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Sydney Water's Innovations to Improve Odour Control Unit Performance in Wastewater Networks

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ABSTRACT

Sydney Water has provided reliable water and wastewater services to customers for 132 years. To remain a leading utility, it is essential to pioneer processes that optimise asset performance and improve operational efficiency. A culture of innovation enables Sydney Water to embrace change, adapt and adopt new technologies, while improving existing ones to maximise performance and deliver the best possible outcomes for its customers and stakeholders.

Sydney Water has around 24,000 kilometres of sewer mains spread over 12,700 square kilometres. The generation and release of hydrogen sulphide and other malodorous gases in wastewater networks can result in customer odour complaints, and increased asset corrosion rates. Odour Control Units are installed and operated at strategic locations to improve ventilation of wastewater networks and reduce odorous compounds to acceptable levels for atmospheric discharge. Comprehensive design standards ensure new Odour Control Units meet all necessary safety, operational and maintenance requirements, and ensure consistency, while still enabling innovation. Implementation of these standards has benefited Sydney Water through capital, operational and maintenance savings.

The development of a Life-cycle Cost Model for Activated Carbon used in Odour Control Units enables carbon selection in terms of cost and performance. Sydney Water developed a specialised test rig to enable it to measure the hydrogen sulphide breakthrough capacity of activated carbon samples in house, the first of its kind in Australia. This stringent testing enables validation against specifications ensuring the most suitable and economical media is chosen. This has resulted in an estimated ***56%*** *increase in media service life, and savings of over* ***$1 Million p.a.*** *Together, these innovations enable Sydney Water to procure its activated carbon for Odour Control Units through long term contracts and maintain storage of a contingency stock to avoid shortages due to lead times of up to four months associated with importation from overseas.*

INTRODUCTION

Sydney Water has been providing reliable water and wastewater services to its customers for over 130 years. Today it supplies water, wastewater, recycled water and some stormwater to around 4.9 million people across an area of operations covering 12,700 km^2. Wastewater is collected via a network of around 24,000 km of pipes and 675 wastewater pump stations in 24 separate sewage systems licenced by the NSW Environmental Protection Authority (EPA) (Sydney Water Corporation, 2020).

Wastewater networks are highly complex, subject to dynamic conditions in terms of both hydraulics and compositions. Wastewater contains sulphates which through bacterial respiration are converted to sulphides and subsequently results in the formation and release of hydrogen sulphide (H_2S) gas in the sewer gas phase. H_2S is a colourless gas, with the characteristic foul odour of rotten eggs and can be detected by the human nose at very low concentrations. Numerous experimental studies have been undertaken to measure the odour detection threshold of H_2S with concentrations as low as 0.00004ppm reported (American Industrial Hygiene Association, 2013). H_2S gas is frequently encountered in wastewater networks and its microbiological oxidation to sulphuric acid that contributes to the corrosion of concrete wastewater infrastructure is widely documented. A range of other odorous compounds are frequently encountered in wastewater systems and include organic sulfides, ammonia, amines and mercaptans (Suez, 2020).

The ventilation of sewers is undertaken for a number of reasons which include allowing the exchange of air with the atmosphere in a controlled manner to aid in the removal of H_2S laden sewer air, control sulphide induced corrosion, reduce the hazards to maintenance personnel, and prevent the risk of air locks during periods of high flow (Water Services Association of Australia, 2017). Many wastewater network ventilation systems rely on natural or passive ventilation that takes place through structures known as vent shafts. Where higher rates of air exchange are required mechanically assisted force ventilation is utilised. Without treatment, discharge of sewer air through natural and force ventilation can result in customer odour complaints. As part of its operating licence agreement Sydney Water must comply with the Protection of the Environment Operations Act 1997 with regards to odour which requires that no offensive odours emanate from Sydney Water’s assets.

To manage corrosion and odour risks throughout its wastewater systems efficiently Sydney Water developed a corrosion and odour strategy and implementation plan. In addition to the dosing of chemicals in the liquid phase to control H_2S generation and gaseous release (Kacprzak, et al., 2019), Sydney Water operate Odour Control Units (OCUs) to assist in the ventilation of wastewater networks and removal of H_2S and other odorous gases from the gas phase prior to atmospheric discharge. Sydney Water has over 60 OCUs installed throughout its wastewater networks with an additional 10 in the planning phase. Most of these units use adsorption control technology with activated carbon as the media source. Sydney Water currently spends approximately $1 million per annum purchasing activated carbon media for OCUs located in wastewater networks, wastewater treatment plants and portable OCUs used to facilitate rehabilitation works. In addition to this it spends approximately a further $600 thousand annually on the costs associated with removal and disposal of the spent activated carbon media and the subsequent activities associated with replenishment.

METHODOLOGY

This paper summarises the improvements that have been made by Sydney Water over the last 13 years in relation to the design and operation of wastewater network activated carbon OCUs and the sourcing and management of the activated carbon media used in these OCUs.

Standardization of Odour Control Unit Design

In order to improve the operability and maintainability of OCUs it was decided that a standard should be developed, as there was no existing national or international standard that was available. The development of the Sydney Water Corporation Odour Control Unit Standard Specification ACP0004 (Sydney Water Corporation, 2018) has provided a more consistent approach to design, construction, commissioning, performance testing and handover of OCUs, and encapsulates lessons learned from past designs. The implementation of these standards has led to capital, operational and maintenance savings to Sydney Water through improving the performance, reliability and serviceability of OCUs. The standard also covers the design of biotrickling filters and chemical scrubber OCUs. It was decided to make the standard freely available to other users through the Sydney Water Website such that they may also benefit from it.

The Standards ensure that OCUs are designed to:

- Be safe to construct, operate, maintain and decommission in accordance with Sydney Waters Safety in Design Procedure D0000653 (Sydney Water Corporation, 2017);
- Provide reliable and effective odour removal to a level specified in the minimum requirements;
- Have a minimum of 20 years' service life, i.e. no major maintenance or renewal required (this does not apply to consumable components such as filter media);
- Comply with all relevant statutory and regulatory requirements, Standards and Codes of Practice including noise;
- Not cause interruption to the normal operation of the Sydney Water wastewater system;
- Be capable of remote monitoring and operation via connection to Sydney Water's Integrated Instrumentation, Control, Automation, and Telemetry Systems (IICATS) for networks and Supervisory Control and Data Acquisition (SCADA) for treatment plants.

One of the major improvements made to OCU design was to move the fan from upstream of the media vessel to be located downstream of the media vessel. When the fan is positioned upstream it puts any subsequent inlet ductwork under positive pressure, and therefore any leakage of odorous gases from the ductwork, fans or the media vessel could result in customer odour complaints. Locating the fan downstream of the media vessel places all inlet ductwork and the vessel under negative pressure, thereby eliminating the potential of any untreated odourous leaks as indicated in Figure 1.

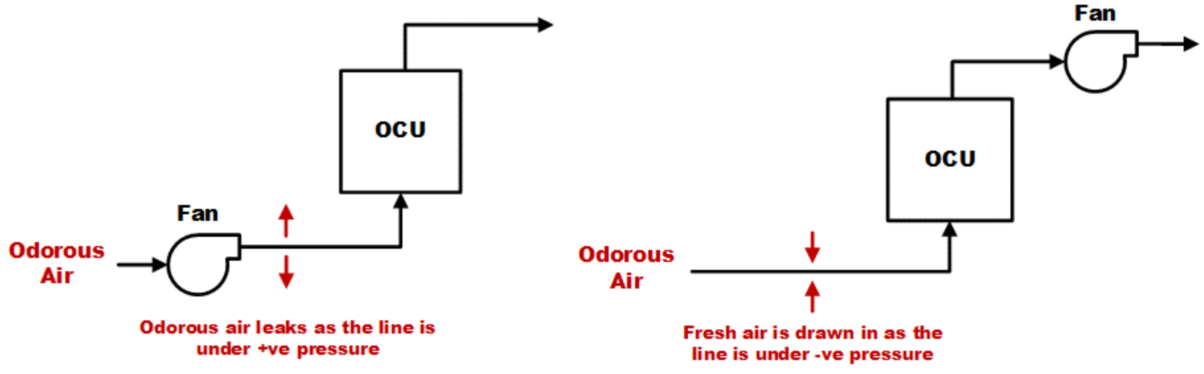

Figure 1 Left – design of OCU with fan pressurising inlet ductwork and media vessel. Right – updated design with fan downstream of the vessel and drawing air under vacuum.

The new configuration also has the advantage of minimising corrosion of the fan, since the air has already passed through the media vessel and reduced the concentration of corrosive gases before the airstream meets the fan.

Based on capital and operational cost benefit it was determined that the optimum design bed life for activated carbon OCUs is 24 months. The bed life is defined as the length of time between replacement of the activated carbon media based on breakthrough of gas contaminants above the target outlet design levels. This provides the best trade-off between the capital expenditure in building the OCU versus operational expenditure in maintaining the OCU, particularly regarding costs related to removing and replacing activated carbon. A 24-month design bed life also ensures the OCU is offline less frequently for change over resulting in fewer impacts on nearby customers. Figure 2 shows the recently constructed OCU SY0044 with fan positioned downstream of the media vessel and just upstream of the discharge vent shaft.

Figure 2 Recently constructed OCU with fan downstream of the media vessel discharging to a vent shaft

Monitoring of Odour Control Units

To enable proactive management and adequate oversite on the performance of its OCUs, Sydney Water utilises continuous monitoring of some key parameters including inlet and outlet H_2S and differential pressure as an indicator of fouling for airflow. While all new Sydney Water OCUs must have online monitoring in IICATS and at most older existing OCUs this has been retrofitted, in some instances it has not been economical to install instrumentation and remote telemetry. At OCUs where fixed online monitoring is not in place, a routine program of performance monitoring using offline instrumentation occurs.

Historically one of the major challenges for ongoing monitoring of OCU performance was a lack of reliability in the H_2S gas measuring system. Air sampling lines were susceptible to water accumulation by condensation, which would interfere with the sensor and produce inaccurate readings. A detailed investigation was undertaken to study the problem and the following improvements were made:

- Sample pumps with adjustable rotameters were installed to provide a steady air flow of known rate. The pump is capable of withstanding system back pressure and provides a minimum flow of 1 L/min to the sensor. Previous designs required pressure in the ductwork to transfer air for sampling to the sensor, and in many cases, this was found to be inadequate;
- Condensate traps are installed on the suction side of the sample pump upstream of the gas monitor and rotameter, in order to remove moisture prior to contact with the sensor improving the reliability of the gas monitoring.
- All sample lines are required to rise steadily to the condensate trap or have one high point only. This eliminates any low points that act as water traps inhibiting the flow of air to the sensor;
- Additional tapping points are required upstream of the OCU for return of the foul air samples from the H_2S sensors. Previous designs had the sample air discharging to atmosphere resulting in release of untreated odorous air;

- Installation of manual sampling ports on the inlet sample line and on the discharge of the sample pump, to allow manual gas measurements to cross check fixed OCU gas monitor operation;
- Calibration of the OCU gas monitors is undertaken by SW following defined procedures;

Figure 3 provides a process flow diagram of a typical OCU monitoring system.

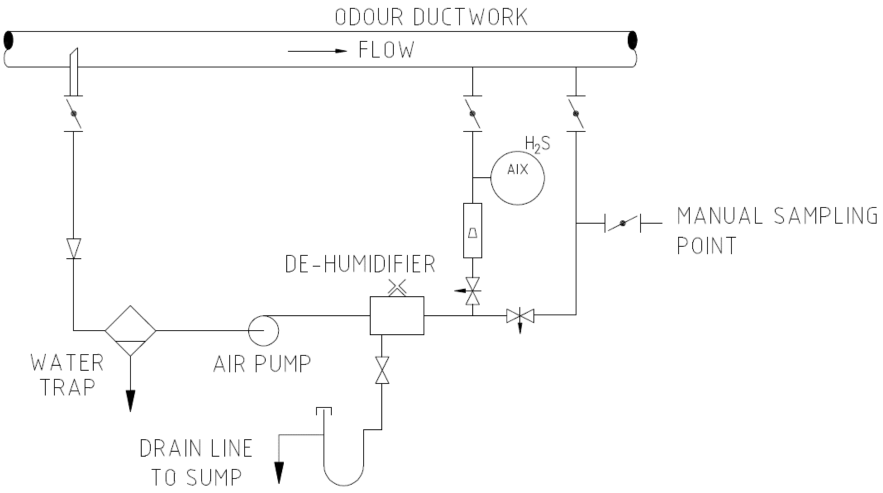

Figure 3 OCU monitoring system process flow diagram showing layout of key components

Figure 4 shows the entire monitoring cabinet at a recently constructed OCU depicting the H_2S sensors and sampling pumps and the differential pressure sensors measuring airflow across the media bed.

Figure 4 Monitoring cabinet with H_2S monitors at top row; water traps and flow regulators on second row; pressure transmitters on third row and sample pumps on bottom row

Adsorption Media

Activated carbon can be produced from agricultural waste materials such as rice husk, palm oil shell and coconut shell. It has a porous structure which contributes to an extremely large particle surface area (>1000 m^2/g) resulting in powerful adsorptive properties. Activated carbon is available in three main forms; these are - powder, granular and pellet. The primary type of activated carbon media that Sydney Water utilises in its wastewater network OCUs for treating odorous gases is pelletised virgin impregnated activated carbon due to its adsorptive affinity to H_2S and other malodorous gases.

Impregnation of activated carbon has demonstrated higher absorption characteristics of the bulk media and therefore is used extensively to extend media life. Of the range of impregnated activated carbon available, Caustic (NaOH, KOH), Potassium Iodide (KI), and Copper Oxide (CuO) are the three most frequently used activated carbon in Sydney Water's wastewater networks OCUs. Potassium Iodide (KI) acts as a catalyst for the oxidation of H_2S to elemental sulfur (Sitthikhankaew, et al., 2013).

$$H_2S + \frac{1}{2}O_2 \xrightarrow{\text{catalytic KI}} S + H_2O$$

Caustic impregnated activated carbon, sodium hydroxide (NaOH) and potassium hydroxide (KOH) both solubilize the gaseous H_2S and form sulfides which would then be oxidized to elemental sulfur by the gaseous oxygen (Yan, et al., 2002). The alkaline oxidation pathway for KOH impregnated carbon is as follows.

$$\begin{gathered}
KOH + H_2S \longrightarrow KHS + H_2O \\
H_2S + 2KOH \longrightarrow K_2S + 2H_2O \\
KHS + \frac{1}{2}O_2 \longrightarrow S + KOH \\
K_2S + \frac{1}{2}O_2 + H_2O \longrightarrow S + 2KOH
\end{gathered}$$

The alkaline oxidation pathway for NaOH impregnated carbon is identical to the pathways shown above with NaOH substituting for KOH. For Copper Oxide impregnated carbon, H_2S is first physically adsorbed on the surface of the porous carbon where it interacts with CuO via the following pathway.

$$\begin{gathered}
Cu(OH)_2 + 2\,H_2S \longrightarrow 2CuS + H_2O \\
CuO + H_2S \longrightarrow CuS + H_2O \\
Cu + H_2S \longrightarrow CuS + H_2
\end{gathered}$$

Quality Assurance of Activated Carbon

Currently all of the activated carbon media that Sydney Water sources for its OCUs is manufactured overseas and imported into Australia. To assist Sydney Water in being able to acquire the optimum activated carbon media for its requirements there was a need to be able to test the activated carbon under laboratory conditions. The industry standard, ASTM D6646 - Standard Test Method for Determination of Accelerated Hydrogen Sulfide Breakthrough Capacity of Granular and Pelletized Activated Carbon was adopted to achieve this. Having the ability to test the physical characteristics and H_2S adsorption capacity of activated carbon enables Sydney Water to ensure that the quality of media being supplied is consistent with the stated product specifications.

As there was no laboratory in Australia capable of testing activated carbon to the relevant ASTM Standard, Sydney Water undertook a research and development project to build and commission its own rig to undertake the testing inhouse. The ASTM D6646 test method is intended to evaluate the performance of virgin, newly impregnated or in-service, granular or pelletized activated carbon for the removal of hydrogen sulphide from a moisture saturated air stream, under laboratory test conditions. A humidified air stream containing 1% (by volume) hydrogen sulphide is passed through a carbon bed until 50 ppm breakthrough of H_2S is observed and the H_2S adsorption capacity of the carbon is then calculated as per (ASTM-D6646-03, 2003). The test rig built was based on the ASTM D6646 Standard (refer to Figure 5) however a decision was made to utilise a H_2S gas monitor with inbuilt datalogger to record the results of breakthrough testing for each activated carbon which is seen as an improvement on the standard.

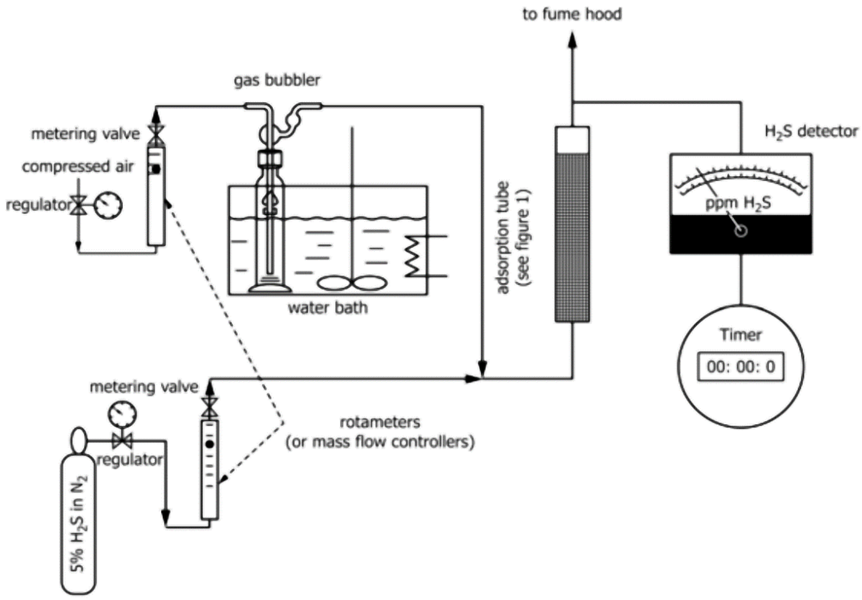

Figure 5 Schematic of Apparatus for Determination of H2S Breakthrough Capacity (from ASTM D6646 Standard)

At the end of each test the data is plotted, and the subsequent breakthrough curve is reviewed to ensure the observed performance of the activated carbon is representative of what is expected. The amount of time taken for the breakthrough to reach 50ppm is then used as the result for the test run. In addition to the H_2S breakthrough testing, as part of its activated carbon quality assurance processes, it is also necessary to undertake testing of physical characteristics. A riffle splitter is used to prepare the sub samples by evenly distributing the sample. This ensures reproducibility in preparation of subsamples. The physical characteristics that Sydney Water tests as part of its activated carbon quality assurance are listed in Table 1:

PARAMETER	TEST METHOD
Moisture Content	ASTM D2867
Apparent Density	ASTM D2854
Ball-Pan Hardness	ASTM D3802
Particle Diameter	ASTM D2862
Particle Length	ASTM D2862
Mean Particle Diameter	ASTM D2862
Total Ash Content	ASTM D2866
Hydrogen Sulphide Breakthrough Capacity	ASTM D6646

Table 1 Physical Characteristics tested using ASTM standards

Safety Considerations for the Test Rig

During the planning stage for the test rig, a thorough risk assessment was performed by the project team to ensure that all risks were identified and that appropriate safety controls were considered in the design before the test rig was constructed and commissioned. Given the toxic nature of H_2S gas it was necessary to incorporate several critical safety systems into the design. These include fail-safe systems to cease H_2S gas flow during the event of any H_2S gas being detected outside the fume hood, and in the event of a power outage that might occur during testing that disables the fume hood. Once a location was identified, modifications were undertaken on the fume cupboard so that it could adequately extract the high H_2S gas levels that are required for the testing.

Critical components of the test rig by way of the glass adsorption tubes were not available off the shelf and had to be sourced and manufactured locally. Once the test rig was assembled, it was proven to ensure the method worked and H_2S gas did not leak out into the laboratory. The testing procedure was checked by undertaking ten sets of test runs on each type of activated carbon to ensure statistical repeatability. A picture of the Sydney Water activated carbon test rig is shown in Figure 6.

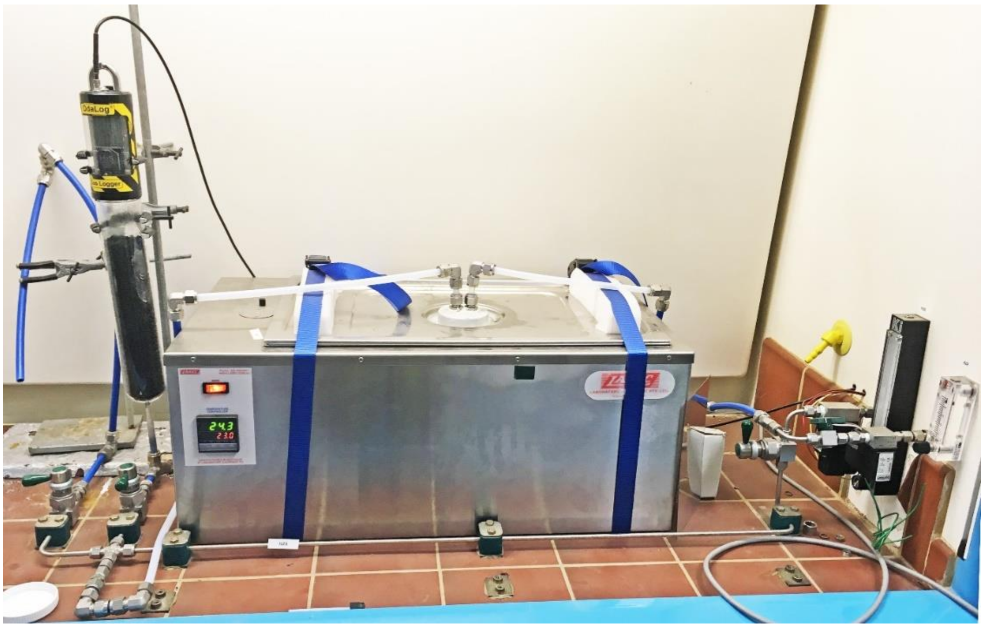

Figure 6 Sydney Water Activated Carbon Testing Rig built to ASTM D6646 with H_2S monitor above adsorption tube on left, water bath in centre, flow rotameters and valves on right of photo

Activated Carbon Life-cycle Cost Model

To facilitate better management of its activated carbon for wastewater network OCUs and assist in selecting the best value media, an activated carbon Life-cycle Cost Model was developed. The activated carbon Life-cycle Cost Model is based on the size and number of Sydney Water's OCUs; average H_2S gas levels treated by the OCUs; the unit cost of the carbon, together with it's H_2S adsorption capacity, and specific density as evaluated through testing. Life-cycle cost refers to the total expenditure including the initial purchase of media, installation of activated carbon, the cost in service through the life of the media and includes any related costs such as but not limited to performance testing, change over, waste disposal and any additional environmental testing. In summary, the model weighs up the cost and performance of the activated carbon against the cost of removal, disposal and replenishment of the media.

Forecasting annual activated carbon usage based on expected lifecycle has enabled Sydney Water to maintain an adequate inhouse contingency stock as part of its critical spares system. This is particularly important given the lead time of up to 4 months between time of order and activated carbon being received from overseas. A contingency stock has also been integral in ensuring asset availability, and hence reducing the impact of any odours on customers. Better forecasting of annual activated carbon required has also enabled for improvements in supply through long-term contracts.

RESULTS AND DISCUSSION

As part of the rigorous validation process of the test rig, three different types of activated carbon with differing particle size were chosen to test the rig in accordance with the requirements of the ASTM standard. The mean particle diameter of the activated carbon to be tested determines the size of the tube that is used together with the test settings for gas flow. For proving the test rig each type of carbon was subjected to 10 tests. Results for each activated carbon chosen showed very good statistical correlation and proved that the activated carbon test rig and testing procedure gave consistent results.

The development of an activated carbon testing rig has allowed Sydney Water to rigorously examine the quality of activated carbon over the last 10 years. The activated carbon testing rig has also been used to test carbon samples submitted by external clients. As part of internal quality control procedures all batches are tested prior to being accepted. Variability in the performance of activated carbon across batches of the same product have been observed.

CONCLUSION

Sydney Water operates an extensive wastewater network and relies heavily on activated carbon OCUs. With its number of OCUs increasing in addition to customer expectations and operating licence requirements, it is important that OCUs are operated reliably and effectively. Development of a design standard for OCUs has brought about significant benefits for Sydney Water through ensuring new OCUs are consistent in meeting all safety, operational and maintenance requirements. Moreover, it has led to significant capital, operational and maintenance savings. The use of water traps, sample pumps and sample line grading have led to improved monitoring accuracy and confidence in the performance of the OCUs.

The development of a Life-cycle Cost Model enables Sydney Water to select the most efficient activated carbon for its OCUs. The development of a specialised test rig has enabled inhouse testing of the hydrogen sulphide breakthrough capacity of activated carbon and was the first of its kind in Australia. This testing has enabled Sydney Water to determine the most suitable activated carbon media for its OCUs. This has resulted in an estimated 56% increase in media service life and an estimated savings of over $1 million per annum. Together these innovations have enabled procurement of activated carbon through long term contracts assisting the ability to maintain an effective contingency stock to avoid shortages.

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AUTHOR BIOGRAPHIES

Gino Iori

He graduated with an honour's degree in Chemical Engineering from the University of NSW in 1988. He holds a Fellow membership grade with Engineers Australia and is an Associate Member of IChemE. He has been with Sydney Water since 1993 with experience in quality assurance, water quality, recycled water, and his current portfolio of corrosion and odour in wastewater networks. Prior to joining Sydney Water he worked at ICI Australia as a shift supervisor and quality engineer and as a graduate engineer with Transfield Construction in protective coatings.

Heriberto Bustamante

Heriberto is a pharmaceutical chemist from Chile. He changed career and received his PhD from Imperial College (London) in Mineral Technology. His almost 30-year career has been in industrial research. Joined Sydney Water in 1996. Previously he spent almost 10 years working for British Petroleum Research (England) on minerals purification and industrial wastewater treatment. His current role is Principal Research Scientist Treatment in Corporate Strategy. He identifies research gaps needed by Sydney Water, develop research scopes and identify research partners to carry out collaborative research that will deliver project outcomes that can be implemented by the businesses

Jeff Scott

Holds qualifications in engineering and a Master of Management (MGSM). He started out in Sydney Water in construction and worked on various tunnelling projects including the deep ocean outfalls. Following a move into the trade waste area, Jeff progressed to become a Plant Manager at several sewage treatment plants. Jeff's current role is managing the "Chemical Dosing Team" which is responsible for operating re-chlorination plants and water quality instruments in the water network, and chemical dosing units and odour control units in the wastewater network.

Robert Lovatt
He is a Senior Air Quality Officer working for Sydney Water with 20 years of experience in atmospheric monitoring and odour investigations. He holds a Degree in Industrial Chemistry from University of Technology Sydney. He joined Sydney Water in 1998. Robert was involved directly in the design and build process of Sydney Water's Activated Carbon Testing Rig. He has been the chief scientist responsible for maintaining and operation of the Rig since conception.

Michael Kacprzak
He is a Scientist working for Sydney Water in the Wastewater Programs Corrosion and Odour portfolio. He started his career in the water industry working for private consultancy specialising in wastewater corrosion and odour undertaking projects for a range of major and regional utilities. Michael has gained significant experience in relation to the monitoring of wastewater networks and data analysis. Since joining Sydney Water in 2014 Michael has worked in roles across hydrometrics and instrumentation with his current position as a Senior Networks Program Scientist.

Lalitha Parthasarathy
She graduated with an honour's degree in Chemical Engineering from UNSW Sydney. She did her Honours Thesis on CO_2 methanation using novel Metal Organic Framework (MOF) based catalysts at PARTCAT UNSW. She joined Sydney Water in 2019 in the Networks – Odour and Corrosion team.

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