering the test box via a 50 mm pipe manifold to each cell.

Fig 17: Connection showing flexible hosing

Fig 18: Before the scrubber installed

(Note: the flexible hose clogged with blood dust)

Fig 19: After the scrubber installed

The scrubber consisted of a simple onion bag that was sprayed with water. The volume of blood dust was substantial as it was first trialled without a scrubber. Pipes became clogged restricting air flow within 24 hours. The system was cleaned and the scrubber installed. The scrubber was cleaned once in the two weeks of the trial.

3.2.5 Nozzle Sprays

The nozzles were locally available garden sprayers giving 360 degree coverage. There were 4 spray nozzles per cell on two water lines as per Figure 20 giving coverage of the 500 x 500 mm surface area.

Fig 20: Nozzle sprayers

To regulate water flow, a low flow pressure reduction valve was installed to each test water line. This negated high pressure fluctuations from the mains supply to maintain pressure within the operating pressure of the nozzles and maintain 20 L/min flow to the test box. Each cell then received approximately 2.8 L/min. The valve is shown in Figure 21.

Fig 21: Low flow pressure reduction valve

3.2.6 Odour Sampling

Odour sampling was undertaken by the Assured Monitoring Group Pty Ltd (AMG) on each of the 9 exhaust pipes as per the same method described in section 3.1.2. Odour unit analysis was subsequently performed by AMG in their laboratory. Results of the sampling are discussed in Section 4.

4 Results

4.1 Milestone 1

The several elements to Milestone 1 are: Literature Review, Establish Sampling Ports, Prepare Test Sites, Measure Basic Operational Parameters, and Experimental Design/Feasibility Study. The full report is held by MLA. Pertinent information as it affects the odour trial is summarised below.

4.1.1 Literature Review (Lit Rev)

One of the objectives of the Lit Rev was to find a design guide for a biofilter that was readily adaptable as the basis for a biofilter for CA using media such as LECA™ that would achieve good odour reduction and have a reasonable design life greater than 3-4 years.

Appendix 1 (Table 1-1) summarises the recommended design considerations from the Lit Rev and modified where needed from the results of the odour testing.

Table 1-2 provides more definitive numerical criteria for biofilter design.

4.1.2 Pressure Drop

Pressure Drop is a key criterion but needs to be rationalised against performance of the biofilter. Consistently, pressure drop increases with air flow as shown in Figure 22 below; this is a key result from Milestone 1. Of particular interest is that two, separated trays, with the same overall depth of media performed better than a single tray of the same media depth.

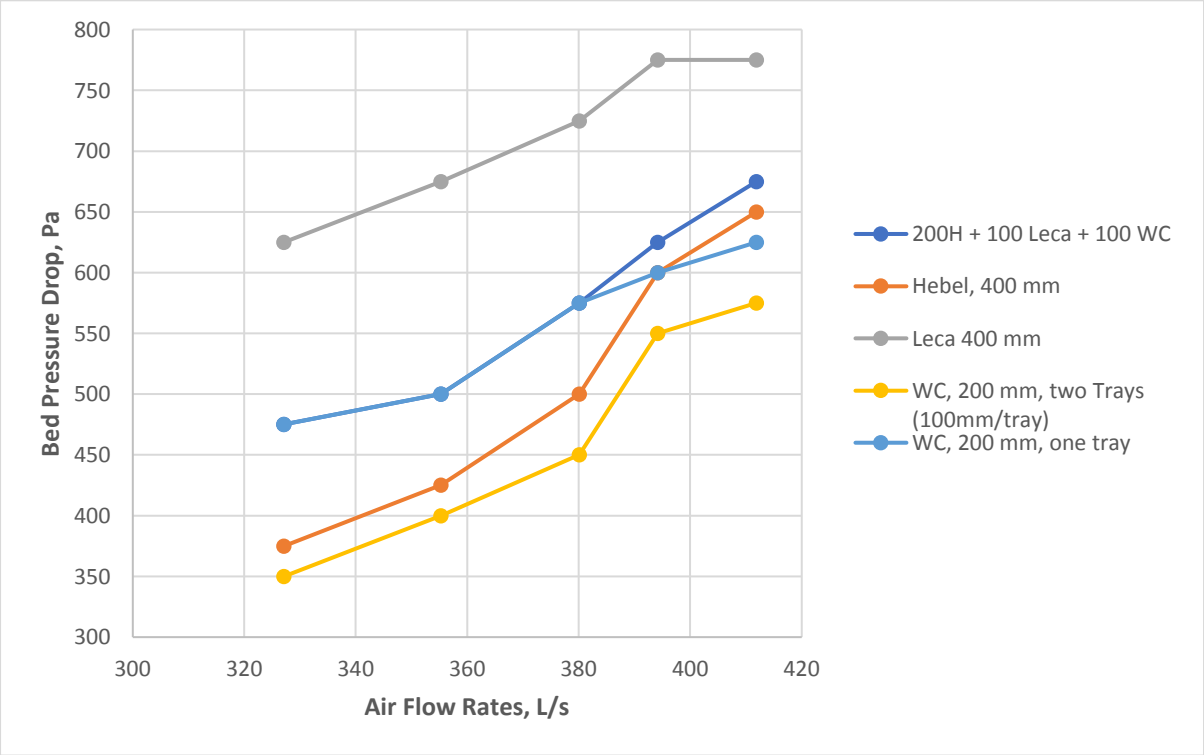

Fig 22: Comparison of biofilter bed pressure drop at variety air flow rates for multiple media supporting trays and combination of media types. Wet conditions.

4.1.3 Media Type

The following media types were tested in the pilot scale biofilters: Screened Boiler Ash, LECA™, Hebel™, Wood Chips, and Bark. The media properties were analysed in Milestone 1; a summary of the analysis is as follows:

> "Bark media has the lowest bulk density for the three types around 200 kg/m^3 then followed by Ash of particle size between >13.2 and <19.0 mm and Hebel with bulk densities of less than 300 kg/m^3, Figure 11. Lower bulk density is favourable because it is easy to handle and reduce the complexity of the biofilter structure. Ash of particle size <6.7 mm and Hebel have the highest porosity among the other media, with 48 and 43%, respectively, despite the fact that Hebel has a higher particle size. " "Higher porosity means higher surface area and if these pores are connected then can contribute in reducing pressure drop in the bed. Water absorption capacity is important as the mass transfer mostly happens between the gas and the liquid phases. The Bark except type C and Hebel media have the highest water absorption capacity, Bark A 84%, Bark B 87% and Hebel around 80%." "It seems from the physical tests done for the different media, Hebel shows superior characteristic compare to the other

media. It is important to mention, Hebel is far better than Bark related to compaction it also expands when wetted similar to Bark media. In addition, some simple tests have been conducted to show the connection between the pores in the Hebel media. Air was blown by mouth into one side of the cubic-shaped Hebel pieces, the test showed that with a little pressure it is possible to blow air into the Hebel media."

While there are differences in the preferred qualities of the different media, selection of a suitable media for full scale odour treatment is more dominantly affected by extrinsic features such as supply, cost, manageability, handling, durability, and maintenance issues. Performance is discussed in subsequent sections.

4.2 Odour Removal

Assured Monitoring Group Pty Ltd (AMG) undertook odour sampling on 12th June and 27th September 2017. The first suite of tests looked at the parameters of the three rendering plant exhaust emissions as discussed in Section 3. Subsequent odour samples were taken post treatment (9 x sampling ports). The full AMG report has been submitted separately to MLA. An extract of the data is provided in Appendix 2.

Table 6 below displays key data from the AMG monitoring and measurements made during testing while Figures 23 to 25 schematically represent the test cells and results as an overview of each exhaust air stream. Analysis of the results is presented in Section 5.

4.2.1 Data Overview

The setup of the cells has is described in Section 3.2.2. The following table and figures show the inlet and outlet exhaust data to the pilot scale test biofilters and the setup of the cells.

Air Exhaust Line	Non-Condensables (N)			Combined Non-condensable/By-products (C)			Blood Furnace (B)		
Cells	**N-A**	**N-B**	**N-C**	**C-A**	**C-B**	**C-C**	**B-A**	**B-B**	**B-C**
Tray 1	300 Hebel	100R+200 Hebel	100R+800 WC	300 Hebel	300 WC	800 WC*	300 Hebel	300 Ash	900 LECA™
Tray 2	300 Ash	300 WC		300 Ash	300 WC		300 Ash	300 Ash	
Tray 3	200 WC+100 B	300 B		200 WC+100 B	300 WC		200 WC+100 B	300 Ash	
OU in	79206	79206	79206	58934	58934	58934	30536	30536	30536
OU out	34372	39063	36834	32750	30882	25892	12793	13567	10114
OU/s in	3111	3111	3111	18735	18735	18735	659	659	659
OU/s out	379	437	421	2779	2491	1695	73	113	141
Residence time	17.2	18.9	17.2	2.5	2.5	2.5	39.5	30.4	18
inflow m/s	20	20	20	8	8	8	11	11	11
outflow m/s	2.3	2.1	2.3	16.2	16.2	14.6	1	1.31	2.2
% reduction OU	N-A-57%	N-B-51%	N-C-53%	C-A-44%	C-B-48%	C-C-56%	B-A-58%	B-B-56%	B-C-67%

Legend: N – Non-condensables, C – Combined, B – Blood Furnace. A, B, and C are the trays in each cell; hence N-A is Non-condensable Cell A. Also shown is the percentage odour reduction for each cell.

WC* - indicates wood chip taken from the old biofilter and is hence considered to be inoculated

Table 6: Data Summary of Each Test Cell

Figures 23 - 25 display the data schematically showing the trays, cells and performance data.

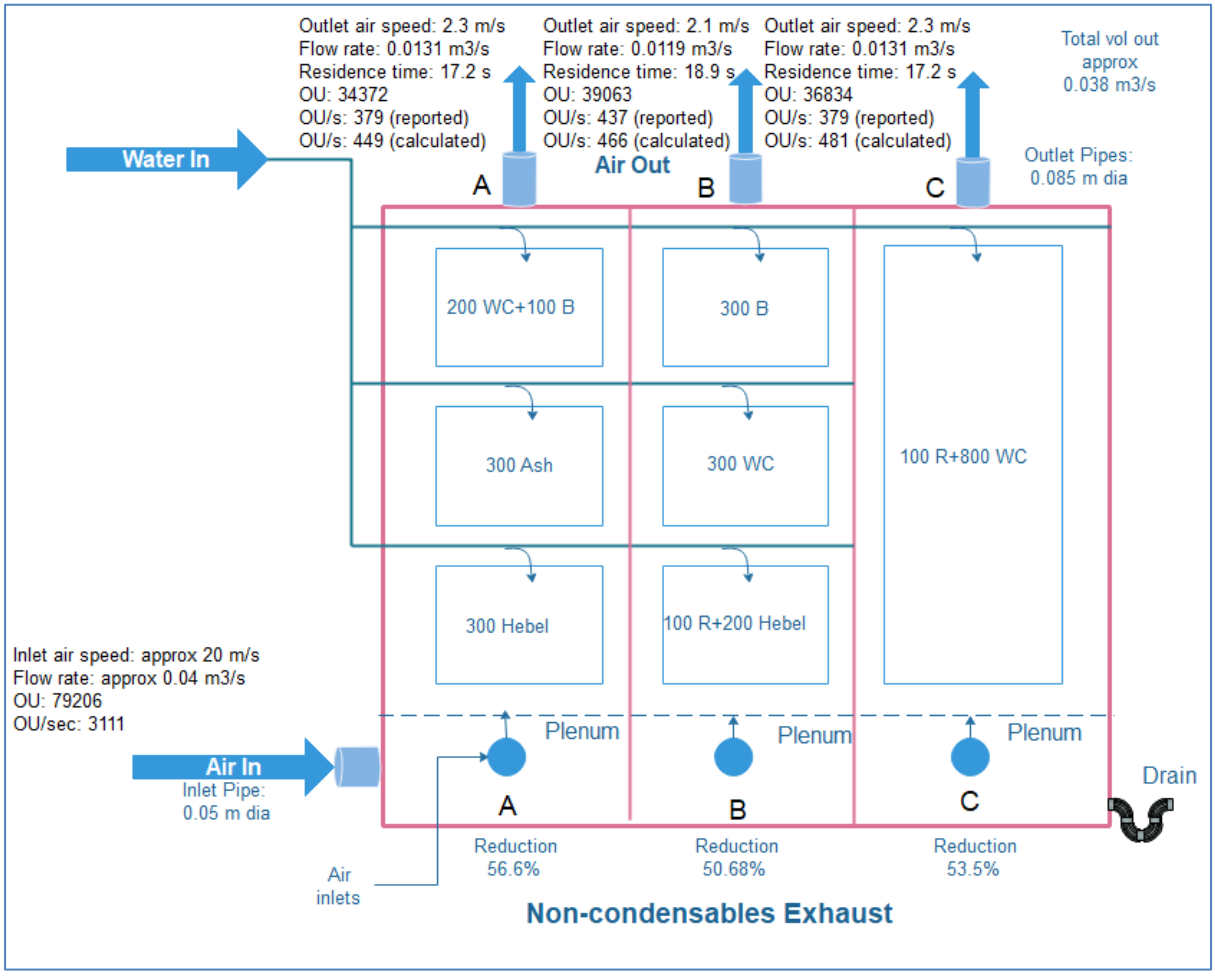

Fig 23: Non-condensables treatment

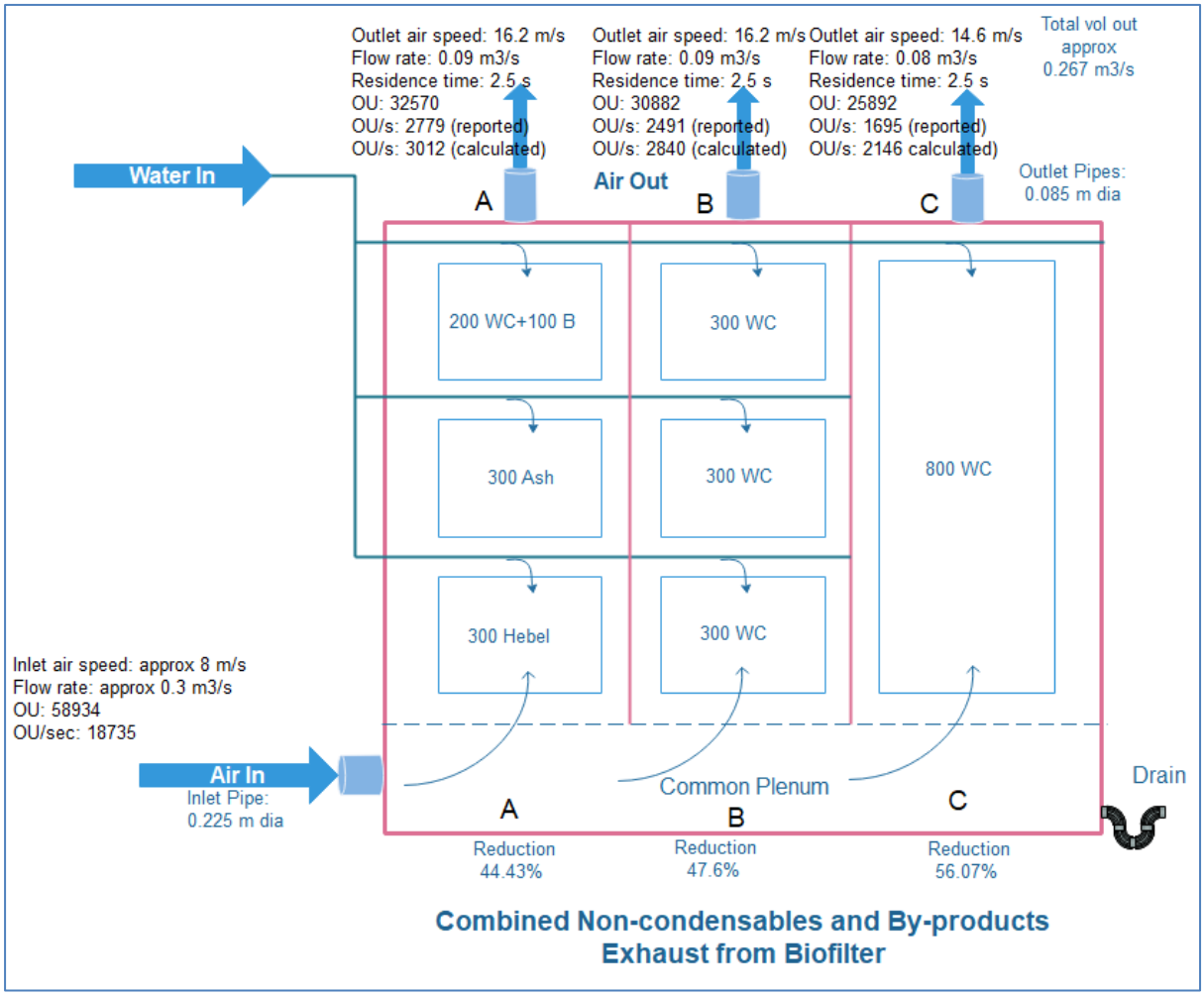

Figure 24: Combined non-condensables/by-products treatment

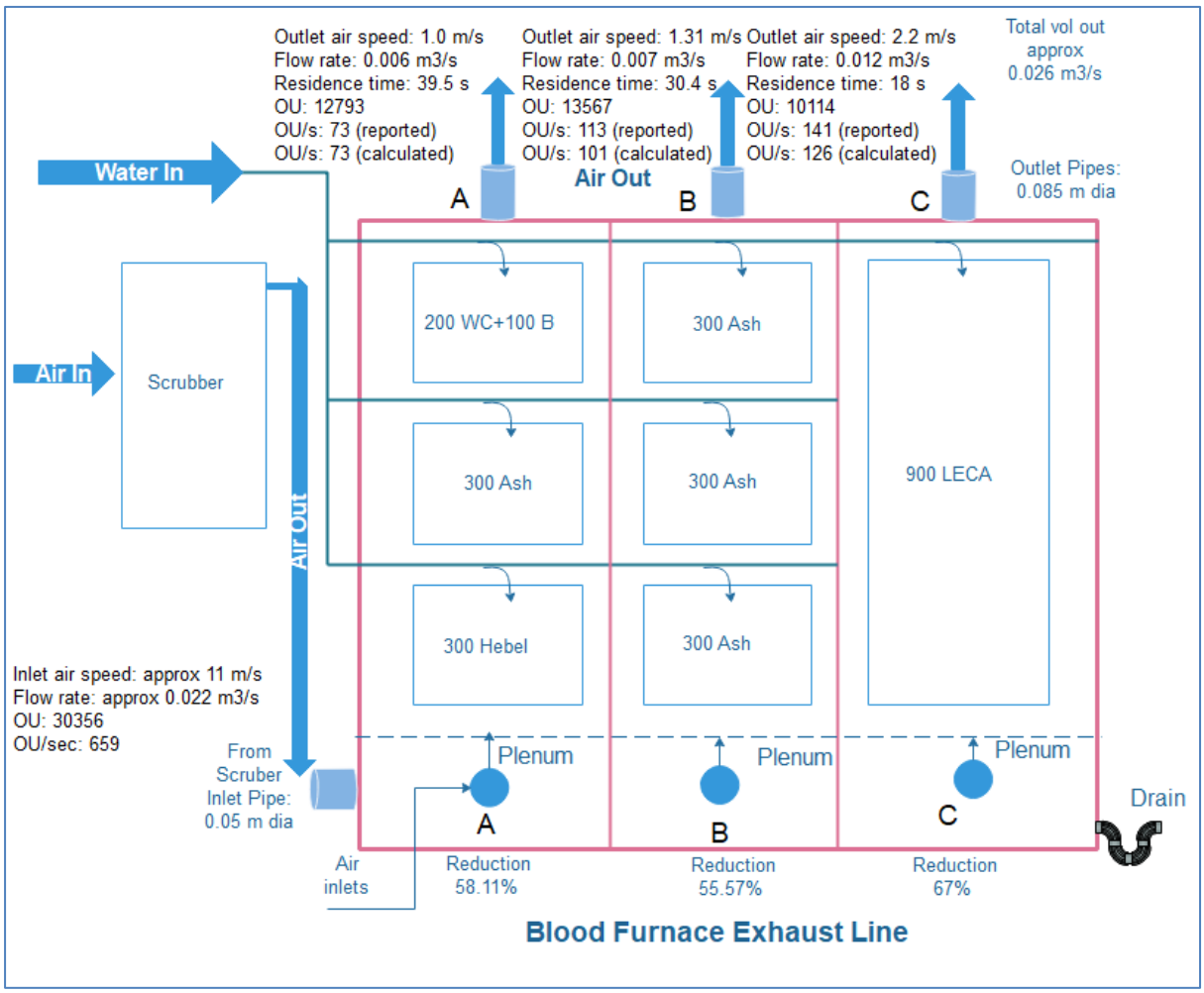

Figure 25: Blood Furnace treatment

The air flow rates, temperature and humidity were measured by the authors for each cell in each biofilter, all the biofilters were covered and pipes were inserted at the top of each cell. A plastic pipe with a diameter of 85 mm was used to concentrate the outlet flow and the odour from each cell for easier collection and measurements. The covers were also used to protect the biofilter from changes in the weather. Table 7 below shows the data collected from the biofilters for each cell. The volume of the media used in each cell is around 0.225 m3 (0.25 m2 surface area × 0.9 m depth), based on the flow rate leaving each cell the residence time was calculated. Cells A and B connected to the blood-line pipe were leaking some water and gas from the door.

	Cells	Outlet gas speed, m/s	Outlet flow, L/s	Temperature, °C	Humidity, RH %	Residence time, s
Non-Condensable	A	2.3	12.8	22.1	92.8	17.2
	B	2.1	11.9	22.3	92.1	18.9
	C	2.3	13.1	22.3	91.6	17.2
Combined By-Products+ non-condensable	A	16.2	91.9	23.3	93.1	2.5
	B	16.2	91.9	23.1	93.3	2.5
	C	14.6	82.6	24.1	93.5	2.5

Blood Furnace	A	1.0	5.4	23.3	91.1	39.5
	B	1.3	7.4	23.5	91.2	30.4
	C	2.2	12.6	26	92.5	18
	Scr	---	---	---	---	---

Table 7: Properties of the outlet gases from the cells in each biofilter and the residence time

Table 8 shows the measured pressure drop between each tray in each cell in each biofilter. It is obvious that the cells that achieved high pressure drop were due to high gas flow rates in the cells. The probe was located below Tray 1 and top of Tray 1, top of Tray 2, and the top of Tray 3. Table 8 results seems to indicate that a higher flow (less resistant), lower tray, is preferable to reduce back pressure on the supply fan.

	Cells	**Tray 1**	**Tray1-Tray 2**	**Tray1-Tray 3**	**comments**
Non-Condensable	A	0-5	5-10	15-20	Low inlet flow rate
	B	0-5	5-10	15-20	
	C	---	---	20-25	
By-Products/Non condensable mixture	A	600-700	600-700	600-700	High inlet flow rate
	B	600-700	600-700	600-700	
	C	---	---	600-700	
Blood_line	A	0-5	5-10	15-20	Low inlet flow rate
	B	0-5	5-10	15-20	
	C	---	---	20-25	
	Scr	---	---	---	

Table 8: Pressure drop measured between each tray in each cell

5 Discussion

5.1 Air Flow and Pressure Drop

There are two issues that were of interest, pressure drop as it affects exhaust fans, and the movement of air through the media. Fan design was not investigated as it was outside the scope of this project. However, it is noted that a high pressure drop will affect performance of extraction fans and hence, for established facilities, good biofilter design to lessen pressure drop will improve performance of the extraction fans. Fig 26 (from Milestone 1 investigation) shows that all media have less pressure drop at low intake air flow rates. This is supported by the pilot cells (Tables 7 and 8 refer). Conversely, knowing the pressure drop can explain extraction fan performance; CA reduced air extraction by about 30% of the total extraction efficiency when pressure drop was 600 Pa in the present shipping container biofilter. It is presumed to have lost 10% (that is a drop from 80,000 m^3/hr air flow to 70,000 m^3/hr) from the change from the original open biofilter to the present biofilter. Actual flow was measured (AMG data) at about 66,000 m^3/hr; this is probably due to compaction of the old wood chip media.

The test cells showed little difference in each of the pilot boxes (Table 8) except that the multi-tray cells were slightly better than full media cells (Cell C in each case) where residence time was less in each case (Fig 27).

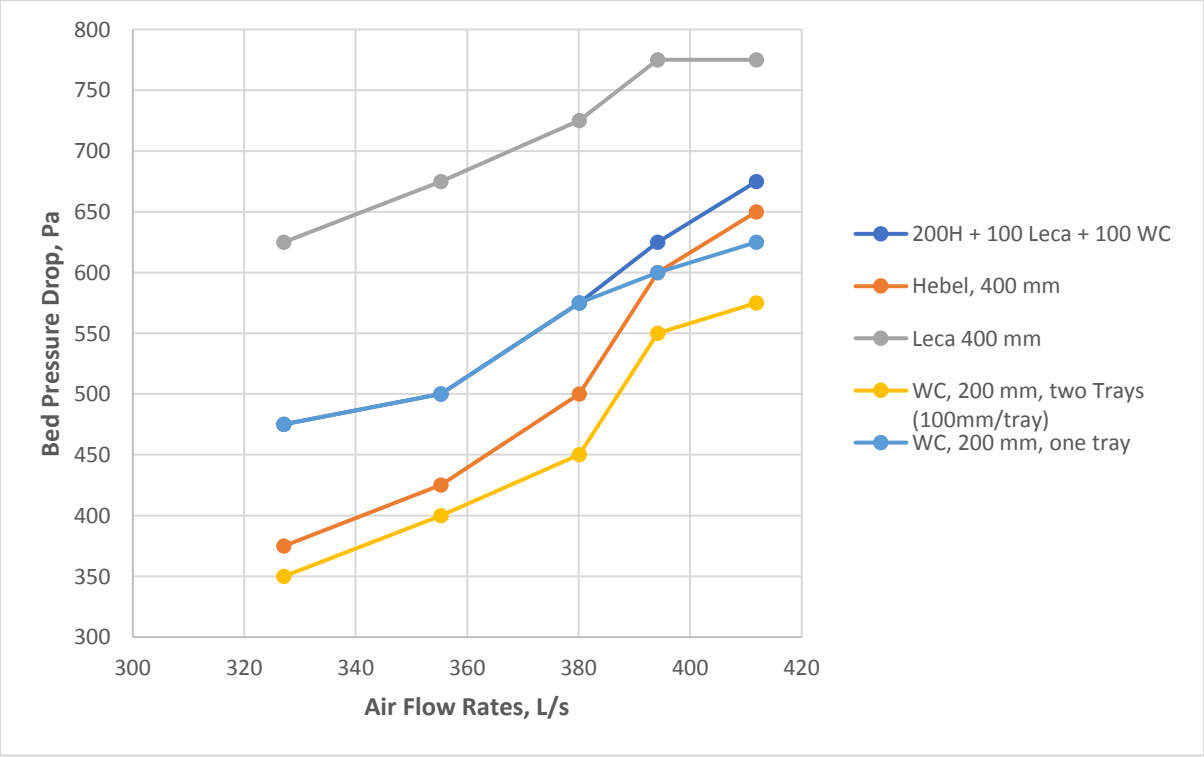

Fig 26: Comparison of biofilter bed pressure drop at variety air flow rates for multiple media supporting trays and combination of media types. Wet conditions.

It could be considered that lowering outflow velocity by means of media and/or multi-tray system would lower pressure drop. Fig 27 supports the concept that lower pressure drop is indicated by lower outflow velocity. This is a general observation as air flow within each of the cells would require more detailed specific investigation. Having said that, there really does not appear to be a significant difference between cells that are affected by the media type except multi-cells appear to

have a slight advantage. Thus, air flow through the media indicates multi-tray system are marginally better than single layers of the same depth but there is not much significant variation between media types except for LECA™ in the Blood Furnace pilot test (cell C).

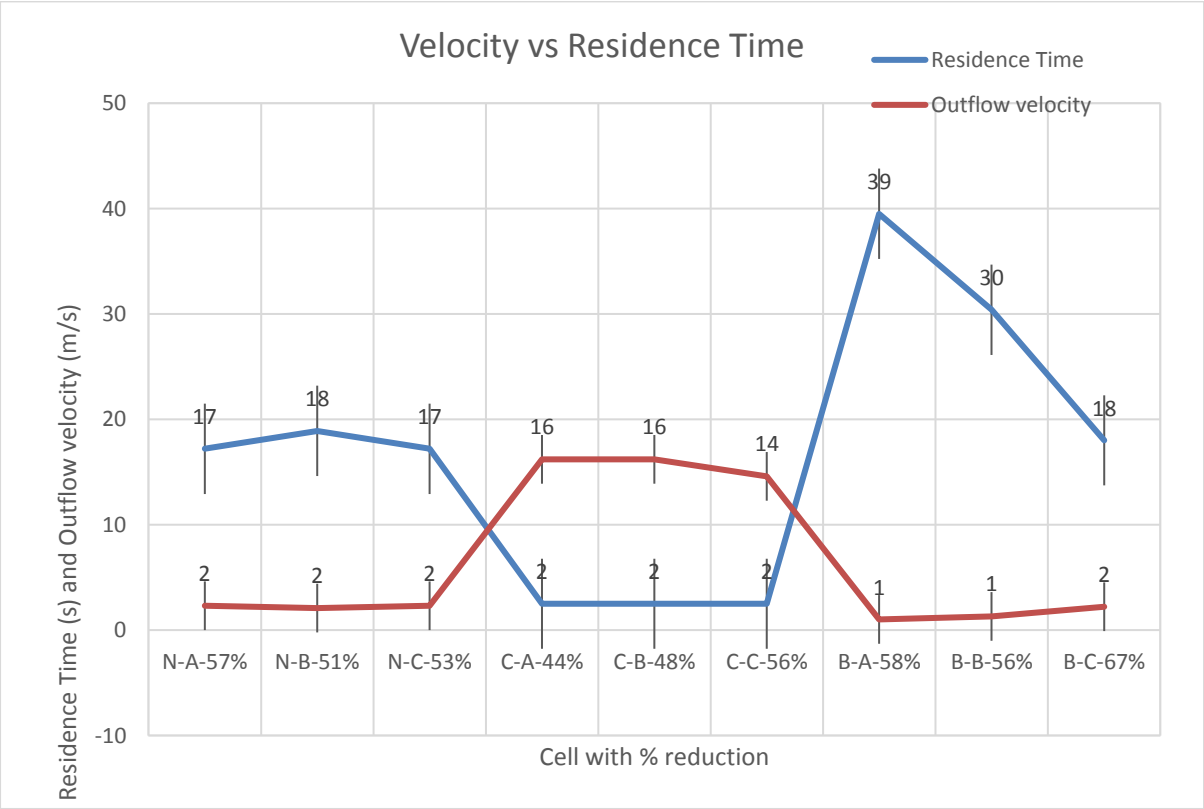

Fig 27: Comparison of Air Flow Rates vs Residence Time Showing % OU reduction by Cell

5.2 Odour Reduction

5.2.1 Odour Units (OU)

The resultant before and after data by AMG (Appendix 2) shows the reduction in gross OU represented in Fig 28 and Fig 29. The odour reduction efficiency ranges from 44% - 67% removal. This result was completely unexpected in that greater removal results were anticipated but is what was analysed according to Australian standards. Some possible explanations are discussed in Section 5.2.3.

Even though the results were not what were expected, the average reduction overall is about 54% across all treatment cells and media type. On reflection, given the input OU, the reduction for media about 900 mm deep and 0.025 m^2 cross sectional area is reasonable. Generally, lower the pressure drop and increased retention time performed better for odour removal (Fig 30).

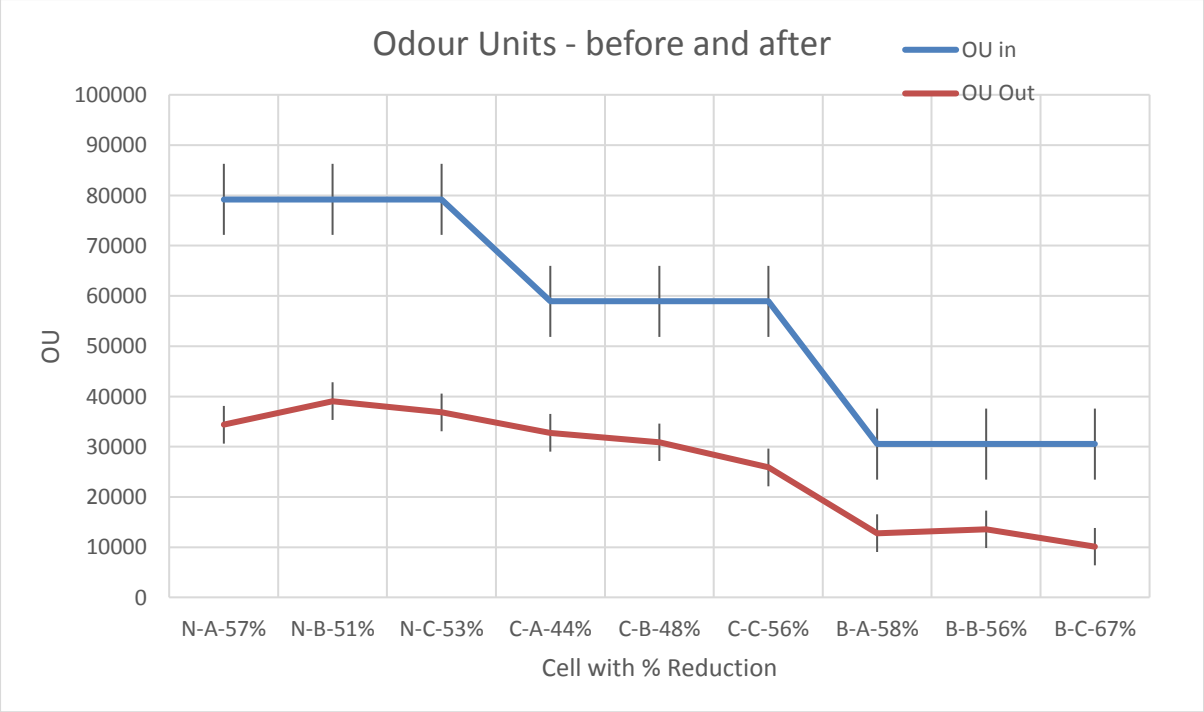

Fig 28: OU Reduction by Cell after Treatment

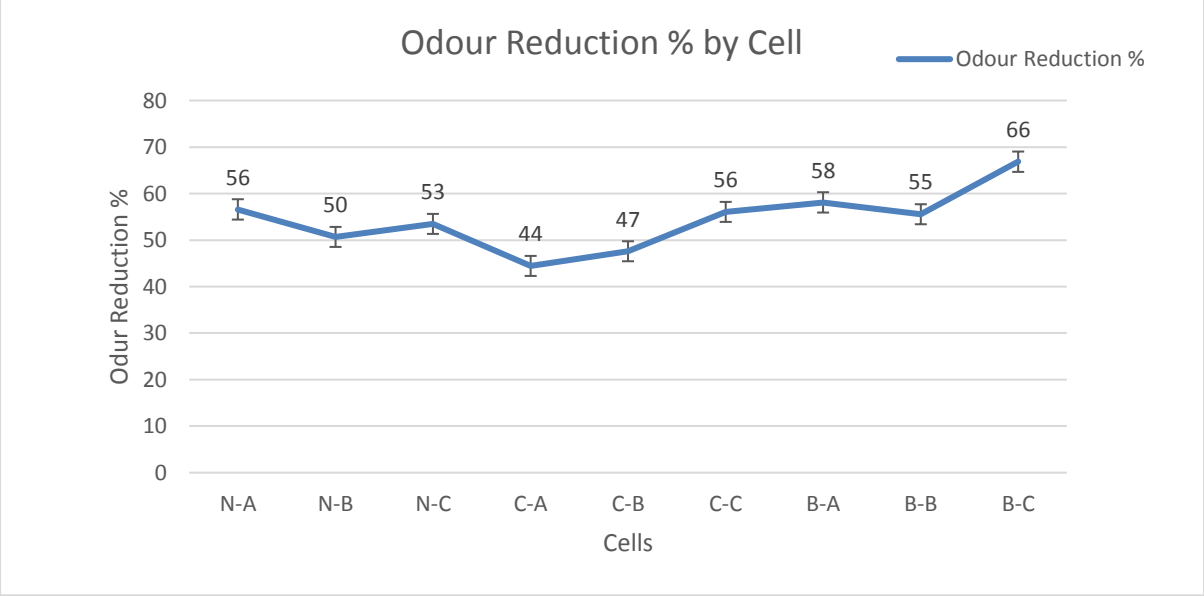

Fig 29: OU reduction by Cell Showing % reduction

(Note: All 'C' cells (N-C, C-C, and B-C) are single 800 mm or 900 mm media tray cells)

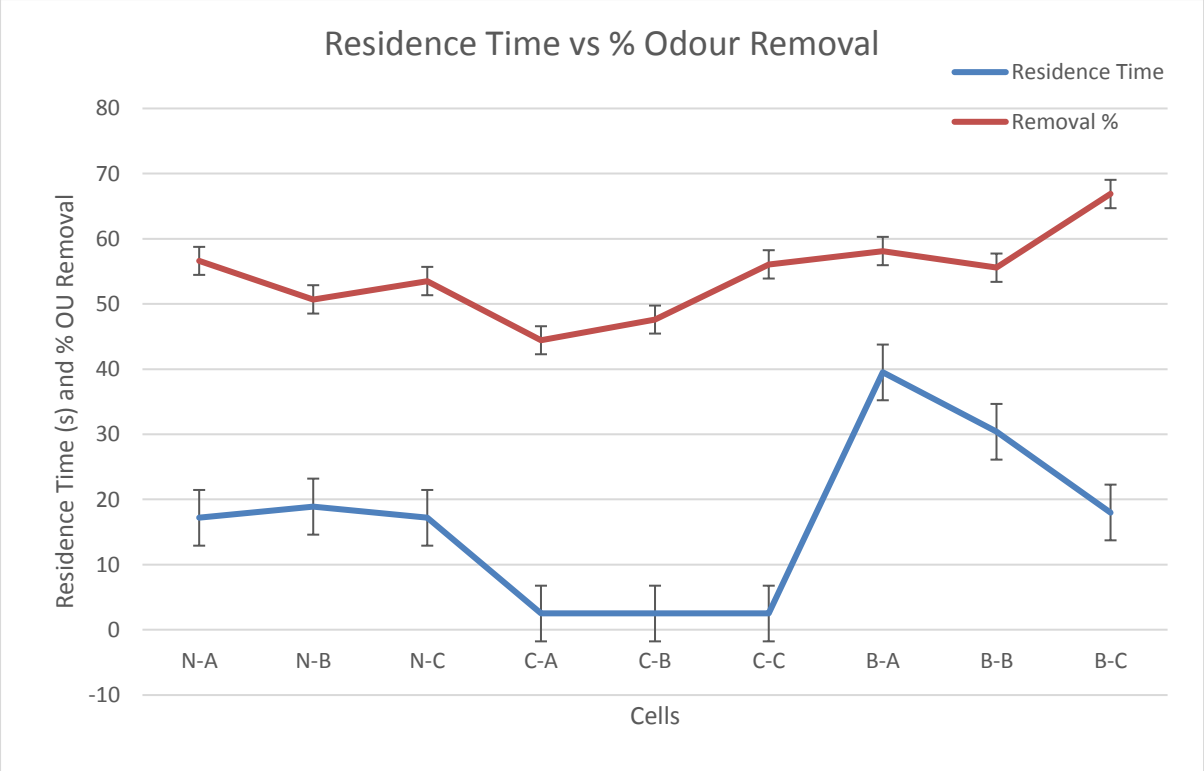

Fig 30: OU reduction by Cell Showing % Reduction vs Retention Time

5.2.2 Odour Concentration and Diffusion

Figures 23 – 25 schematically show the results of the pilot scale biofilters while Table 8 below shows the difference between Emission Rate IN and emission Rate OUT. What is not readily comparable is the two emission rates on a % basis as the distribution of total flow into each cell is not known and that OU IN is a calculated value based on non-observable factors assuming Qin = Qout.

Air Exhaust Line	Non-Condensables (N)			Combined Non-condensable/By-products (C)			Blood Furnace (B)		
Cells	**N-A**	**N-B**	**N-C**	**C-A**	**C-B**	**C-C**	**B-A**	**B-B**	**B-C**
Tray 1	300 Hebel	100R+200 Hebel	100R+800 WC	300 Hebel	300 WC	800 WC*	300 Hebel	300 Ash	900 LECA™
Tray 2	300 Ash	300 WC		300 Ash	300 WC		300 Ash	300 Ash	
Tray 3	200 WC+100 B	300 B		200 WC+100 B	300 WC		200 WC+100 B	300 Ash	
OU/s IN	**3111**	**3111**	**3111**	**18735**	**18735**	**18735**	**659**	**659**	**659**
OU/s OUT	**379**	**437**	**421**	**2779**	**2491**	**1695**	**73**	**113**	**141**
Residence time	17.2	18.9	17.2	2.5	2.5	2.5	39.5	30.4	18
% reduction OU	57	51	53	44	48	56	58	56	67

Table 9: Extract from Table 6 Highlighting Emission Rates In and Out (OU/s)

What Table 9 does show is that the emission rate of the odour at each outlet, except for the Combined non-condensables/by-products flow, is relatively low although the total OU (i.e., OU as a concentration per m^3) is high. This issue was an unknown during the development of the experimental model.

During operation of each of the pilot scale biofilters, several staff were invited to 'sniff' the outlets of each cell. Most everyone invited knew the characteristics and strength of the full odorous exhaust gases from each source. All agreed that the source odours were both very bad (as in offensive) and very strong (very easily detected). Although this does not corelate with laboratory OU detection, it is a reasonable broad scan of odour strength and obnoxiousness. There are also other factors such as personal sensitivity to odour, background odours, and ability to distinguish odour type (taste) amongst other things that may affect response to odoura.

While there are a number of limitations to odour observations, most people asked indicated that:

a. Non-condensables:
   i. Test Cell A had very little or no smell;
   ii. Test Cell B had very little odour or no smell; and
   iii. Test Cell C had a faint odour and a bit 'bark like'.
b. Combined Non-condensables and By-products:
   i. Test Cell A had some odour but not too offensive;
   ii. Test Cell B similar to A but a bit worse; and
   iii. Test Cell C similar to A.
c. Blood Furnace:
   i. Test Cell A had very little or no smell;
   ii. Test Cell B had very little odour or no smell; and
   iii. Test Cell C had a stronger 'blood furnace' smell and was not good.

These observations were requested as an *ad hoc* check to see if, what was thought to be reasonable for a biofilter, indicated that the pilot scale boxes were working prior to controlled samples being taken. It was a surprise when the OU results indicated large absolute concentrations when the *ad hoc* 'sniffing' indicated significant odour removal. Of interest and not explainable is that of all the OU results, the 900 mm LECA™ in Test Cell C for the Blood Furnace exhaust line performed best overall while all 'sniffers' indicated that this was the worst of the 9 cells tested.

The observations versus absolute OU reduction measurements produced a quandary to explain why the OU were high, relatively speaking, when expectations were that the OU results should be lower. Although it is too late to investigate, there are two possible reasons for high OU post treatment.

a. Odour Sampling. AMG are a well-respected monitoring company and are rigorous in applying quality systems to the relevant standards. The OU results are accepted and may be due to the sample collected and the researchers lack of expertise in this aspect of the experimentation. Each of the samples had a humidity of between 91.1% - 93.5%. There may have been some interaction within the test bags between the time of sampling and laboratory analysis. This is supposition but may bear further investigation. Odour analysis using olfactometry also does not distinguish between 'good' and 'bad' odours. Some of the OU may have been wood chip or bark smell that may have been discounted by the people 'sniffing'.
b. When people 'sniffed' the air flow from each of the test cells, the amount of time spent sniffing was very short. From Table 8, emission rate varied from 73 – 2779 OU/s with varying air flow velocities. It is suggested that the volume of air 'sniffed' was likely to be very low and may have given the impression of none or slight odour. The exhaust air may have been diffused somewhat with 'normal' air around the exhaust outlets by the time it

was 'sniffed'. Thus, when the full exhaust streams were open, they had both a high concentration and extremely high emission rates and were, as expressed, strongly obnoxious whereas low flow rates and less emission rates were considered comparatively benign.

Even though there may be a reason for the discrepancy between measured and perceived odour strength, the query remains and leaves no option but to accept the OU concentrations recorded in the laboratory.

5.3 Water Diffusion

The testing period was very short due to circumstances previously explained and the operational phase was thus curtailed. Simplistically, the general description of how a biofilter works is that moisture adsorbs odourous compounds onto the media where bacteria metabolise the compounds into non-odourous substances. The literature varies widely on the time required to seed biofilters and the time for the biofilter bacteria to become well established.

The shipping container biofilter at CA that was constructed in 2012 removed odour from the combined non-condensables/by-products exhaust air stream almost immediately (1 – 2 days) and worked consistently well for 3 years. The biofilter was seeded with a mature compost layer.

Each test cell was irrigated with 4 spray nozzles (thus a 3 tray Cell a had a total of 12 spray nozzles and the single tray Cell had a total of 4 spray nozzles). Table 10 gives the volume of water recorded flowing out of the drain pipes (in hindsight, the data suggests that extra water entered the base of the non-condensables and the combined air stream from water from the main non-condensables exhaust line). In addition, the exhaust air from each cell had a >90% humidity.

	Cells	L/h	comments
Non-Condensable	A	190	
	B	207	
	C	71	
Combined Non-condensables/By-Products	A	196	Leaking from the door
	B	162	Leaking from the door
	C	28	Leaking from the door
Blood Furnace	Scr	67	
	A	138	
	B	30	Leaking from the door
	C	12	Leaking from the door

Scr: scrubber *(Note: Cell A in each test box was the first cell in line to receive both water and exhaust air)*

Table 10: Average water drained from each biofileter by each cell

The overall average OU reduction for all cells is about 54%. The short test period (2 weeks) tends to indicate that main odour removal mechanism may be due to odour compounds being removed by the water rather than the action of bacteria except for Cell C in the combined air stream exhaust. Cell C-C achieved a 56% reduction compared to 44% and 48%; Cell C-C used wood chips from the existing biofilter and was considered to have been 'seeded'. This would indicate that bacterial action had been taking place even though the flow rate was very high. It is expected that each cell would have performed better over time.

5.4 Media

5.4.1 Media and OU Reduction

Table 8 indicates that pressure drop in A and B cells was about the same and cell C in each case had slightly higher pressure drop. Table 8 also indicates that residence time between cells was not significantly different except for Cell B-C (18 seconds) in the Blood Furnace setup and was nearly half that of the other 2 cells (39 and 30 seconds) in that group.

From Table 11, the Non-condensables had a 6% variation in OU Removal %, the Combined exhaust had a 12% variation while the Blood Furnace an 11% variation.

Air Exhaust Line	Non-Condensables (N)			Combined Non-condensable/By-products (C)			Blood Furnace (B)		
Cells	N-A	N-B	N-C	C-A	C-B	C-C	B-A	B-B	B-C
Tray 1	300 Hebel™	100R +200 Hebel™	100R +800 WC	300 Hebel	300 WC	800 WC*	300 Hebel	300 Ash	900 LECA™
Tray 2	300 Ash	300 WC		300 Ash	300 WC		300 Ash	300 Ash	
Tray 3	200 WC +100 B	300 B		200 WC +100 B	300 WC		200 WC +100 B	300 Ash	
% reduction OU	N-A-57%	N-B-51%	N-C-53%	C-A-44%	C-B-48%	C-C-56%	B-A-58%	B-B-56%	B-C-67%

Table 11: Extract from Table 6 Highlighting Cells and OU Reducion %

5.4.2 Tray System

From Table 8 there does not appear to be any substantial positive or negative effect on odour reduction due to trays/no-trays scenarios. The primary reason was to examine air flow and pressure drop commensurate with a media that had a longer useful life than wood chips/bark. There appears to be some benefit in pressure drop but it is difficult to quantify a cost/benefit case to install trays. Certainly, a reduction in back pressure on the exhaust fan will help improve efficiency in exhaust extraction and a tray system will aid this.

In each test cell, each 300 mm layer of media was irrigated separately by 4 x spray nozzles. For the same water flow rate, it achieved a better wetting effect than a single set of nozzles above a single depth of media as was the case for Cell C in each pilot scale apparatus. It would be beneficial to do a separate study on flow rate through various depths of media to determine efficient flow rates and moisture content at depth.

Because of the wetted mass of the media, removing trays was made easier whereas handling of the 900 mm media tray was difficult and cumbersome. While a full scale biofilter will be constructed using machines, the handling principle of ease of manipulation using trays holds. This concept may aid replacement/maintenance of media if a method of using trays is developed.

5.5 Project Objectives

Not all project objectives were completed as the abattoir unexpectedly closed down during Milestone 2. However, the preliminary work to test pilot scale biofilters for each of the three exhaust air streams was successful but modified to change from the By-products exhaust steam to a combined Non-condensables/By-products air stream due to access issues to the By-products exhaust line.

5.5.1 Characterisation of physical propertis and odour units from 3 x sources – rendering plant building, non-condensibles fan, and blood dryer exhaust

This was a Milestone 1 objective and the results are summarised in Appendix 1. The full report in .pdf format by AMG was forwarded separately to MLA.

5.5.2 Pilot scale test of odour removal efficiencies using bark, LECA™®, and coal ash media

Three test apparatus boxes were constructed comprising three separate cells in each box. Two of the three cells in each apparatus allowed for three trays to be used while the remaining cell had a single tray to hold 900 mm depth of media. The boxes were used to treat exhaust air as previously explained. The media was expanded to include wood chips as a variation on generic 'bark' and Hebel™ Block, a porous lightweight concrete.

LECA™ was tested for a comparative analysis but discounted for full scale use because of cost and supply issues. Hebel™ was tested in phase one and is recommended as a LECA™ replacement. The difficulty with Hebel™ is breaking down the blocks into a suitable size without excess wastage. Test pieces were cut by hand but large volumes will require mechanical reduction. Fig 31 below shows blocks after being put though the 'Hogger'. 50 mm thick blocks performed better than the thicker blocks that had more wastage. Fig 31 shows results from a larger 200 mm thick block where there is a lot of fines.

Fig 31: Hebel™ at Outfeed Screw below the Hogger

Unless a suitable supply of Hebel™ at the right size between 10 – 20 mm is available Hebel™ is not likely to be attractive as the prime media but may suffice as a primary layer underneath wood chips.

Wood chips are in plentiful supply and, unlike softwoods of Europe, Australian hardwoods are durable but still only have an effective life of about 3 years before needing replacement/maintenance. Figure 32 shows a plume of water vapour from the existing biofilter where short-circuiting within the wood chips occurred. The wood chips compressed and the gas found the least resistant path in the centre of the media.

Fig 32: Water Vapour Plume due to Short-Circuiting within the Media

Wood chips from the existing biofilter worked well in the Combined exhaust stream (Cell C). Seeding with runoff water from an existing biofilter, existing wood chips as in this case, mature compost, or treatment plant sludge is recommended as per literature. Treatment plant sludge may be problematic for those plants that are export accredited whereas mature compost works just as well and involves less work than the treatment plant sludge.

5.5.3 Identification of potential prime odour monitoring chemical species – chemical compound indicators of performance (if feasible)

This was a desirable outcome to have but was over-reaching as the Lit Rev demonstrated that the chemical odour species could involve up to 200 compounds. Advice from AMG and others was that identification of a marker species and ease of measuring was a very difficult request. To that end, speciation of odour compounds was discontinued as not practical. There may be a case to investigate if VOC's (shown in the AMG data) from several rendering plant air exhausts show similarities and if a correlation exists between VOC and OU from varying air streams.

5.5.4 Design of biofilter for CA

This was undertaken and is discussed in Section 5.5.6 below.

5.5.5 Identification of maintenance issues and media replacement mechanisms

The primary issue we believe is media collapse and an increase in pressure drop. Other researchers, from the Lit Rev, identify bacterial/algal build-up on the media. Experience suggests that wood

chip/bark is the most common media and hence replacement techniques/methods is an issue. Those open biofilters simply use an excavator or small Bobcat™ type machine to remove the media. This may be an issue where underground pipes may collapse but this may be overcome by designs used (not seen in the literature).

Of concern for this project is above ground, container/enclosed systems. The existing CA biofilter had some media partially cleared and replaced by hand, a labour intensive and time-consuming activity. Of note is that the supporting structure was sound; there may have been the possibility of collapse and possible resultant injuries otherwise.

During the development of the project proposal, media replacement was an important factor; to be able to replace the media simply and quickly without being offline for more than 2 days (weekend/non-operational period for those plants without an annual shutdown). The concept of baskets was mooted and the development of trays, to also minimise pressure drop, was adopted for the pilot scale trials. The use of trays/basket concept was adopted for the suggested CA full scale biofilter discussed below.

5.5.6 Model biofilter design methodology

The design of a biofilter is dependent upon several factors:

- OU
- Flow Rate
- Media Type
- Depth of media
- Bed area
- Pressure Drop
- Scrubber/s
- Plenum
- Dust/Fats
- Area available
- Type of construction
- Maintenance
- Bacterial/algal build-up
- Arrangement of the media
- Water Supply
- Dispersion of treated biofilter air

In the literature, Biofilter design varies widely from very large surface areas and shallow (0.5 m depth) to small surface area and deep (up to 2 m depth) and most are either media specific or industry specific or both. Generic designs are for the most part lacking in the literature or are ‘trade’ secrets of companies installing biofilters. This project was initiated to determine sizing and other construction/operational parameters.

It is proposed that design is based upon the factors listed above but that they can be broadly grouped into two functional areas: OU Reduction and Construction parameters.

1) OU Reduction parameters would be:
    a) OU
    b) Flow Rate
    c) Media Type
    d) Depth of media

e) Bed area
f) Pressure Drop

2) Construction:
a) Scrubber/s
b) Plenum
c) Dust/Fats
d) Area available
e) Type of construction
f) Maintenance
g) Bacterial/algal build-up
h) Arrangement of the media
i) Water Supply
j) Dispersion of treated biofilter air

5.5.6.1 OU Reduction Parameters

The OU inputs are known and the output reduction % is also known. There is some concern over the perceived offensiveness' of the treated odour or lack of and the absolute OU measured in the odour laboratory. Working with what we have, for ease of calculation, an approximate 50% reduction in odour was recorded across each of the cells.

Since there are no formulae to calculate sizing of a biofilter that are applicable in this situation, a gross error check of existing facilities has been used and a ratio of inputs to performance was used as a starting point for sizing.

		Non-Condensables	**Combined Non-condensable/By-products**	**Blood Furnace**
Source Value (AMG)	Nm^3/s	0.2	18.71667	0.716667
Pilot input value	m^3/s	0.039	0.318	0.022
Pilot bed area	m^2	0.75	0.75	0.75
Calculated Biofilter bed size	m^2	3.81	44.11	24.87

Table 12: Ratio of input flow rate to estimate full scale biofilter bed area by source

		Non-Condensables	**Combined Non-condensable/By-products**	**Blood Furnace**
Source Value (AMG)	OU/s	16598	866519	659
Pilot input value	OU/s	3111	18735	659
Pilot bed area	m^2	0.75	0.75	0.75
Calculated Biofilter bed size	m^2	4	35	29

Table 13: Ratio of input OU/s to estimate full scale biofilter bed area by source

While these methods are purely an approximation as there are a range of external issues and assumptions about inflow rates and OU/s that need further certainty, the total area from both methods is about 67 – 72 m^2. For a depth of 900 mm, the total media volume would be between 60

– 65 m^3. This also based on an approximate 50% reduction in odour for all cells and a bed depth of 900 mm.

The current shipping container biofilter is approximately 13.8 m^2 with a working volume when first installed of about 28 m^3. Just using the non-condensables and by-products derived bed size this would be from 39 – 48 m^2 with a volume of 34 – 43 m^3. Using these figures, the existing biofilter is undersized by 2.8 – 3.5 times by bed area and 1.2 – 1.5 times by volume.

A large rendering plant in Southern Queensland is at least four times the output of CA and has a wood chip/bark biofilter of about 200 m^2 and 2 m deep but higher OU. This biofilter works extremely well and is within license limits (pers. comm.). As a gross comparison, the estimations in Tables 12 and 13 are about right when scaled for the lesser production at CA.

The next larger size shipping container, commonly call a 40 foot standard container, has dimensions as shown in Table 14.

Inside Cubic Capacity	67.2cu.m	
Tare weight	3,980 kg	
	OUTSIDE:	***INSIDE:***
Length	12.19m	12.01m
Width	2.44m	2.35m
Height	2.59m	2.38m
Surface Area		28.22m^2

Table 14: Dimensions of a 40 foot Shipping Container.

One 40-foot shipping container at 2 m bed depth would essentially satisfy the requirements of the combined air streams by volume (43 m^3 to 67m^3 capacity of the container). Area remains less than predicted (28 m^2 for the container to 48 m^2 predicted).

There is no discernible advantage in OU reduction by media type. Wood chip is common (although bark is commonly used as a description for any wood type media). Wood chip with a layer of bark and a layer of matured compost as seeding is preferred. Hebel™ block underneath would be preferred but until a suitable supply is identified it is too cumbersome to use. A rock layer is recommended to be placed beneath the wood chip. Media selection based on construction parameters is further discussed in the following section.

Flow rate and surface area have effectively been discussed but is conditional upon bed depth. The bed depth of 900 mm with the parameters shown achieves variable OU reduction efficiency but 50% is a suitable descriptive number to use. Common usage does seem to be about 2 m for wood chip/bark.

Flow rate is important in terms of pressure drop. The lower the flow rate, the lower the pressure drop although a higher pressure does force the air flow through the media. Flow rate is generally fixed unless a new facility is being constructed. Not measured is the effect the non-condensables has upon the by-products flow rate and vice-versa. It is known that the by-products exhaust fan operates less efficiently after the existing biofilter was installed. The solution is to use a larger bed surface area. While this would decrease pressure drop, the % reduction is unknown with a 2 m deep bed or less.

5.5.6.2 Construction Parameters

Most sources indicate that a scrubber prior to the biofilter is essential to remove dust and other gross particulates. The non-condensables stream has free running condensate with those non-condensables gases that negates the need for a scrubber. Particulates were observed in the by-products steam but were generally between 0.5 – 1 mm is diameter. The by-products MC content measured was 2.5%, so smaller particulates are possible. A scrubber would normally be indicated in this case but this may be overcome by other means as the mixing with the non-condensables may negate a scrubber.

The blood furnace line needs a scrubber. The moisture content of 12.8% turned the particulates into a mass of wet solids that collect along the bottom of the ducting. The pilot scale biofilter soon became clogged within 24 hours and a scrubber was installed to remedy the air flow. Of note, the mass of solids indicated that the blood ring dryer or other component was not working 100% efficiently.

While dust and fat were not observed in the non-condensables but the raw exhaust air had a 'fatty, cooked meat' aroma. Dust and blood dust have been discussed; a scrubber is needed for the Blood Furnace and should be located as close to the Ring Dryer as possible. Should there be dust and or fatty gases that deposit fats, the literature recommends a scrubber.

The pilot scale apparatus with the spray nozzles inserted between trays worked well and maintained constant moisture throughout all the beds. If the rock was separated from the filter media, sprays could be placed above the rock/Hebel™ and this would act as a scrubber for any potential dust and fat from the by-products air stream.

Plenum sizes are not discussed in any detail in the literature. Pressure equalisation occurs within the plenum chamber although a larger plenum should allow any dust to settle better than a smaller plenum. The object is to provide sufficient area to allow air to be distributed evenly to the bed. Potentially there are three air streams that need to be joined. If they are joined in the plenum then a larger volume would be required; if before, then it is only a matter for air distribution within the plenum itself. A depth of 300 - 500 mm would seem reasonable for three air streams entering the plenum.

Area available for the biofilter may limit the type of biofilter to be installed. In-ground biofilters on flat ground do have some limitations for access, pipes, and media replacement. A biofilter on a side slope allows better access for machinery and pipework. In-vessel systems allow easier access but media replacement is more difficult. A full 40 foot shipping container may weigh as much as 60 tonne when full so simply lifting the container and emptying may be problematic. For CA, an in-vessel system is preferred due to area restrictions and layout. This indicates a need for a media management system as part of the design.

Shipping containers have featured prominently in the discussion. They are relatively cheap (second-hand), are structurally sound, and easily installed. The drawback is rust, installation of a sump and media access. The alternative is tilt panel or concrete block construction; no price differential has been investigated.

Maintenance is an issue in that after about 3 years the media should be replaced as placing new media on top to maintain depth has not worked at CA to prevent collapse and short circuiting. Removal and replacement of all media should take no longer than 2 – 3 days as previously discussed.

It is recommended that the container, if used, be painted with an appropriate hard-wearing sealant paint to minimise rust. Welded joints are particularly susceptible to rust. Concrete/block structures do not necessarily have this issue.

Researchers indicate bacterial/algae build-up over time can inhibit performance and that filling the container with water will loosen and remove that build-up or drenching in hot water will achieve the same result but has the drawback of potentially killing the micro-organisms. No particular build up was noticed on the CA wood chip after 5 years but this was a cursory observation; however, nothing untoward was observed.

There are advantages to separating the media into trays but the results do not indicate sufficient evidence to support multi-layers of media although it is believed that the initial layer, rock or Hebel™ is best served by being irrigated separately for dust and other materials and will act as a scrubber and increase the MC of the air steam into the media. For practical management and maintenance reasons, a series of full depth baskets that can be removed by a backhoe or forklift (or suitable machine) would be beneficial. However, the mass of each basket would need to be measured and an engineering design undertaken to determine the structural integrity of a basket. A basket 2 m x 0.5 m x 1.8 m high would weigh approximately 1.8 tonne when saturated. There may be some arrangement using baskets that are shallow but longer where several layers could be added or removed to suit.

The arrangement suggested would be similar to Fig 33.

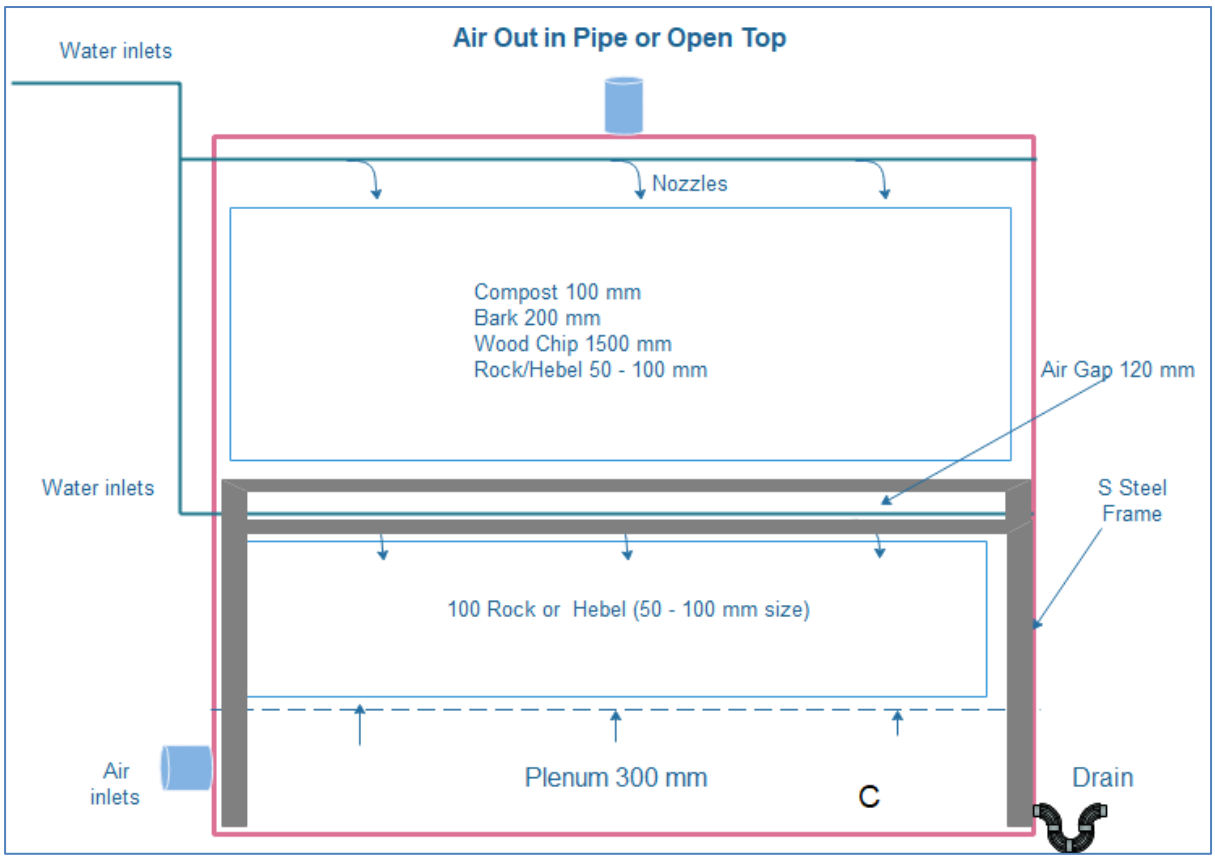

Fig 33: General Suggested Arrangement of Media

With a shipping container, a sheet of stainless steel at the door end would allow media to be contained if and when the doors are opened and the media could be extracted using an excavator.

Figure 33 shows a depth of media of 1500 mm; this may be too deep and so a depth of 1000 mm is suggested after which more can be added is necessary.

Water distribution is reasonably easy to accomplish; the top series is easy to install while the lower one above the dispersion/scrubber layer should be removable. Holes can be made in the side of the container/vessel and rust proofed and flanged to prevent air escape. Lines and fittings should be stainless steel. Flow rates to the nozzles can be checked after measuring outflow rates (noting that the non-condensables contains a large volume of water). It is suggested, not shown in Figure 33, that port holes and lights be installed to examine the interior of the plenum for build-up of solids.

The literature is varied on whether a biofilter should be covered, have extraction fans on top to lessen pressure drop or be open. Having a tall extraction pipe will assist in releasing the exhaust gases at a height where dispersion can diffuse any odour remaining over a wider area and hence be diluted to a very low concentration. This would need expert advice from an odour specialist in dispersion modelling.

5.5.7 Demonstration working biofilter

Due to closure at CA this was terminated. Should the plant re-open then it would be installed as per the design.

5.5.8 Additional Details

The project also had additional details that were identified to be investigated; some have been discussed in-depth previously but are summarised here as a check against project deliverables.

1. **Roof**. The pilot scale filters were enclosed. A roof was not investigated but observation of the existing open biofilter indicates that a roof would be beneficial.
2. **Depth of Bed**. A bed of at least 1200 mm is recommended depending on media type
3. **Bed Width/Length**. Discussed previously, conditional on pressure drop, air flow and media.
4. **Plenum**. Plenum size may be critical if too small. A plenum of 300 mm has been suggested.
5. **Dust and Fatty Material.** Previously discussed.
6. **Maintenance**. Previously discussed.
7. **Containers for LECA™**. These have been discussed but LECA™ was discounted early in the project when supply and cost ruled the material out of contention.
8. **Location**. Discussed previously
9. **Dual or Single Biofilters**. This was a CA issue to bring the Blood Furnace line to the area of the existing/planned biofilter location. The same method for sizing would apply for separate exhaust lines as a combined line. A single biofilter can be used at CA.
10. **Drainage**. In this case is related to water from the biofilter to the wastewater treatment system/Saveall. This is a design feature to avoid pumping where possible. An associated issue is draining water from the biofilter, a U-Bend or other air seal is required to limit fugitive emissions. Ideally, a sump within the biofilter would be a good feature.
11. **Building Materials**. Previously discussed
12. **Time to Operate Fully**. The plan was to continue operation of the old biofilter while the new one was constructed and CA had constructed a concrete slab for that purpose.

13. **Seeding with Waste Water**. Seeding with waste water was not undertaken and hence not observed but one cell used pre-seeded wood chips from the old biofilter and substantiated the recommended pre-seeding/seeding of the media.
14. **Blood Dust**. This was blood dust and how it affected the efficiency of the boiler. Until testing by AMG, the MC of 12.8% was not within the collective memory of the staff. It was found that the blood ring dryer/blood system was not optimal and that the blood exhaust reduced boiler efficiency by about 10%. There is an imperative to treat the Blood Furnace exhaust in a biofilter.
15. **Observation Ports**. Not included in the original concept but portholes in the plenum base may be beneficial to allow observation of the bottom of the media and water flow. If a container with opening doors then the material, if need be can be hosed out. If sealed, a system of small doors to allow a hose to be used is considered useful.

5.5.9 Previous Research

Previous research appears to be location specific for rendering plants as a design model for different material does not exist relative to odour sources and strengths. It is believed that investigations into biofilters in a range of locations and situations at meat plants/rendering plants investigating basic parameters would be ideal to gauge effectiveness of media type to flow rate and OU outputs.

The use of shipping containers is not new (only one was mentioned in a passing conversation after testing had finished; that one was installed in Victoria but no other detail is available) but not reported in scientific articles and was just an idea for a low cost biofilter when the CA one was constructed. The idea of a shipping container was derived from seeing a partially in-ground block construction biofilter on the NSW mid north coast.

Based on previous research in the literature, large surface area biofilters were used for two purposes: to increase the residence time, and dilution of the outlet odour. It is not clear if the dilution effect has been considered when the outlet odour was measured from open biofilters. Odour measurement can still be questionable in terms of measurement and handling even when following good QA and standards.

5.5.10 Practical Implications for Industry

Pilot scale experimentation is important to be carried out as different plants may have different exhaust odour combinations which need customized biofilter design lacking any generic design formulae.

5.5.11 Unanswered Questions/Additional Research Recommended

Further research is recommended to investigate the impact of the following parameters on odour removal:

- The impact of inoculation of the media,
- The impact of irrigation rate,
- The impact of media particle size on odour removal
- An inventory of existing biofilters and performance
- Depth of media type to odour removal
- The removal of odourous compounds in the water stream

- Specialist examination of the OU concentration, emission rates and flow rates.

5.5.12 What Could have been Improved in the Project Delivery (what worked, what didn't)

The project would be delivered better if more time and more funds were available to carry out more in-depth research. We wished to be able to do the following list:

- Investigate higher depth biofilter more than 1 m,
- Investigate Hebel media as a sole component of the biofilter,
- Measure some components of the odour such as hydrogen sulphide and others mentioned in literature,
- Measure the pressure drop for each cell and all over the cells using more reliable equipment,
- Take multi-measurements of odour for each cell and under dry conditions.

As is often the case, some things are unknown until after the project commences, such was the case with using Hebel™ and the unavailability of LECA™ ™.

What worked in the project was:

- Reduce pressure drop in the bed using multilayer design,
- Hebel™ and Ash as two new media have shown good potential,
- Introducing the media in cartridges has enhanced the ease of handling the media,

What did not work well in the project;

- The air blower used in the pressure drop experiments,
- Measuring the odour concentration while wet,
- The water supply at the facility due to pressure fluctuation,
- The time constraint to let the media settle although this was in part due to a lack of full appreciation of seeding and in part to minimise seeding variation
- Cutting Hebel to specific particle size.

6 Conclusions/recommendations

6.1 General

Like many projects, the logical assumptions and deductions upon which an activity or research project are based vary when more information of findings come to light. This was partially the situation for this project such as the presumption that LECA™ was a good biofilter media (this is true within limits) but what was unknown was the cost, availability, and more importantly, the variation in quality from suppliers.

What was not understood was the relationship in physical terms what happen within the biofilter plenum in relation to airflow, emission rate and OU concentration. There was a discrepancy between what people could 'smell' and the absolute OU concentration measured and emission rate post treatment.

The effective 900 mm media depths achieved good odour reduction with the best reported at 67%. Seeding is important to get media active almost immediately but media not inoculated still achieved a 50% reduction. The importance of a scrubber for the Blood Furnace line was reinforced. Generally, the size of the biofilter based on the findings is larger than the one commissioned by CA some 5 years ago but far less than the literature suggests. Realistic depth of media is yet to be determined but 1.5 to 2 m is acceptable but closer to 1.5 m is realistic. 900 mm LECA™ as originally believed is unrealistic. Hebel™ appears to be a good LECA™ substitute but obtaining the right size material is problematic.

As a PIP, the aim was to build a biofilter based on the research. This was not to be because of external factors but the design using 2 x 40 foot shipping containers with wood chip media is considered to be a good result. The OU/m^2 using the 40-foot containers is about 2700 OU/m^2 and about 16000 OU/s emission rate for a bed depth of 1200 – 1800 mm.

6.2 Future R & D

It is believed that a review of a large number of biofilters would add greatly to the knowledge base and extend that knowledge gained from this project. Specific elements of future R & D are identified in Section 5 of the report.

6.3 Practical Application

The test setup of the pilot scale biofilters, with modification to allow additional media depth and additional measurements, would assist any plant in reviewing and/or replacing a biofilter or improving performance.

6.4 Development and Adoption Activities

This report is very long and involved; the proposed dissemination would have been after the construction of the working biofilter and summary results provided to the industry. It is recommended that a fact sheet with key elements be developed for meat plants to assimilate and seek further information if and when required.

7 Key messages

Odour control for point sources such as rendering operations have seemed confusing and daunting in the past with little or no guidance on tried and true methods and results. A lot of work overseas has been done in recent years but is not directly applicable due to a number of reasons. The work on LECA™ has been well done and is applicable but needed to be assessed here before time and money was employed to take it on board.

The PIP was beneficial and many useful observations and conclusions were made. It is imperative that pilot scale testing is done to ensure the operating parameters are known. The benefit is that more efficient systems are possible with reduced odour complaints.

8 Bibliography

Fogarty M and **Curran** TP. Evaluation of Optimum Biofilter Performance at a Meat By-Products Rendering Plant. Written for presentation at the **2008** ASABE Annual International Meeting Sponsored by ASABE Rhode Island Convention Centre Providence, Rhode Island June 29 – July 2, 2008.

Nuevaespana J and Matias JR. Comparison of the physical profile of Klayton and LECA™ as media for Aquaponics. AquaOrganikA, retrieved on 10th of March **2017** from http://www.poseidonsciences.com/Paper_The_physical_profile_of_Klaytons_and_LECA™_as_media_for_Aquaponics.pdf

Shareefdeen Z, Herner B and Wilson S. Biofiltration of nuisance sulphur gaseous odors from a meat rendering plant. J Chem Technol Biotechnol **2002**; 77: 1296–1299.

Akdeniz N, Janni KA, Salnikov IA. Biofilter performance of pine nuggets and lava rock as media. Bioresource Technology **2011**; 102: 4974–4980.

Nicolai RE, and **Janni** KA. Effect of Biofilter Retention time on Emissions from Dairy, Swine, and Poultry Buildings. presentation at the **1999** ASAE Annual International Meeting Sponsored by ASAE and CSAE-SGCR, Paper No. 994149, USA.

Ben Jaber M, Couvert A, Amranea A, Rouxel F, Le Cloirec P, Dumont E. Biofiltration of H2S in air—Experimental comparisons of original packing materials and modelling. Biochemical Engineering Journal **2016**; 112: 153–160.

Park J, Evans EA, Ellis TG. Development of a Biofilter with Tire-Derived Rubber Particle Media for Hydrogen Sulfide Odor Removal. Water Air Soil Pollut **2011**; 215: 145–153.

Andreasen RR **and Poulsen** TG. Air Flow Characteristics in Granular Biofilter Media. J. Environ. Eng., **2013**; 139(2): 196-204.

Malhautier L, Cariou S, Legrand P, Touraud E, Geigerb P and Fanlo J-L. Treatment of complex gaseous emissions emitted by a rendering facility using a semi-industrial biofilter. J Chem Technol Biotechnol **2016**; 91: 426–430.

Nielsen AM, Nielsen LP, Feilberg A & Christensen KV. A Method for Estimating Mass-Transfer Coefficients in a Biofilter from Membrane Inlet Mass Spectrometer Data. Journal of the Air & Waste Management Association **2009**; 59 (2): 155-162.

Anet B, Couriol C, Lendormi T, Amrane A, Le Cloirec P, Cogny G, Fillières R. Characterization and Selection of Packing Materials for Biofiltration of Rendering Odourous Emissions. Water Air Soil Pollut 2013b; 224:1622.

Normal text

9 Appendix 1: Literature Review – Design Principles

Serial	Literature Recommendation	Comment/Observation
1	A pilot study will be required when designing a biofilter, especially if the gas stream contains a mixture of pollutants such as from rendering plants.	Nil/Nothing to add
2	It is important to draw the extracted air through a humidifier and a unit to remove entrained particulate matter before introduced to the biofilter.	Depending upon the design this may not be required. However, it may improve biofilter performance. Dust from a blood ring dryer does indicate a scrubber is needed. No correlation between spray jets and humidification of the air stream has been identified. Installation of spray nozzles between layers is believed to improve performance
3	It is important to distribute the extracted air uniformly before it passes upwards through the biofilter. Using a biofilter media with a wide range of particle sizes and a rougher surface enhances gas mixing inside the biofilter. Also, using porous particles will increase mixing and provide a larger mobile gas-filled volume fraction to the filter.	This is important. Most references indicate large rocks or other to distribute the air uniformly. Mixing of air within the media is seen as important but has not been discussed well in the literature. Not adequately described in the references is compaction of the media over time, especially organic media. Compaction can create short circuiting and significant pressure drops across the bed. A replacement time for wood chip media is about 3-5 years depending on depth
4	Media with pore size diameter less than 1 µm is not recommended, because it is poorly accessible for microorganisms. Mass transport is directly proportional to the dispersion coefficient; increased dispersion results in better gas distribution inside of the filter and increases mass transfer from the gas phase to the particle/liquid surfaces (Adsorption/absorption).	Nil/Nothing to add
5	There are some advantages of closed biofilters compared to open ones. Open biofilters are	Closing a biofilter and using air extraction has benefits but adds more

	exposed to climate changes, thus plant growth may occur. After excessive rain, the filter bed could be too wet and after sunny periods it may be too dry. Over all, open biofilters are difficult to stabilize. For closed biofilters, the process parameters such as fluid flow, fluid composition, temperature, etc. are easier to monitor and control. The media components are better protected against wear and external weather conditions so that their service life can be longer.	degrees of complication. Open biofilters, either in-ground or in a vessel would benefit from a roofed structure (car port/open pergola type) that does not cause back pressure. Open in-vessel biofilters are recommended from the project with a roofed structure overhead.
6	Sulphur and nitrogen are common compounds that exist in the exhaust gasses from a variety of agricultural facilities. When the biofilter entraps these compounds from the inlet air, they eventually convert to sulphuric acid (H_2SO_4) and nitric acid (HNO_3) and may build-up in the biofilter; this can cause a drop in the pH. Buffering capacity must be adequate to prevent acid accumulation by addition of limestone or other water-insoluble alkalis to the filter packing. Buffering has proven to be a viable solution against a drop in pH. Coupling a biofilter with a wet scrubber may benefit overall system performance, especially for removing dust and NH_3.	Nil/Nothing to add – see serial 2 above Buffering in rendering plant biofilters has not been seen as an issue
7	Excess biomass removal is important; for example, filling the biofilter with water and draining. This method does not result in any biological inhibition to biofilter performance and is the least efficient for biomass removal. This method can be more efficient by 5–10 times when temperature of the feeding water increased from 30 °C to 60 °C, but the effect of temperature on microorganisms are not reported.	Observation and monitoring is required. A technique to make cleaning more efficient is an identified shortfall Media systems in baskets for all media is seen as a way to overcome this.
8	Generally, EBRTs between 4 and 10 s should be sufficient for a biofilter designed to control odours and VOCs from agricultural sites (this is only applicable providing that moisture content is controlled adequately) although some references allow up to 3 minutes EBRT..	While EBRT/EBCT (synonymous terms) are widely referenced, the usefulness of this measure is poorly explained in the literature and is believed to have marginal use in biofilter design
9	Biofilters do not operate efficiently with media below 40% wet basis. Thus, reducing the residence time below 5 s may cause excessive drying in these biofilters. Optimum moisture	The literature leans towards humidification of the air stream to optimal achieve moisture content. Overhead sprayers may be just as

	content of the media should be 40% to 50% and the humidity of the gases entering the bio-filter should be maintained above 60%. If necessary, a water spray nozzle can be located in ducting to humidify the air. At low residence times, effective odour reduction can be achieved by maintaining the depth and decreasing the media area.	effective. A common regulatory condition (in QLD at least) is that biofilters must maintain 95 -100% inlet relative humidity (this indicates a non-specific approach but on balance is a reasonable assumption). See serial 1 above reference pilot studies
10	The recommended temperature for operation of biofilters is in the range of 20°C to 40°C (35°C). It has been reported that temperature within the biofilter should be maintained at a minimum of 15 ^{o}C to avoid lower removal efficiency.	Nil/Nothing to add
11	Media depth of 0.25 to 0.50 m has been recommended as optimal for agricultural biofilters.	This is generally accepted although some references indicate up to 2 m A minimum of 900 mm and recommended 1500 has been suggested
12	Optimal pH for biofilter operation is in the 7 to 8 range. The bed is washed weekly to minimize the pH drop. The media pH can be controlled by irrigating the bed with pH buffer solutions such as $Ca(OH)_2$, K_2HPO_4, NH_4Cl or urea.	Nil/Nothing to add
13	Checking the media is required (on a monthly basis) by taking a core sample and testing to ensure the media is not breaking down, and tested for total counts of micro-organisms (typically, total counts of >105 will be present).	Nil/Nothing to add – although non-performance would be a good indicator for micro-organisms in a practical sense
14	The maximum suggested water loading rate for biofilters is about 20 L/(m^2 h) and/or indirectly through humidification of the inflowing polluted air to 95-99% saturation.	Nil/Nothing to add – see serial 2 above A water spray nozzle directly above the base rock layer and below the media is suggested.
15	Dust is known to clog media pores, thus causing an increased air flow resistance of the media. This may not only lead to biofilter failure but could also damage the air handler resulting in air quality decline in the facility due to a reduction in ventilation capacity. Installed dust filters are important to avoid such issues and increase the life of the biofilter. It is recommended to keep the pressure drop through the biofilter below 50 Pa, so the existing fans in the facility may be used for operating the biofilter.	If required. The issue of pressure drop to 50 Pa is noted but many references indicate higher. From initial work (yet to be written for this project), achieving a 50 Pa pressure drop may be impractical and calls into question how this was achieved in the various references. Closed systems with air extraction may be the solution. The area of concern was durability and efficiency of the main air extraction fans from the rendering plant to maintain a

		negative pressure within the building.
16	The media can be inoculated with a selected Pseudomonas culture, with effluent water from the previous biofilter media, by spraying the packing material with supernatant (60 L) from activated sludge collected at a wastewater treatment plant, with a diluted solution of activated sludge (about 50 mg of dry sewage sludge per litter) collected from a domestic wastewater treatment plant, with swine manure and compost and allowed to acclimate for 3-5 months at high moisture content and 5 s EBRT.	Nil/Nothing to add - A layer of mature compost on top of the bed has been used successfully.

Table 1-1: Summary of design considerations from the Lit Rev

	Unit	Recommended/Acceptable	Comments
Bed Pressure Drop	Pa	50 - 100	May be significantly higher in practice
Bed Depth	m	0.25 - 2	Depend on Bed Pressure drop
Bed Surface Area	$m^2/(m^3/h)$	1/120	Odour pilot scale testing should be undertaken
Media Type	--	LECA™, Bark, Wood Chips,	LECA™ generally not available in Australia
Media Surface area	m^2	High porosity media	
Media Particle Size	mm	2 – 12	Closer to 10 mm overall
Media Moisture Content	%	40 - 50	Most use continuous watering
Inlet Gases Humidity	%	> 60	100% is ideal
Inlet Gases Distribution	--	Coarse media at the bottom	
Scrubber	--	Recommended	Remove dust, fat, Ammonia Essential for the Blood Furnace
Odour Concentration*	mg/m^3	0.001 - 5	This is generally meaningless unless there is a known correlation. OU is more commonly used
Odour Concentration	OU	20,000-1,100,000	
Inlet Gases Flow Rate	m^3/h	< 100,000	
Empty Bed Residence Time	s	5 - 600	600 is to optimistic. More work needed

Pilot-Scale test	--	Recommended	
Open/Closed construction	--	Closed	Preferred is open for CA with a roof
Operation Temperature	^{o}C	20 - 35	
pH	--	7 - 8	
Inoculation	--	Diluted solution of activated sludge, compost	
Inoculation Period		n/a	

n/a no sufficient information; * Depend on the odour threshold of each odour components, odour unit (OU) can be calculated from odour concentration in mg/m^3, OU=component concentration in $mg.m^{-3}$/component concentration threshold in $mg.m^{-3}$, for example odour threshold for H_2S is 0.2-2.0 $\mu g/m^3$, so the recommended concentration for H_2S in OU unit is 0.5 – 25,000 OU.

10 Appendix 2: Odour Test Results

The following is an extract from the odour sampling conducted by Assured Monitoring Group Pty Ltd (AMG) on 12th June and 27th September 2017. The first suite of test looked at the parameters of three

"EXECUTIVE SUMMARY

Table 3 provides an overview of the test results from Churchill Abattoir via three separate sources, Non-condensable, By-products and the Blood furnace.

- Post treatment samples were collected on the 27th September 2017.
- A comparison of the odour concentration only (not emission rates) has been made.
  This is due to the leakage of the treatment systems and their passive nature.
- A single inlet sample for the non-condensable plus by-products bio-filter was collected, the percentage reduction for this bio-filter is based on that sample, not the sample collected on the 12th June, 2017.
- The inlet samples concentrations from the two days are comparable.

Table 3: Executive summary

Release Point Parameter	Unit of Measure	Non-condensables	By-products	Blood furnace
Date of testing	dd-mm-yy	12-06-17	12-06-17	12-06-17
Exhaust Velocity	m/sec	7.2	12.2	8.8
Average stack temperature	°C	24	35	100
Moisture	%	1.9	2.5	12.8
Dry standard stack flow rate	Nm^3/min	12	1123	43
Carbon dioxide concentration	%	0.01	0.01	1.34
Oxygen concentration	%	20.9	20.9	18.5
Total VOC's (as propane)	mg/Nm^3	48.2	45.6	24.0
emission rate	g/min	0.594	51	1.037
Odour	ou	79,206	45,144	30,536
emission rate	ou/sec	16,598	866,519	25,235
POST TREATMENT (27th September 2017)				
Odour average(1)	ou	36,876	29,841	12,158
Reduction based on odour concentration	%	53%	64%(2)	60%

Notes:

(1) Average of cells A, B and C of the bio-filter units.

(2) This reduction percentage is based on an inlet concentration of 58,934 ou. This is the concentration of an inlet sample collected on the same day as the post treatment samples. "

***Comment**: The figure referred to in Note (2) should read 49.3% reduction based on 58,934 OU ((58934-29841)/58934 = 0.493) as it is the treatment of a combined source from the by-products and con-condensables, not solely by-products.*

Testing on the 27th September 2017		Non-condensable	Combined Non-condensable/by-products	Bloof Furnace
Inlet	ou		58934	
Zone A	(Conc) ou (E) ou/sec	34372 379	32750 2779	12793 73
Zone B	(Conc) ou (E) ou/sec	39063 437	30882 2491	13567 113
Zone C	(Conc) ou (E) ou/sec	36834 421	25892 1695	10114 141