RUSTY IRON – A COST-EFFECTIVE ODOUR CONTROL UPGRADE FOR OVERLOADED SYSTEMS

Results of the first Australian installation of a rusty iron catalytic filter

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Abstract

This paper presents the results of the first Australian installation of a rusty iron catalytic filter (RICF) as part of a load reduction system in an odour control facility. The RICF was installed to treat high-gas phase hydrogen sulphide concentrations at the Sydney Street Pump Station in Mackay, Queensland.

The Sydney Street Sewage Pump Station was recently upgraded as part of a major sewerage system reconfiguration. The upgrade to the pump station included the installation of an odour control system consisting of a biotrickling filter (BTF) followed by activated carbon. Following commissioning, the observed load of hydrogen sulphide on the odour control system was significantly higher than allowed for in the design. The net effect was an overloaded BTF, excessive consumption of activated carbon and odour complaints.

Mackay Water Services required a cost-effective method of bringing the hydrogen sulphide concentrations within the design envelope of the odour control system, thereby reducing consumption of activated carbon. In partnership, MWH Global designed, and Mackay Water Services installed, an RICF prior to the biotrickling filter. The RICF was chosen due to its low capital cost and track record of removing 60% of the hydrogen sulphide in waste gas streams when used as a pre-filter. Rusty iron catalytic filters, also known as catalytic iron filters (CIF), are not a new technology. CIFs have been used in the United Kingdom as components of odour control systems in sewerage installations since the 1990s. Prior to this they have been used to reduce the hydrogen sulphide concentration in reticulated gas systems. However, while being used overseas, to the authors' knowledge they have never before been installed for hydrogen sulphide reduction as part of an odour control system in Australia.

The initial results indicate that in excess of 70% of the hydrogen sulphide is being removed over the RICF. With this performance it is estimated that there will be a saving of $21k per year in activated carbon, giving the project a six-year payback period.

Introduction

In response to growth in the Mackay Region, Mackay Water Services undertook a major reconfiguration and upgrade to the sewerage network, sewage treatment and effluent disposal infrastructure as part of the Mackay Water Recycling Project between 2006 and 2008. The project included the diversion of sewage from the decommissioned Mt Basset Sewage Treatment Plant to the upgraded Mackay South Water Recycling Facility. The Sydney Street Pump Station was used to divert the flow.

The upgraded Sydney Street Pump Station has a peak pumping capacity of 1190L/s. The pump station receives flow from a combination of gravity and daisy chain pump stations servicing a population of approximately 70,000 people. The design anticipated increased odour generation at the site. The upgrade included an odour control system incorporating a biotrickling filter (BTF) followed by activated carbon. Following commissioning, the observed levels of hydrogen sulphide were regularly in excess of 600ppm, more than double the peak design load for the odour control system. A comparison of the design to actual hydrogen sulphide concentrations is shown in Table 1.

While the BTF was operating surprising well given the loads entering the plant, the load passing through the BTF onto the activated carbon was high. The activated carbon depleted rapidly, resulting in a significant increase to operating cost and periodic odour complaints. MWH and Mackay Water Services undertook a review of the potential options to reduce the odour generation at the site. The installation of a rusty iron catalytic filter (RICF) prior to the BTF wac chosen due to the low capital and operating costs and the ease of operation. The aim of the design was to use the RICF to reduce the inlet odour concentration to the BTF back in line with the original design. With the BTF operating within its design load, improved BTF performance was anticipated, thereby reducing the load on the activated carbon.

Table 1. Loading of odour control system.

Hydrogen Sulphide Concentration (ppm)	Design	Actual
Average	37	>150
Peak	270	600

This paper discusses the design and operation principles of an RICF, together with the results obtained from the first Australian installation at the Sydney Street Pump Station.

Chemistry of a Rusty Iron Catalytic Filter

Rusty iron or catalytic iron filters (RICFs or CIFs) were originally used to remove hydrogen sulphide from reticulated gas systems in the United Kingdom (UK) during the 19th Century. The technology was introduced into the water industry as a method of odour control by Arthur Boon in the 1990s. Since their first adoption in the water industry RICFs have been widely adopted throughout the UK to remove gas phase hydrogen sulphide and reduce the load on downstream odour control systems.

Catalytic iron filters work by passing foul air containing hydrogen sulphide over a packed bed of iron in a humid environment. The RICF reduces the concentration of hydrogen sulphide through a series of reactions that convert the gas phase hydrogen sulphide to sulphur that is returned to the sewer as a waste stream. The process occurs in three basic steps:

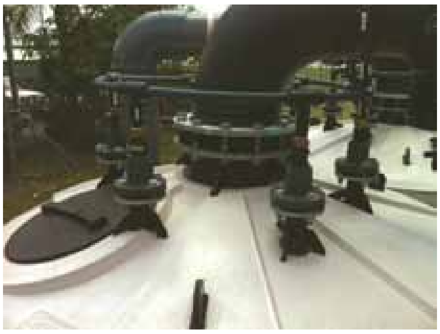

Figure 1. View of RICF roof showing wash system.

Step 1. When the unit is initially commissioned the surface of the iron packing material is converted from iron to rust. This reaction initiates the process.

Step 2. The rust is converted to iron (II) sulphide when it comes in contact with the hydrogen sulphide in the foul air.

Step 3. The rust layer is then regenerated by the reaction with oxygen in the air, leaving elemental sulphur attached to the media.

The chemistry of the process is detailed below.

STEP 1: Rust Formation on Iron

In the presence of oxygen and water a series of internal galvanic cells or batteries is created on the surface of carbon steel. The carbon impurities become the site of reduction.

Figure 2. Media being pre-rusted prior to commissioning.

Reduction half equation:

$$4e^- + 2H_2O_{(l)} + O_{2(g)} \rightarrow 4OH^-_{(aq)}$$

Oxidation half equation:

$$Fe_{(s)} \rightarrow Fe^{2+}_{(aq)} + 2e^-$$

When the $Fe^{2+}_{(aq)}$ and $OH^-_{(aq)}$ ions meet they combine to produce the precipitate, iron (II) hydroxide $Fe(OH)_2$:

$$Fe^{2+}_{(aq)} + 2OH^-_{(aq)} \rightarrow Fe(OH)_{2(s)}$$

$Fe(OH)_2$ is further oxidised in the presence of air and finally hydrated to produce rust.

$$Fe(OH)_{2(s)} + 1/2O_{2(aq)} + H_2O_{(l)} \rightarrow Fe_2O_3.xH_2O_{(s)}$$

(rust)

Figure 4. General view of RICF and booster fan.

STEP 2: Reaction of Rust with Hydrogen Sulphide

When rust is placed in direct contact with hydrogen sulphide gas, the iron oxide is reduced to form iron (II) sulphide in the following reaction:

$$Fe_2O_3.xH_2O_{(s)} + 3H_2S_{(g)} \rightarrow 2FeS_{(s)} + 3H_2O_{(l)} + S_{(s)}$$

It has been stated by some texts that iron (III) sulphide ($Fe_2S_{3(s)}$) is also formed. Iron (III) sulphide is a solid, black unstable powder which does not occur in nature. Should it be formed it will decay rapidly at ambient temperature into a yellow-green powder as per the following reaction:

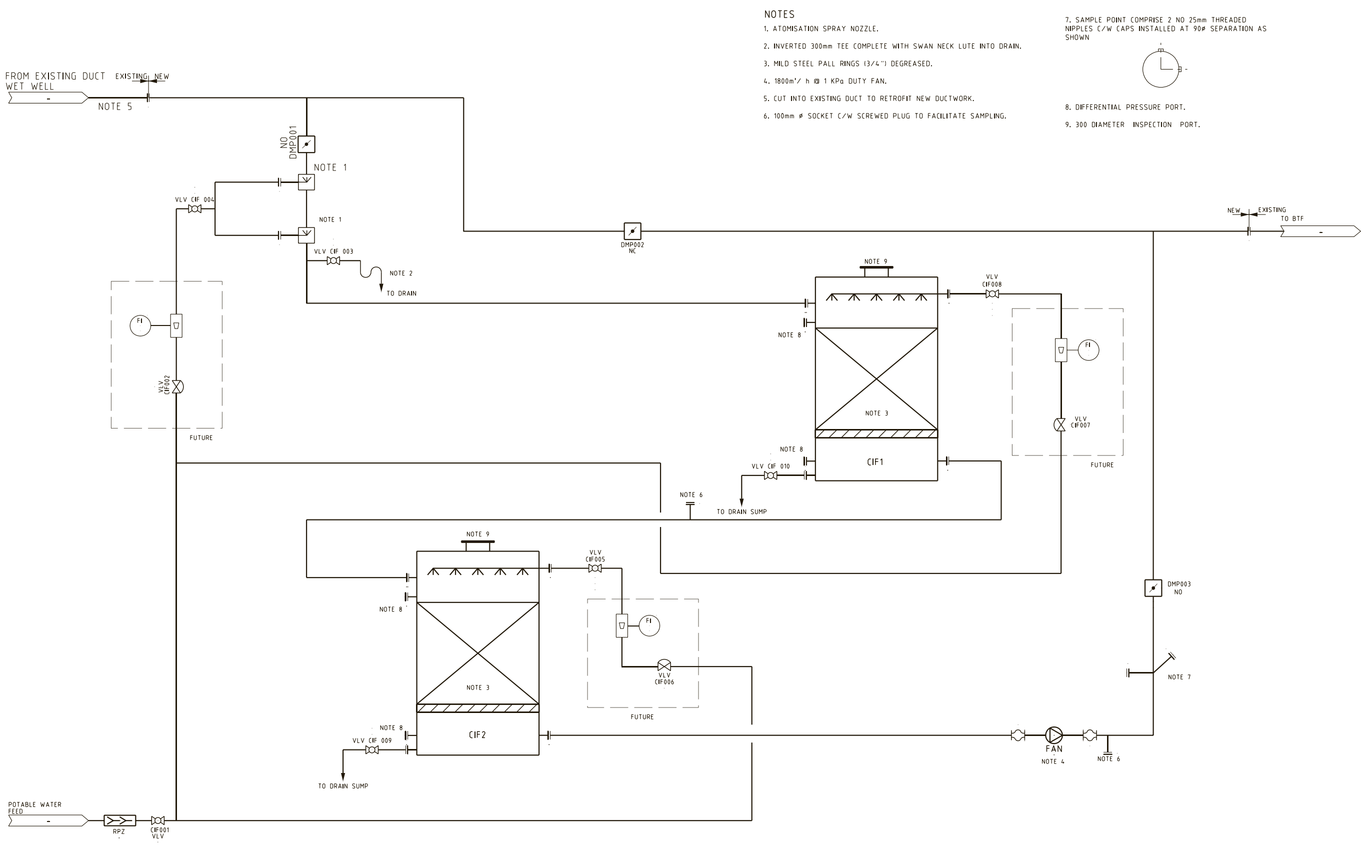

Figure 3. P&ID Sydney Street RICF installation.

$$Fe_2O_3.xH_2O_{(s)} + 3H_2S_{(g)} \rightarrow Fe_2S_{3(s)} + 3H_2O_{(l)}$$
(unstable product)

$$Fe_2S_{3(s)} \rightarrow 2FeS_{(s)} + S_{(s)}$$

STEP 3: Regeneration of Rust Layer

Iron (II) sulphide, when exposed to oxygen in air, is oxidised back to iron oxide. Either free sulphur or sulphur dioxide gas is formed in this reaction. The reaction between iron (II) sulphide and oxygen is accompanied by the generation of a considerable amount of heat. The rapid exothermic process of oxidation of the sulphide to oxide occurs, as shown in the equations below:

$$4FeS_{(s)} + 3O_{2(g)} \rightarrow 2Fe_2O_{3(s)} + 4S_{(s)} + heat$$

$$4FeS_{(s)} + 7O_{2(g)} \rightarrow 2Fe_2O_{3(s)} + 4SO_{2(s)} + heat$$

The heat produced by this reaction has been known to be extreme in some circumstances resulting in fire/explosion (Jeffries, 2010). This has occurred where large volumes of iron (II) sulphide have formed, and then been allowed to come into contact with air instantaneously. However, where hydrogen sulphide concentrations are less than 10,000ppmv and oxygen is continuously present, the formation of sufficient quantities of iron (II) sulphide to cause safety issues does not occur. In effect, the exothermic reaction works in favour, oxidising the iron (II) sulphide so rapidly that it cannot accumulate. Therefore, in most wastewater odour control applications there will be no risk of explosion.

Design and Operation of a Rusty Iron Catalytic Filter

The design of the RICF for the Sydney Street Pump Station was influenced by the site constraints and the existing odour control equipment. Factors taken into consideration included:

Figure 5. Washing nozzle assembly.

Table 2. Design parameters for RICF at Sydney Street.

Parameter	Value
Airflow	1,800m^3/h @ 20°C and 101.3kPa
Design peak hydrogen sulphide load	600ppm
Design removal capacity at peak load	>60%
Number of units	2 (duty, duty series operation)
Superficial gas velocity	0.2m/s
Media type	0.5" degreased mild steel Pall Rings
Media volume	8m^3
Overall pressure drop	<200Pa
Gas loading rate	0.24kg/s.m^2
Inlet gas humidity	60%rh
Design gas humidity into RICF	100%rh
Humidifier feed rate	12l/h
Water feed during media wash	2.5l/s

- Head loss and velocities through the existing odour control system;
- Site space constraints;
- The desire for low-cost, simple installation and a short construction timeframe to address the immediate odour issues.

In order for the unit to be installed and commissioned quickly, "off the shelf" components were specified where possible. The design was performed and centred on the use of standard carbon steel mass transfer packing (to provide a substrate for rust formation), and standard size poly tanks as reaction vessels.

Gas Velocity and Reactor Configuration

Gas velocities up to 4m/s can be used through the RICFs. The higher velocity increases the conversion yield of hydrogen sulphide to sulphur per square metre of rust surface area (Boon, 1999). However, the high gas velocities also yield significant pressure drop.

While in a new system this differential pressure could be accounted for, the constraints of the existing odour control equipment at the Sydney Street Pump Station site dictated as small a pressure drop as possible. This outweighed the increased performance obtained at higher velocities. A superficial gas velocity of 0.2m/s was chosen. Although an overall pressure loss of just 200Pa was achieved, a small booster fan was installed to ensure the design airflow of the existing odour control equipment was maintained.

While selecting a superficial gas velocity that was lower than usual to reduce pressure loss, the gas velocity still dictated a vessel with a height:diameter ratio of 4:1. In order to fit into standard poly tank sizes the reaction vessel was split into two units in series. Two 1.8m diameter tanks were used, each containing 4m^3 of carbon steel media. Figures 1 to 3 show a block flow diagram and photographs of the system as installed.

Media Selection

The media used in RICF can be any iron material that rusts readily. A manufactured iron mass transfer packing was chosen for the Sydney Street Pump Station installation to maximise iron surface area given the site pressure drop constraints.

In theory the reaction involved is fully catalytic and, therefore, the iron would not require replacement. In practice, however, iron is lost continuously via sloughing of rust particles during the intermittent media wash. As a result the media generally requires replacement every two to five years. There have been some instances in the UK where the media and unit efficiency has been retained for over 20 years.

Degradation of media occurs most quickly where the hydrogen sulphide concentration is at its greatest (the inlet); as the media degrades it loses its structural integrity and can be easily compressed. Therefore, the system was designed with down-flow units. If up-flow units are installed, pressure drop is generally observed to increase over time as the bottom layers of media collapse.

Wash Regeneration

The main cause of a reduction in performance of RICFs is the production of free sulphur, which coats the surface of the iron in the reactor. Sulphur production is an integral part of RICF operation. It is produced both during the reaction of rust with hydrogen sulphide and the rust

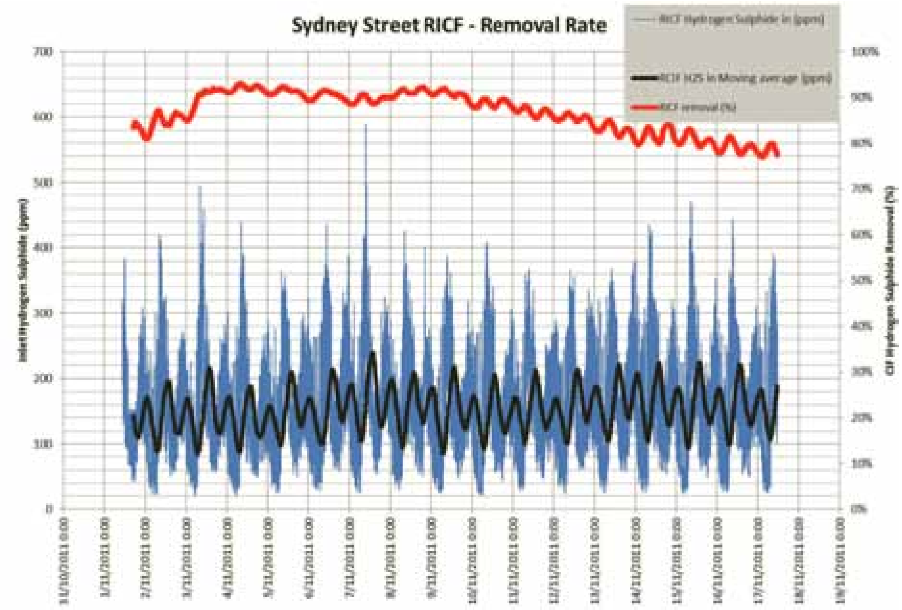

Figure 6. RICF hydrogen sulphide removal rate.

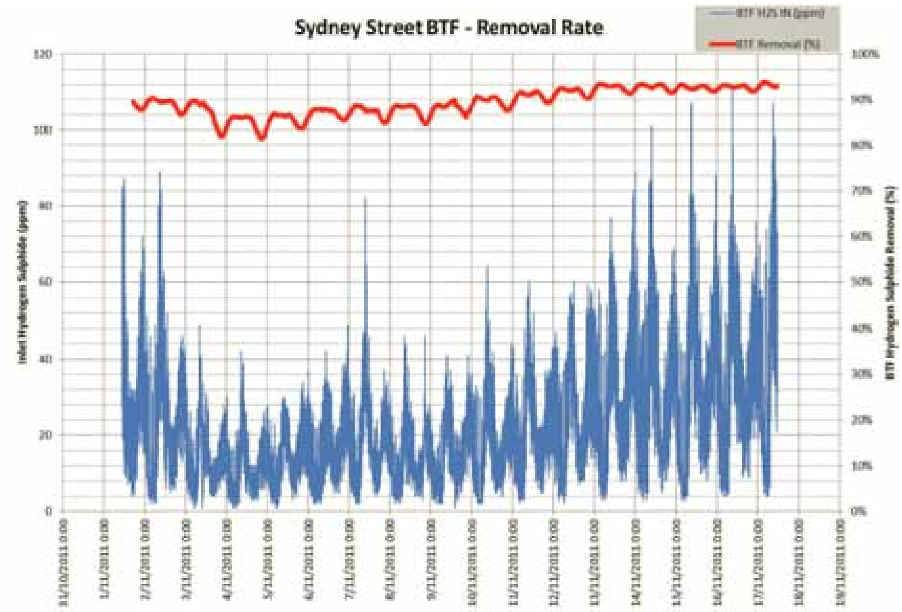

Figure 7. BTF hydrogen sulphide removal rate.

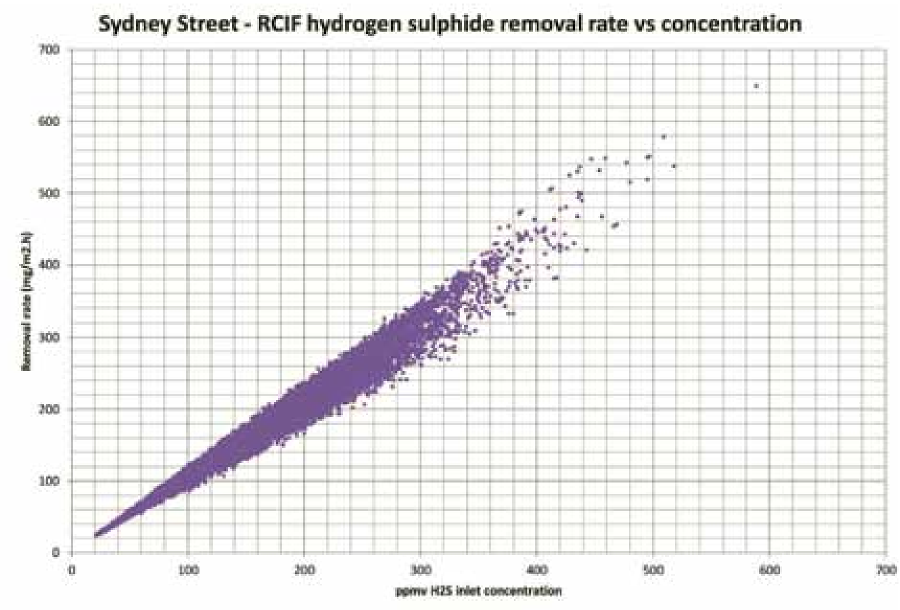

Figure 8. RCIF hydrogen sulphide removal capacity.

regeneration reaction. This free sulphur effectively puts a physical barrier between the hydrogen sulphide and rust, preventing further reaction.

In order to reduce the sulphur barrier, reactors are periodically washed with service water. The removal is achieved through general attrition or promotion of further rusting causing flaking of the iron surface. Spent water containing sulphur is discharged back to the pump station.

The length and frequency of washes is a function of the hydrogen sulphide load. In the case of the Sydney Street Pump Station a daily wash of no less than five minutes in duration is required due to the high load. The wash regeneration is responsible for iron loss over time, but is unavoidable if efficiency is to be maintained.

Duty Cycling

Some installations include standby units to allow duty cycling. This configuration provides a "rest" period, allowing rust to re-form. This resting period where fresh air is blown through the unit stems from iron filter's original use, where the general gas had low to zero oxygen content. The reaction to re-form rust could not occur until the unit was taken off-line and "rested". As the chemistry shows, such resting is not required in wastewater odour control operation, where the gas is essentially air with 21% oxygen content and comparatively very low contaminant concentrations. As such, multiple units to allow "resting" have not been integrated into the design of the Sydney Street Pump Station.

The system design parameters as installed at Sydney Street Pump Station are shown in Table 2.

Results

Due to the simplicity of design and operation, the plant was commissioned in less than a day, with foul air introduced at the end of day one. Performance proving was carried out over the following three weeks. OdaLogs were placed on the RICF inlet, outlet and BTF outlet to monitor RICF hydrogen sulphide removal rate, BTF hydrogen sulphide removal rate and hydrogen sulphide load onto the activated carbon respectively. The results are shown in Figures 6, 7 and 8.

The hydrogen sulphide inlet concentration average steadily increased over the test period, varying on a daily basis from 25 to 600ppm. The initial RICF hydrogen sulphide removal rate was measured at an average of 85%. This high removal rate was achieved by allowing the

Table 3. Installation costs.

Detail	Cost
Design, specification, commissioning, proving (MWH)	$34,771
Media vessels (poly tanks)	$14,500
Booster fan	$2,076
Carbon steel packing	$20,700
Duct, piping, installation	$44,957
Total	$117,004

iron media to obtain a rust layer prior to installation (by leaving the media outside for a week prior to installation).

The removal rate of the RICF was observed to leap up to 90% quickly, then settle back to the expected range of 75% after a two-week period. This cycle is due to the media having a very high initial high-rust per cent per surface area value, which is then degraded slightly and maintained by the production and sloughing of sulphur on the surface.

As the hydrogen sulphide concentration into the BTF had been dramatically reduced, the BTF began to recover, with removal rates increasing steadily over the test period from an average of 87% to 95% as the BTF inlet concentrations dropped back to within the design range. It is expected that the removal rate of the BTF should reach 99% based on the original supplier's guarantee.

The data obtained from the installation was compared to results from previous installations, with the following relationships confirmed:

- The relationship between the removal rate (mg of H_2S per m^2 media surface area per minute) and superficial gas velocity is linear in nature, with the removal rate increasing with gas velocity and thus differential pressure (when compared to past data).
- There is a linear relationship between inlet concentration and removal rate per metre square surface area.

A key objective of the project was to reduce the odour load at a low cost. As a result, the design of the RICF used commercially available equipment where possible. A summary of the costs for the installed system is shown in Table 3.

An assessment of the whole-of-life cost of the project has shown that the reduced load on the activated carbon units will reduce the frequency of carbon replacements. This is anticipated to generate a saving of approximately $21,000 per year, a payback period for the project of less than six years.

Conclusion

A rusty iron catalytic filter was installed as a method of bringing the hydrogen sulphide concentrations within the design envelope of the odour control facility at the Sydney Street Pump Station. The project has shown that rusty iron catalytic filters can be a cost-effective means of managing odour in an overloaded system. The results from the first Australian installation have shown that:

- The RICF is achieving greater than 80% removal of hydrogen sulphide;
- The performance of the BTF has improved following the installation of the RICF due to the reduced hydrogen sulphide concentration;
- The improved performance of the odour control units is estimated to save $21,000;
- There have been no odour complaints from the facility since the installation of the RICF;
- Initial results are very promising for the trial unit, with an intention to continue recording data and monitoring performance.

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