AUSTRALIAN MEAT PROCESSOR CORPORATION

Trickling Filter Technology for Treating Abattoir Wastewater

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Executive Summary

Abattoir wastewater can be high in organic matter and nutrients, and biological treatment may be required to achieve approved environmental discharge standards. Treatment systems for Australian abattoirs usually involve dissolved air floatation (DAF) and an anaerobic system, followed by an activated sludge process. The two key shortcomings of this type of treatment system involves spatial footprint (i.e. large anaerobic lagoons) and high power costs (i.e. to power activated sludge systems). As a result, abattoir operators wish to evaluate alternative methods for removing organic waste from abattoir wastewater and this report considers the potential for application of trickling filters (TFs) for the industry.

Trickling filtration is a biological treatment technology which potentially represents a simple, reliable, and low-cost method to remove organic waste from abattoir wastewater. A review of this alternative technology was undertaken based on literature and operational experience of the author.

It was found that there are a number of significant advantages of the trickling filter system compared to activated sludge. Despite this, very few trickling filter applications in Australia catering for abattoirs were found. Some references are made to overseas application and a number of alternative industries. This review indicates that the trickling filter is potentially viable for the red meat industry (downstream of the DAF and / or anaerobic systems, and partially replacing activated sludge or aerated pond). Loading rates have been reviewed and discussed, as well design arrangements and alternative media / packing for the trickling filter.

A number of potential shortcomings have been identified and discussed, including:

- Inability to achieve nitrogen reduction
- Odour generation
- Filter flies
- Clogging and ponding of filter media
- Blocking of distributor nozzles.

However, there are means to overcome these, and appropriate design of the system is required to provide optimal performance.

Given this, there are considered to be a number of opportunities for research and development for the red meat industry, and recommendations for pilot plant work include undertaking an assessment of:

- Greases / pre-treatment requirements
- Organic loading and requirements for nitrification
- Irrigation rate
- Appropriate recirculation
- Odour generation particularly where located downstream of anaerobic ponds

- Effluent Quality – achieving appropriate quality of treated water
- Costs / Benefits – energy efficiency, cost of media, savings for energy, operations, etc.

Overall, the TF process is potentially suited to the red meat industry for treatment of wastewater. However, there will be a need for good pre-treatment to remove the bulk of grease (nominally < 150 mg/L) and all floatables. Pre-treatment might include DAF or an anaerobic system, however, care will be required to avoid odours from the latter.

The key advantage of the TF process is a significant reduction in energy requirements compared to activated sludge systems. If high BOD or TN reductions are required, a combined TF-AS system could be adopted.

1. Introduction

1.1 Project Background

This project is to evaluate the potential for application of alternative treatment systems – trickling filters – for meat processing wastewater. Trickling filter technology potentially presents a simple, reliable, low-cost and biological means to remove organic waste from abattoir wastewater.

Abattoir wastewater is typically high in organic matter and nutrients. Consequently biological treatment of the wastewater is required to achieve environmental discharge standards. A typical treatment system for abattoirs involves Dissolved Air Flotation (DAF), anaerobic system (long detention time but minimal operating costs) followed by activated sludge process (relatively short detention time, but high power cost system) to provide suitable effluent quality. The two key shortcomings of this type of treatment system involves spatial footprint and high power costs. As a result, abattoir operators wish to evaluate alternative methods to remove organic matter from wastewater in an economically viable and environmentally responsible manner.

1.2 Objectives

The objective of this project will be to identify viable application of the technology, suppliers, shortcomings and opportunities for research and development for the industry. Recommendations will be made on potential adoption / application, development, investment and potential delivery.

1.3 Workscope and Basis

In today's environmentally conscious approach towards industrial cleaner production, there is a greater focus and emphasis on reducing energy usage and greenhouse gas emissions, although energy costs are also a key driver. The energy usage associated with red meat wastewater is typically associated with aeration and sludge management as a result of treatment. Trickling filters use less energy (some 40 – 60 %) and produce less sludge (approx. 15%) than mechanically aerated systems (Zahid 2007 & Laginestra 1992).

Consequently, a review of this alternative technology is regarded as timely and is evaluated in this report based on literature review and operational experience. A significant aspect will be identification of opportunities to enhance energy efficiency while providing environmentally appropriate treatment.

The basis for achieving the above project objective will include the following:

1. Review technologies and capabilities identifying economic, regulatory, environmental and social benefits and disadvantages of the technology
2. Evaluation of the potential for application of alternative treatment systems – trickling filters – for meat processing wastewater.
3. Providing Abattoir operators and the industry with knowledge of on alternative technology / methods of removing organic matter from wastewater in an economically viable and environmentally responsible manner.
4. Assessment of the technology in terms of treatment performance, sustainability, environmental

capability for the red meat industry.

5. Undertaking a review of an international literature review of tricking filter technology (also known as a biofilter or biological filter) in use in the food processing industry, and its potential application to new and existing waste water treatment systems at abattoirs of varying size, configuration and location.
6. Estimation of costs based on information provided by suppliers as part of the evaluation and comparison with other more traditional processes.
7. Identification of opportunities for application of the technology and assessment of suitability to treat abattoir wastewater.
8. Identification potential for R&D opportunities
9. Presentation of findings to the industry.

1.4 Overview

It has been identified through consultation with AMPC member businesses, that trickling filter technology could present a simple, reliable, low-cost and biological means to remove organic waste from abattoir wastewater. It is used in other industries, although it is uncommon and is rarely adopted these days since activated sludge systems are regarded as more technologically advanced, have a high demonstrated performance, and have the capability to reduce BOD and nitrogen. All of which is accurate, except there are a number of disadvantages with activated sludge variants, including:

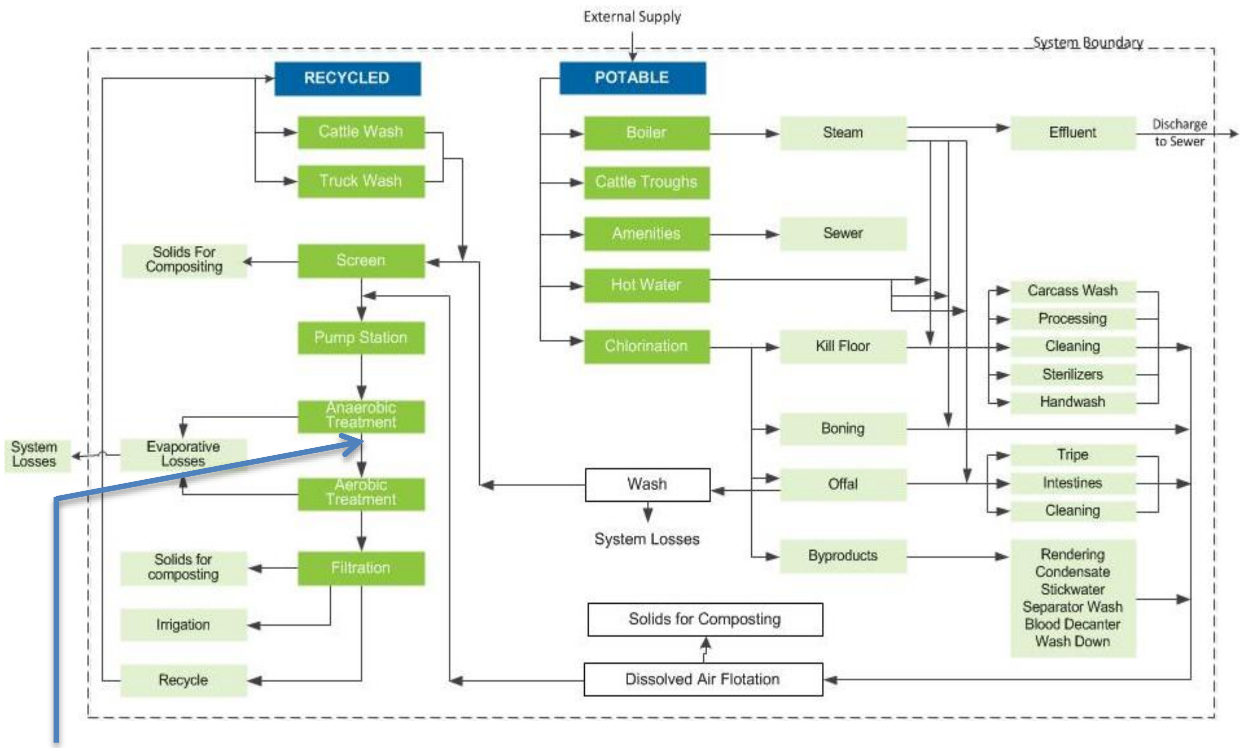
- Complex operational regime (with required understanding of wastage rates, oxygen requirements, microbial biomass concentration etc.). As a result, many systems do not operate satisfactorily
- Inability to recover from shock loading (CIP chemical and periodic high organic loading), which can play havoc with the biomass within the systems, resulting in poor performance and foaming
- High operating costs associated with power for aeration.

Trickling filters do not suffer from any of the above. They involve a single pass system (although recirculation is often employed), with biomass growing on support media, and atmospheric oxygenation provided by the void space between the support media. As such they are extremely simple to operate, with excess biomass simply sloughing off, and collected via settlement, without having to worry about wastage rates to maintain appropriate microbial population. The non-requirement for mechanical aeration is perhaps the greater advantage of the systems, significantly reducing energy costs for the system compared to activated sludge systems. The advent of plastic media (older installations previously installed stone) provides for greater surface area for slimes to grow and thus reduces spatial footprint of the system. However, there are some potential shortcomings which are discussed to provide a balanced consideration for adoption of the technology.

In reviewing wastewater treatment applications, there is no panacea, and a "horses for courses" approach, i.e., based on site specific criteria, that should generally be adopted. There is no doubt that trickling filtration is more environmentally sustainable than activated sludge systems, being a low energy user, involving minimal use of concrete in construction of the reactor, and potential use of recycled material for support media (polyethylene). However, this needs to be balanced against:

- High costs of plastic media
- Potential for more odours (biomass is exposed through a high surface area / air, so if the trickling filter is nearing peak load, there can be odours generated from the tank)
- Need for additional tankage if total nitrogen reduction is required (although trickling filters can achieve significant nitrification, denitrification is necessary to reduce total nitrogen)
- High headloss through the trickling filter bioreactor tank (some 3 -5 metres), which is significantly more than activated sludge systems (typically 0.5 – 1 m). Gravity flow is only possible with a significant slope at the site. So pumping of wastewater is typically required for treatment (although head is comparatively low and energy for pumping is much less than aeration costs for activated sludge systems).

Figures 1 and 2 show diagrams of wastewater generation from an abattoir, and a schematic diagram of a trickling filter system, respectively.



**Position of where trickling filtration could be applied as part of the process arrangement / treatment train*

Figure 1: Process flow diagram of generic abattoir wastewater generation and treatment

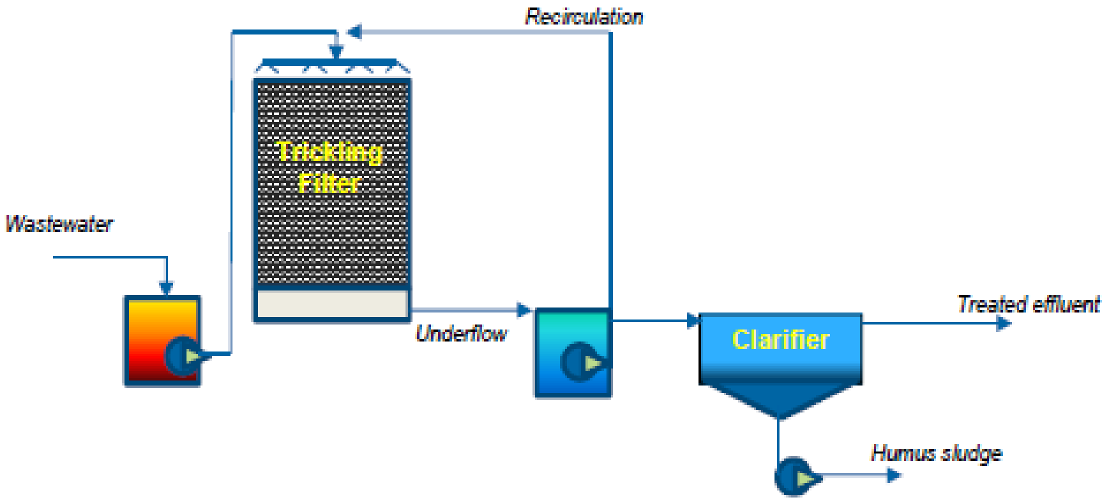


Figure 2: Schematic Flow diagram of Trickling Filter Process

Figure 3 indicates a generic arrangement of the trickling filter (bioreactor) unit, indicating feed and underflow components.

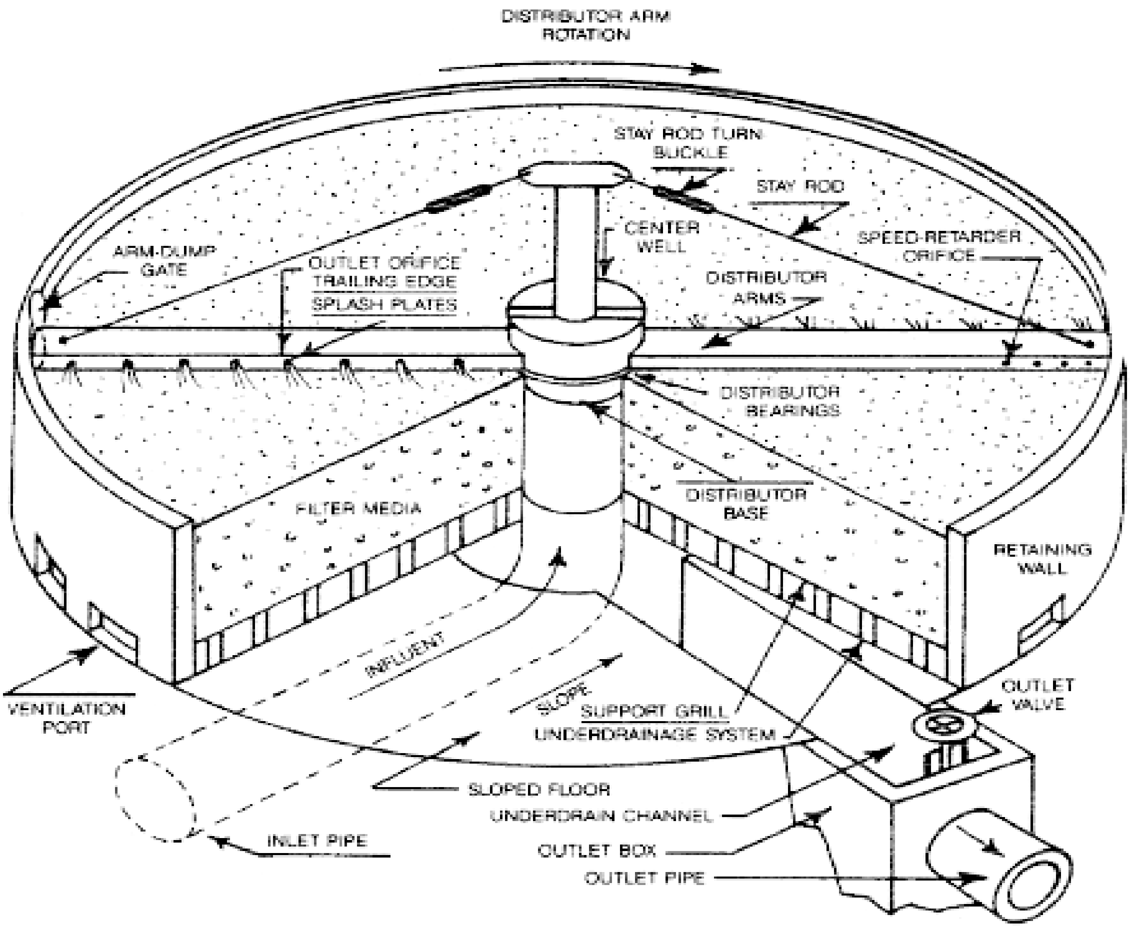


Figure 3: Trickling Filter Design Arrangement (WEF, 2007)

2. Treatment of Abattoir Wastewater

2.1 Characterisation of Wastewater

Wang et al (2006) note that wastewater from abattoirs are typically loaded with solids, floatable matter (fat), blood, manure and a variety of organic compounds (which stems from proteins). Contamination of the wastewater stems from lairage, slaughter, hide / hair removal, paunch handling, carcass washing, rendering and clean-up. These contain a variety of readily biodegradable organic compounds (mainly fats and proteins, present in particulate and dissolved forms). Strength of wastewater depends on plant control of water usage, by-products recovery, and waste source separation. Typical concentration of red meat processing wastewater is contained in Table 1, and is important in consideration for development of a suitable treatment process.

Table 1: Wastewater Characterisation for Red Meat Processing Wastewater

Parameter	General Value	Range
BOD, mg/L	2,500	450 - 5,000 mg/L
COD, mg/L	5,000	1,300 - 13,000 mg/L
TSS, mg/L	4,000	500 - 8,000 mg/L
Total Oil/Grease, mg/L	1,250	100 - 2,500 mg/L
TKN, mg/L	250	100 - 600 mg/L
Total Phosphorus, mg/L	60	10 - 100 mg/L
pH.	7.3	6.0 - 9.0

Wang et al (2006), Laginestra (2012) Jensen & Batstone (2014)

The key focus, currently, on environmental disposal of abattoir wastewater is reduction of biological oxygen demand (BOD), nitrogen and oil / grease concentration (Lemaire et al 2009).

2.2 Typical Treatment Train

Wang et al (2006, 2010) and Johns (1995) note that treatment of abattoir wastewater typically involves:

- Primary treatment – for solids and grease removal (typically involving DAF), and screening;
- Secondary treatment to reduce the bulk of the BOD comprising:
  - Anaerobic digestion (lagoons are most common in USA and Australia, but constructed reactors have also been used, although mainly in Europe)
  - Aerobic treatment downstream of anaerobic lagoons – either biological (trickling) filters, activated sludge, waste stabilisation ponds or aerated lagoons.

Anaerobic systems are considered to be well suited to slaughterhouse wastewater (Johns 1995, EPA 2004) achieving high BOD reduction (and also grease) at low cost, and generating less sludge and providing flow equalization. The ability to use the generated biogas is also an advantage. In Australia, many abattoirs treat wastewater via anaerobic ponds as a first stage.

Downstream of anaerobic ponds, aerobic systems are appropriate to enable environmental discharge and control odours. In most countries ponds remain the most common form of aerobic treatment (Johns 1995) for removal of chemical oxygen demand (COD) from wastewater. However, a wide array of mechanical systems, including activated sludge systems (more common) and trickling filters have been used (Arvanitoyannis & Ladas 2008, Johns 1995).

2.3 Treatment

2.3.1 General

Environmental factors are paramount in developing a strategy for wastewater management at any facility. Kincannon & Sherrard (1976) and Banks & Wang (2004) note that selection of a treatment process, involves determination of desired objectives, with factors including:

- concentration of effluent BOD
- whether nitrification is required
- incidence of shock loading
- land area availability
- known difficulties associated with certain wastewater types (such as bulking and stable foam formation)
- identification of sludge disposal requirements
- energy efficiency
- economic factors.

2.3.2 Anaerobic Treatment

Anaerobic lagoons/ponds are used to treat a variety of wastewaters around Australia. The main advantage of lagoon systems is their simplicity to build and operate, although their non-mechanical aspect means a greater volume (and subsequently area / footprint) is required to treat wastewater than conventional (mechanical) treatment systems. Anaerobic lagoons are designed to cater for high organic loading, and are typically absent of DO producing biogas. This type of system would be appropriate upstream of aerobic treatment and are commonly applied for red meat processing wastewater. Constructed above ground in-vessel anaerobic digesters are also suitable although there are no known systems employed in the red meat industry in Australia (although Berrybank piggery, Victoria, has such a system).

2.3.3 Aerobic Treatment

Aerobic treatment is typically adopted to further reduce BOD (after anaerobic processes) and to reduce nitrogen (additional role). Banks & Wang (2004) report that the most common aerobic biological processes used for the treatment of meat industry wastes are biological filtration, activated sludge plants, waste stabilization ponds, and aerated lagoons. The activated sludge system is the most commonly used aerobic system in the US (EPA 2004). Johns (1995) notes that the activated sludge system is most widely used to achieve BOD reduction and nitrification. Nitrogen removal from wastewater is typically achieved via nitrification / denitrification as part of an activated sludge system (although other processes may be incorporated to enhance nutrient reduction, such as Anammox and struvite precipitation).

It is important to realize that the energy costs of conventional aerobic biological treatment (activated sludge systems) can be substantial due to the requirement to supply air to the process (Wang et al 2006). In addition there are a range of operational issues which have been found with activated sludge systems including:

- treatment interference from fats (presumably if pre-treatment is poor) Johns (1995)
- low aeration (leading to sub-optimal biomass, and proliferation of filamentous organisms, which impairs settleability)
- bulking and stable foam formation
- excess biomass production (EPA 2004)
- inability to settle solids in the clarifier (presumably industrial effluent variability) (Arvanitoyannis & Ladas 2008).

Kincannon & Sherrard (1976) noted that the trickling filter process has lower operating costs and manpower requirements (due to simplicity), making it attractive as an alternative to activated sludge process. However, high strength wastewater may limit mass transfer reactions and 2 – 3 stage is necessary, and requiring primary treatment for removal of settleable solids, greases and reduce organic load and prevent plugging. Consequently, appropriate design is key in minimizing problems for application of the technology.

On the other hand, Kincannon & Sherrard (1976) note that many problems associated with operating activated sludge systems are direct relationships of the skill of the operator (difficulty in maintaining operational control, particularly with capability of influent) and a skilled operator is required. Metcalf & Eddy (1991) note that factors affecting the activated sludge process include:

- Reactor type and hydraulic detention time
- Hydraulic and organic loading
- Aeration capacity
- Mean cell residence time (or sludge age)
- Food / micro-organism ratio (F/M)

- Return sludge recirculation rate
- Nutrients
- Environmental factors.

In contrast, factors affecting the performance of the trickling filter process include:

- Media type and depth
- Hydraulic and organic loading
- Ventilation
- Recirculation rate
- Flow distribution.

Based on the above it can be seen that most factors associated with trickling filtration are related to design whereas most factors for the activated sludge process might be regarded as operational. This perhaps demonstrates the greater need for operational control of the latter which becomes an issue through increased complexity and hence reliability.

Whereas trickling filtration is the original treatment system, in reality trickling filters have not been considered for any municipal upgrades for many years. The activated sludge process has overshadowed trickling filtration, generally on the basis of enhanced effluent quality and operational control aspects. It should however be noted that trickling filtration process has a very low energy usage, regarded as marginally above lagoons. However, pre-treatment is generally regarded as critical for trickling filter systems (more so than activated sludge) since screenings and coarse solids can block the distribution system.

Further discussion of activated sludge versus trickling filter is undertaken below, after a description of the trickling filter process.

3. Trickling Filtration

3.1 General

The application of fixed film systems for high strength industrial wastewater (such as red meat) has been somewhat limited. However, downstream of primary and anaerobic treatment, it is likely to be most feasible.

Global Water Research Coalition [GWRC] (2011) note that biological filters (TFs) are regarded as the lowest energy usage of any secondary processes in hierarchy of wastewater treatment processes (potential energy efficiency).

While the trickling filter process has very low energy requirements, where pollution and standards demand higher effluent quality (due to site locality / discharge criteria), activated sludge process or their derivatives will be appropriate. In some industrial and municipal cases there are both trickling filters and activated sludge systems on the same site (including Bundaberg, Burwood Beach, Cessnock, Lithgow, Rosny, Liverpool, Bowral, Milton municipal plants, although some trickling filters are believed to have been decommissioned, and industrial plants at Te Aroha poultry processing and Huntingwood soft drink manufacturing).

This section details the following aspects of trickling filtration:

- General description
- Design factors, such as media type, recirculation, etc.
- Comparison of trickling filter technology with the activated sludge process.

3.2 Description

A trickling filter is made up of a vessel (not water retaining) containing inert media which support microbiological growth to degrade wastewater organic material. This is termed an aerobic attached or fixed-film bioreactor typically relying on natural air flow for oxygen supply (unlike activated sludge, which is suspended growth system relying in mechanical aeration). Original trickling filters used rocks as the support media for the fixed-film of biological slime. Current industrial trickling filters, use engineered plastic packing with high surface area/volume ratios with high void volumes, to avoid blockages and to achieve high loading rates. All trickling filters comprise a vessel, packed with the inert media. Wastewater is distributed over the top of the media and trickles downwards as a thin film across the surface of the packing, where oxygen and soluble organics diffuse through the slime layer and are utilised by the biomass to produce waste products (CO_2, H_2S and new bacterial cells). A biological slime layer grows on the media and treatment is provided by the microbes which absorb and use dissolved organic matter for their growth and reproduction as the wastewater cascades randomly through the voids between the media. The complex population of microorganisms is predominately aerobic. Thickness of the biological layer increases (and is a function of hydraulic as well as organic loading), until the outer layer absorbs all organic matter and causes the inner layer to enter an endogenous growth (whereby food is provided by the microbial cell protoplasm rather than external sources) and lose its ability to cling to the media, sloughing off. The "sloughed" material is carried out with the effluent as suspended solids. Consequently, effluents from trickling filters usually require secondary settlers, often called “humus” tanks (reflecting the type of sludge generated).

Air flows upwards, through the voids in the packing, created by the chimney effect of the filter vessel. Circulation of air can be enhanced by forced ventilation consisting of fans, although most TFs rely on natural ventilation to supply oxygen for the aerobic treatment (WEF, 2007).

The retention time in a trickling filter is a function of the specific surface area of the packing (which indicates area of the packing available for growth, per unit volume of packing (m^2/m^3), the gross filter volume (m^3) and flow rate (m^3/d). WEF (2007) states that the trickling filter system comprises:

- Distribution system – fixed nozzle or rotary distributor (former have declined because of difficulty to access and clean). Rotary distributor comprises centre well mounted on distribution plate or pier. The distributor has 2 or 4 arms that carry the wastewater to varying sized orifices for distribution over the media surface. The thrust of the water spray drives the filter arms. Speed retarding back spray nozzles are often used to adjust speed of rotation. Some TFs also have motorised units to control speed, and thereby distribution.
- Filter media – typically plastic. A number of studies indicate cross flow media may offer better flow distribution at lower loading. Vertical media provides good distribution and prevents plugging at high organic loadings.
- Underdrain system – for rock media, consists of precast blocks laid over the sloping floor. For plastic – consists of network of concrete piers and supports placed with centres (0.3 – 0.6 m apart, and 0.3 – 0.6 m high) to enable air movement. Floor slopes to central collection trough which also enable air movement to the centre of the TF.
- Containment structure (not water retaining) – concrete for rock media, whereas filter towers, for lightweight plastic media are typically precast concrete, fibreglass, or other materials. Ventilation ports are required at the base. Structure sides are typically 1.0 – 1.5 m above filter media, to minimise splashing and other structures may need a structural base to support covering.
- Filter feed pump or dosing siphon is a key part of the TF. A pump station lifts wastewater and recirculated effluent to the top of the media. Sometimes a siphon dosing tank or gravity flow feeds the distributor. Trickling filter is typically elevated so hydraulic grade allows gravity flow to the secondary clarifier or downstream units.
- Secondary clarifiers – typically side water depth of 2.4 – 3.0 m deep (deeper with low rate filters, up to 3.7 m).

WEF (2007) notes that process control variables for trickling filters include:

- Flow patterns (recirculation, operation in series or parallel)
- Distribution rates – recirculation can serve to dilute strength of wastewater, increase hydraulic loading rate (reduce flies, snails, other nuisance) and maintain distributor movement / wetting

during low flows), produce hydraulic shear (to increase sloughing), dilute toxins and prevent drying out

- Clarifier operation – can impact on TF performance (although not as critical as activated sludge systems). Sludge should be removed quickly before gasification or denitrification occurs with resultant rising solids.

3.3 Trickling Filter Media

Media for trickling filters were historically rock, and key criteria are specific surface area (microbial support area per unit volume) and percentage void space. Organic loading is directly related to the specific surface area available to treat the wastes. Plastic media, e.g. hollow ring arrangements and modular plastics, were developed over 20 years ago for use in trickling filter biological treatment processes has largely replaced rock. These media provide a large surface area for microbial growth, coupled with an extremely high voidage within the bed [greater than 90% compared to about 40% for stone filters (University of Texas, 1971)]. This allows greater biomass growth, increased hydraulic loading and enhanced oxygen transfer (Corbitt, 1999), and so much deeper beds can be built (up to 10 m, but typically 5-7 mm, compared to 2 m for stone trickling filters), and less land area is therefore required. Studies have shown that 3 times the hydraulic load could be applied to plastic media filters (with media of 3 times the surface area) compared to stone media filters of the same dimensions, to produce similar quality effluents (Hemming & Wheatley, 1979). Comparison of media is shown in Table 2.

Table 2: Trickling Filter Media Characteristics

Media	Nominal size (cm)	Specific surface area (m^2/m^3)	Void space %
Rock (granite)	2.5 - 10	43 - 69	35 - 50
Redwood (slats) stacked	19 x 19 x 0.8	46	76
Random media, polypropylene	20 cm diameter	90 – 280	
(nitrification 130)	90 - 95 %	48 - 95 kg/m3	
Plastic moulded blocks (cross flow) PVC	24 x 24 x 48 to 60 x 60 x 120	75 - 115	94 - 97
Plastic tubular		217	

(Corbitt 1999, Daigger et al 2011, Laginestra 1992, Logan et al 1987, WEF 2007)

Photographs of type of plastic media available include random and various flow module types and are shown in Figure 4.

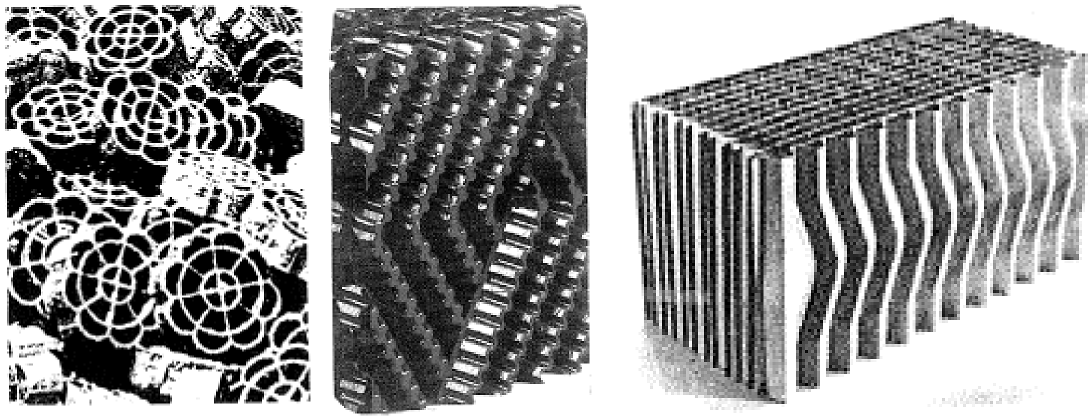


Figure 4: Trickling Filter Random Media, Crossflow and Vertical Media (Laginestra, 1992)

3.4 Construction

In the past, capital costs for trickling filter systems and activated sludge plants have typically favoured the latter. Stone media filters required concrete structures to retain the weight of the rocks. However, with the advent of plastic media and innovative construction for the trickling filters (you don't need a water retaining structure) only light weight construction walls are required, as shown in Figure 5. These include:

- Pre-cast concrete panels
- Fibreglass panels
- Other materials.

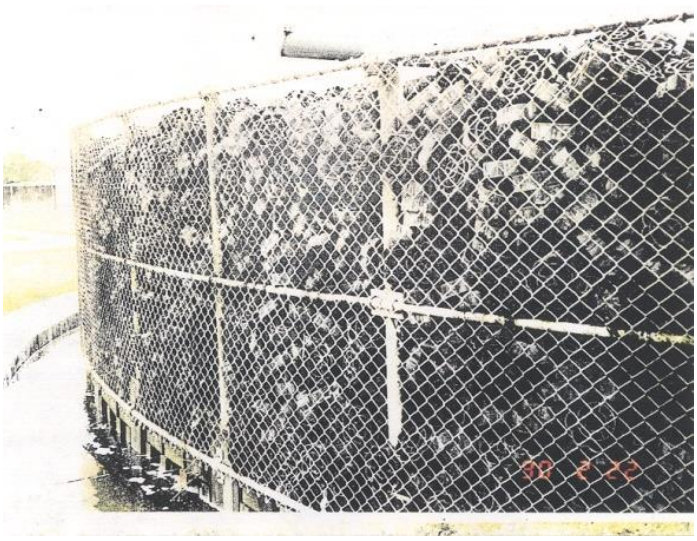


Figure 5: Mesh construction of modern plastic media TF

3.5 Recirculation

While there are a number of once-through flow systems for trickling filters, recirculation is commonly practiced with industrial wastewater. Recirculation is a process in which the clarified filter effluent is recycled and recycling of filter effluent increases the contact time with the biological film and helps to seed the lower portions of the filter with active organisms.

This is where part of the underflow from the trickling filter is brought into contact with the biological film more than once to improve wetting and flushing of the filter medium (EPA 2000, Canter 2010). Close to continuous flow to the trickling filter media is required to provide food for biomass and prevent drying out of the attached growth. This is especially important for higher rated systems using plastic media. The minimum recommended irrigation rate is 30 – 60 m^3/m^2.d (Corbitt, 1999). Recycling may be practices only during periods of low flow to keep rotary distributors in motion, to prevent drying of the filter growths.

Observation has shown that the thickness of the biological growth is directly related to the organic strength of the wastewater (the higher BOD, the thicker the layers of organisms). With the use of recirculation, the strength of wastewater applied to the filter can be diluted, thus preventing excessive build-up (Canter, 2010). Due to high strength of meat wastewater, TFs operate better with effluent recirculation. This effectively increases surface hydraulic loading without increasing the organic loading. It also provides greater control over microbial thickness. French guidelines typically use a recirculation rate of 3 – 4 (Wang et al, 2006).

3.6 Air Access / Circulation

It is essential that sufficient air is available for the successful operation of the TF. Typically, natural draft and wind forces are usually sufficient if large enough ventilation ports are provided at the bottom of the filter and the medium has enough void area (EPA, 2000). Although additional studies have indicated that forced draft blowers can improve efficiency by circulating fixed air volumetric rate through the media.

Air circulation will affect the height of the trickling filter, so with stone media (where voidage is low), height of the TF is restricted to about 2 m. With plastic media filters (high voidage), height can theoretically be up to 10 m (but at this height, forced draught is required to reliably provide the oxygen through the depth of the packing). The reported limit of height for natural draft is around 6 m.

3.7 Broad Design

3.7.1 Pre-Treatment

Trickling filters require primary treatment for removal of settleable solids and oil / grease to prevent accumulation and / or excessive growth which can lead to system blockage (Wang et al, 2006). Effluent quality of trickling filters is typically a function of influent quality. For this reason, for high-strength industrial wastewaters, recycle of effluent is usually practiced. However, DAF and anaerobic digestion may be appropriate for TFs to remove excessive solids and fats.

3.7.2 TF Criteria

Design criteria for TFs is summarised in Table 3:

Table 3: Design Aspects of the Trickling Filter Process (Corbitt 1999, Logan et al 1987, EPA 2000)

Design Feature	Unit Criteria	Comments
Diameter	6 – 65 m diameter	Plastic media TFs are usually less than 30 m
Depth	1.5 – 2.5 m depth (rock media), 4 – 12 m for artificial media	
Tip speed of distributor arms	< 1.2 m/s (peak)	
Height of distributor arm above media	0.15 – 0.3 m	
Ventilation / airflow	Natural 0.03 m^3/m^2/min Forced draught 0.3 m^3/m^2.min	Typically achieved through design of underdrainage system Deep (plastic media)filters
Organic loading rate	0.08 – 0.1 kg BOD/m^3.d (rock media) 0.4 – 1.6 kg BOD/m^3.d (plastic media high rate) 2 – 4 kg BOD/m^3.d Very high rate / roughing filters)	Refer Table 4 for different TF modes
Hydraulic loading	1 – 4 m^3/m^2.d (low rate) 8 – 40 m^3/m^2.d (high rate)	
Recirculation	High rate TFs = 0.5 – 4	Rarely used on low rate filters
BOD removal (with clarification)	80 – 90 % (low rate filters); 65 – 85 %(high rate)	Nitrification can be achieved on low rate filters Temperature can be a factor if wastewater temperature drops below 15 ^oC
Clarifier surface overflow rate	40 m^3/m^2.d (low rate) 32 m^3/m^2.d (high rate)	

3.7.3 Loading Rates

There are two key criteria for trickling filters:

- Organic loading rate – for plastic media it is typically 1- 2 kg BOD/m^3.d and it is possible to achieve well over 80 – 90 % BOD reduction. Even higher loads (up to about 4 kg BOD/m^3.d) are possible but above 2 kg BOD/m^3.d is more of an odour risk (and forced ventilation may be required if the filters are higher than about 4 – 5 m depth)
- Irrigation rate (volume per surface area) – because of more open packing, media can dry out faster, so it needs to be wetted at a higher irrigation rate (and may require some recirculation) – 10 m^3/m^2.d (minimum).

The loading rate defines the type of TF. Low loading rates are usually used where TF is the main biological treatment system and effluent quality is required to be high, and may incorporate nitrification (removal of ammonia). Organic loading will impact on nitrification ability, since heterotrophs grow faster than nitrifiers. Hydraulic loading is also a factor, and recirculation is advantageous since reduction of influent BOD makes nitrifiers more competitive, and thereby increases efficiency. Temperature, DO, pH also impact on nitrification ability. EPA (2000) also notes that predation (by fly larvae, worms, snails) decrease the nitrifying ability. Two stage TF treatment involves first stage TF for carbon oxidation and second stage providing nitrification.

The different loading rates for alternative operational modes of trickling filters are outlined in Table 4.

High rate filters refer to plastic media, but usually only BOD reduction is required without nitrification. Very high rate TFs are often designed for loadings up to 3.2 - 4.8 kg BOD / m^3.d before concern over dissolved DO in the underflow eventuate. However some TFs involve design < 2.4 kg BOD/ m^3.d to mitigate odour issues.

Roughing filters are sometimes used as a preliminary stage prior to activated sludge (often stone media filters which are existing) and are used to reduce BOD load on the next stage. It should be noted that loading for stone media TFs is typically less than 0.09 kg BOD/m^3.d to ensure adequate DO and low odour potential (WEF 2007).

An additional description of trickling filtration as an intermediate stage is outlined in Section 7.

Table 4: Trickling Filter Operating Modes (EPA 2000, Wang et al 2006, WEF 2007)

Filter type	Loading	BOD removal performance (%)	Comments
Low rate	BOD < 0.40 kg / m^3.d Wetting > 0.4 L/m^2.s (plastic), [0.001 – 0.002 m3/m^2.d], down to 0.1 L/m^2.s for rock	80 – 95 Achieves nitrification	Fewer issues with flies, odours, plugging
Intermediate	BOD 0.4 - 0.64 kg / m^3.d	60 – 90	Filter to be recirculated. Solids not as well digested
High rate	BOD 0.64 – 1.6 kg / m^3.d Hydraulic 0.003 – 0.013 m^3/m^2.d	65 - 90	Likely to be for second stage process (combined process more typical)
Roughing	BOD 1.6 – 4.8 kg / m^3.d	50 - 65	Allow significant soluble BOD to bleed through to next stage

3.8 Activated Sludge versus Trickling Filters

Amenu (2014) notes that while activated sludge is the most widely used biological treatment system for most wastewaters around the world, key drawbacks are the sludge bulking, excess sludge production and demanding operations and maintenance requirements.

Advantages of TFs are the low energy usage compared to activated sludge, but there is a disadvantage with low loading rate TFs making the plant larger and resultant higher capital cost (Wang et al, 2006). However, there are other advantages around reduced complexity and sludge handling.

Fixed film systems are less susceptible to toxicity and shock loads than activated sludge systems. However, TFs are more sensitive than suspended growth to temperature drop and typically to cater for cold temperature climates, TFs are oversized for winter. TFs have traditionally taken up more land. With the high rate plastic media TF process, this is no longer the case. Because of the high concentration of biomass attached to the media surface area, the reactors can handle higher loads per unit volume than activated sludge (Laginestra, 1992).

Effluent quality is not regarded to be equal to that of the conventional activated sludge process (Laginestra, 1992), however, TF is regarded as providing a very good effluent quality and the process is capable of significant removal of pollutants (including COD, ammonia-nitrogen, oil and grease).

A broad comparison of features comparing activated sludge with trickling filtration is contained in Table 5. The comparison is necessarily subjective as there are too many variables associated with site specificity to enable quantification. However, an attempt has been made to provide some broad ranges based on general experience. Zahid (2007) looked at comparison of trickling filtration versus activated sludge plants for treatment of municipal sewage. It was found that TFs cost around 12 % less in terms of capital cost and about 50 % less in terms of operations and maintenance costs than activated sludge plants. While this is municipal treatment, it would be expected to be somewhat similar for industrial applications dependent on the extent of nitrogen removal requirements.

Table 5: Comparison of activated sludge and trickling filter processes (Bliss 1983, Ch. 4-5; Metcalf & Eddy 1991; Amenu 2014; Moodie 1979; EPA 2008)

Factor	Activated Sludge	Trickling Filter
Capital Cost	Lower	Higher (10 – 25 %)
Operating Cost (power)	High	Lower (40 – 60 %)
Land Area	Low	Higher (5 – 10 %)
Process Control	Complex	Simple
Climatic Problems	Problems during dry months	Best at high ambient temperatures
Ability to Treat Industrial Wastewater	Prone to failure (largely due to variability)	Good
Operational aspects	Better flexibility	Better reliability
Effluent Quality	Better (5 – 15 %)	Good (prone to high suspended solids)
Fly / Odour Nuisance	Generally little	Can be high
Head Loss	Low (0.3 m)	High (2 – 5 m)
Mechanical Equipment Requirement	High (aeration system, return & waste sludge pumps)	Low (delivery / recirculation pumps, distributor arm)
Sludge Handling Requirement	High	Lower (20 – 40 % less volume)
Ability to nitrify / denitrify	Yes	Generally nitrifies only
Ability to Handle:		
High Hydraulic Loads	Poor	Good
High Organic Loads	Poor	Good

4. Potential Trickling Filter Issues

4.1 General

Moodie (1979) reports that trickling filtration has been successfully used for treatment of wastes from abattoirs, dairy processing and fruit and vegetable processing. After the fats and greases are removed, wastewater can be distributed to the media.

Kincannon & Sherrard (1976) note that improperly designed trickling filters can have a number of issues, including:

- Failure to achieve required organic / nitrogen reduction
- Odour generation
- Filter flies
- Clogging and ponding of filter media
- Clogging of distributor nozzles
- Media collapse.

WEF (2007) identified common problems may result from increased growth, change in wastewater characteristics, equipment failures. These may result in odours, ponding, flies, and / or an increase in effluent suspended solids (SS) or BOD. It is however noted that for low rate filters loadings less than 0.4 kg BOD/m^3.d there are likely to be fewer problems with flies, odours or plugging (WEF, 2007).

On a general note, for treatment by trickling filtration, it is considered that there are risks of:

- excess BOD / COD, leading to development of anaerobic conditions in the TF, and resultant odours
- Fat and grease build up, which may increase within the TF (with cooling) if not previously removed. Again this will lead to odour generation.

Application of trickling filtration after an anaerobic lagoon might be suitable, (since BOD and fats have been reduced). However, presence of solids, ammonia and dissolved sulphides may result in blocking and stripping of odours respectively. Effective design will be required to ensure the use of the technology is employed appropriately.

4.2 Odour

Excessive organic loading, causing anaerobic decomposition in the trickling filter or inadequate ventilation may cause odours (and increased recycle or cleaning out may be required). Inadequate ventilation may also lead to odours, and appropriate air circulation below the media and access to within the TF structure is required, as illustrated in Figure 6.

Figure 6: Underdrain support deck of trickling filter (space above floor of drainage collection slab should be about 0.4 – 0.5 m)

Heavy organic loadings can produce heavy accumulations of solids in filter or cause ponding, which will also generate odours. There will be a need to reduce organic load and / or increase hydraulic recirculation to flush (EPA, 2000). In the worst case, if the filter is highly loaded and likely to cause a nuisance, then covering and deodorising the off gases will be required, however air ventilation through the media must be retained (Cantor, 2010).

4.3 Filter Flies

Canter (2010) reports that due to the increased flow rate per unit of area, higher velocities through the TF occur which tend to cause more continuous and uniform sloughing of excess growth. Ponding and restriction of ventilation are potential issues which increase the opportunity for snail and filter fly breeding. Filter Flies (Psychoda) are typically caused by inadequate moisture in the TF. Increase hydraulic loading / wetting may be enough to mitigate this problem (EPA 2000, Harrison & Daigger 1987). Distributor arm slowing or stopping from low flow or clogged orifices, or arms not level can also create fly (and other) issue(s). As a general rule, flies exist within and around the filter, however, because of the micro-climate (moist conditions) cannot survive at substantial distances away from the filter and typically travel no further than 1 - 2 m away from the structure.

There was a case in the Blue Mountains, west of Sydney, where a bowling club was very close to the sewage treatment plant, and became infested with filter flies when the wind blew in the wrong direction. However, this was prevented by installation of a mesh (shade-cloth material) around the perimeter of the trickling filter for a height of some 1.5 m.

4.4 Inflow Blockages

Inflow to trickling filters must be largely free of solids to avoid blockages of the distribution arm nozzles. Consequently, fine screening (nominally 10 mm or smaller) is typically employed upstream of the trickling filter.

Figure 7 shows a TF at a sewage treatment plant in South Australia, which does not use screens. As a result, the filter arm distributor nozzles frequently become blocked and the media becomes dried out, leading to reduced performance.

There are also alternative feed arrangements, which do not use nozzles (spill over gutter arrangement), but typically these would require mechanical drives, and screenings could still block the media and would require cleaning off. It is considered far simpler to use fine screens to remove the coarse solids before application to the TF.

Figure 7: Blockage of distribution arm ports can lead to poor feed and drying out

4.5 Media Clogging and Drying Out

Corbitt (1999) notes that for high rate and roughing filters, increased hydraulic loading is required to flush the sloughed material through the filter and avoid anaerobic conditions as a result of filter clogging. Realistically clogging is only likely for rock media filters and / or where screening is not applied as part of pre-treatment phase.

Operating characteristics of the TF may include proper wetting of media (associated with inflow distribution). Different media types have different requirements (Harrison & Daigger, 1987). Inadequate moisture may be caused by distributor arm slowing or stopping (because of low flow or clogged orifices). Irrigation rate (volume per surface area) for plastic media is high since it dry out faster (void space, and required support for greater biomass) and may require some recirculation.

4.6 Poor performance

WEF (2007) report that low dissolved oxygen (DO), load variations or nutrient deficiencies and / or low pH, can result in proliferation of poor settling organisms such as filamentous bacteria and fungi, which are nuisance, and don't settle in the clarifier.

Fixed film reactors vary in their ability to absorb seasonal and shock industrial wastewater loads. Extremes may cause a bleed through of BOD or severe sloughing of the biomass (die off). Recycled TF effluent is often used to dilute incoming raw waste and dissolved oxygen. Using recirculation, treatment of wastewater of BOD concentrations > 10,000 mg/L is reportedly possible.

5. Abattoir Trickling Filter Applications – Literature Review

5.1 General

While the trickling filter (TF) process is widely adopted in US (particularly in development of combined systems), no reports of abattoir installations could be found. In contrast, there are many reported TF installations for abattoirs in Europe, based on low space requirements and energy requirements. The concept of using TFs to nitrify ammonia in wastewater is documented by a number for plants, no application to abattoir or rendering plant was noted.

In Europe high rate roughing TFs have been successfully used to treat raw abattoir wastewater (favoured over anaerobic ponds). They achieve 60 – 75% BOD removal at loadings up to 8 kg BOD/m^3.d. In the US and Australia, anaerobic lagoons followed by aerobic lagoons or activated sludge have been preferred. Most nutrient removal (Europe) is achieved via activated sludge systems, although little has been undertaken on denitrification. A German rendering plant has used TF as roughing upstream of a BNR system for many years. Similarly there have been several successful plants reported in UK since 1970's, with BOD reduction > 75 % at loadings of 3 – 8 kg BOD /m^3.d. However good fat removal is required to prevent coating surfaces of the unit (Johns, 1993).

TFs are not typically adopted for treatment of abattoir waste, despite lower operating costs. Achievement of low BOD effluent and nitrification can provide ideal conditions for proliferation of fly larvae (which may be unacceptable in vicinity of the slaughterhouse). Also very high fat removal is required (which otherwise would coat the media) (Banks & Wang 2004, Wang et al 2006).

This section considers case studies from journals and supplier information.

5.2 Cases

Banks and Wang (2004) noted some 9 TF cases (8 of which were plastic media) with various loading rates 1.2 – 8.1 kg BOD / m^3.d with BOD removal rate ranging from 60 – 85 %.

Amenu (2014) reports that TFs have successfully been used as a roughing system to achieve preliminary removal of BOD from rendering plant and slaughterhouse wastewater (2 different applications), prior to further treatment.

Johns (1995) states that high-rate TFs have been successfully used as roughing filters (Europe) to achieve preliminary BOD reduction (rendering and slaughterhouse wastewaters). Key advantages are their low space and energy requirements. Good fat removal is required to prevent coating of surfaces of the TF media. It was also noted that this technology has not been widely adopted by US or Australian slaughterhouses, although its suitability has been demonstrated. Nutrient removal plants, based on AS BNR system have been developed where nitrogen reduction is required. No nitrifying TF systems for slaughterhouses have been reported. The major issue is reportedly lack of denitrification capability. However a number of nitrifying and denitrifying filters have been developed since the 1990's.

Azad (1976) reported that some experience with meat wastes with TFs proved "unsatisfactory". However, this remark related to stone media, and only limited pre-treatment was used. It was node that high protein content of the wastewater led to heavy biological growth resulting in clogging. The advent of plastic media has undoubtedly reduced tendency to clog. In addition, Azad reports that that there are successful TF systems (presumably with appropriate pre-treatment) that achieve very good BOD and grease reduction, including a "combined system" (not specified whether this is activated sludge or anaerobic system) with a two stage TF which provide nitrification.

Moodie and Greenfield (1978) reported the high rate (plastic media) TF process installed at 3 Australian abattoirs (not named). TFs were noted to be particularly suitable for partial or roughing process due to operational simplicity, low operating costs and resistance to shock loads. A pilot plant set up (Brisbane at an abattoir) 3.7 m high, area of 0.74 m^2. Inflow involved primary treatment (to remove solids and fats). Nutrients in the wastewater (like most abattoir wastes) were above requirements for biological degradation. It was noted that 50 % of COD was insoluble, so clarification is important. It was reported that recycle does not necessarily improve the efficiency of the filter, but may be necessary to maintain good liquid distribution over the filter during low inflow.

Li et al (1984) undertook a study of a two stage biofiltration tower (series operation, each TF 2.4 m high and media surface area 98 m^2/m^3, voidage of 98%) for treating meat wastewater. A pilot plant was set up, with inflow wastewater generated after DAF unit (including coagulation) to remove oil / grease and floatable solids.

Organic loading rates were varied between 10 – 40 m^3/m^2.d. It was found that:

- Pilot DAF system only removed some 40 – 50% of oil and grease (effluent still some 250 mg/L)
- Removal efficiency increased with lower hydraulic loading rate
- Optimal organic loading rate was found to be 1.75 kg/m^3.d
- Some 70 – 85 % BOD removal over wide range of loading rates was achieved
- Increased tower height was found to be beneficial (better effluent concentration) – associated with increasing DO profile through tower
- No conclusions on oil / grease reduction / impact on tower performance were made (reference to oil / grease to be below 75 mg/L for influent)
- Nitrification achievement was dependent on loading rate (70% achieved at 5 g BOD/m^2.d, while 20 % at 20 g BOD/m^2.d)
- Clarifier overflow rate of 50 m^3/m^2.d was appropriate after high rate loading.

Phillips (1975) reported on upgrade of a municipal plant to cater for new meat processing plant (the industry was some 25 times the organic load of domestic). The process chosen was the proven technology of TFs to handle strong organic wastes without upset. Preliminary treatment consisted of flocculation and primary sedimentation. There is a primary (high-rate filter) followed by two secondary biofilters with intermediate clarification. A high rate of recirculation has overcome problem of low incoming flow. The plant has consistently achieved BOD reduction greater than 95 %, however a strict operations and maintenance regime is on place.

Oleszkiewicz (1981) reported on successful treatment by trickling filtration on piggery wastewaters (which are known to frequently induce AS system bulking).

Tanaka et al (2007) reported on a lab-scale demonstration system which took wastewater from piggery wastewater treatment plant at the Japanese National Institute of Livestock and Grassland Science - reportedly using treatment via a plant consisting of an anaerobic treatment reactor (UASB reactor) and an aerobic treatment reactor (TF). Discharge effluent from the swine wastewater treatment plant was BOD 10 – 335 mg/L, ammonia 20 – 148 mg/L.

The author is aware of a red meat industry application of trickling filtration at an abattoir in Corio (Victoria). It is understood that it is used as a roughing system prior to sewage discharge and it performs satisfactorily.

5.3 Trickling Filter Media and Equipment Supplier Feedback

A number of suppliers were contacted regarding whether they had been involved with TF installations (specifically on red meat wastewater but generally industrial, where dealing with high BOD, fats). Suppliers contacted (from Australasia and overseas) included:

- Brentwood (USA)
- EPCO (Australia)
- GEA Water Technologies (US / Germany)
- John Sullivan and Associates (Australia)
- Ovivo (Australia)
- Raschig (US) – Sessil TF strip Media (high density polyethylene sheets or strips).

At the time of writing, no positive identification of red meat applications were found from the suppliers. Most noted that high fats was a significant issue with TFs and pre-treatment was required.

Raschig responded with some estimations of what could be done, and for a theoretical load of 1,500 kg/day, proposed a tower of 6 m high, 12.5 m diameter using their proprietary media (loading of 1.6 kg soluble BOD/m3.d) to achieve 80 % soluble BOD removal.

Figure 8: Raschig polypropylene strip media being installed, inside galvanized steel frame.

Ovivo indicated they use activated sludge, sequence batch reactor (SBR) or moving bed biofilm reactor (MBBR) systems for meat/dairy applications. They noted there had been an increase in requests for packed bed systems in the last 12 months but mostly in other food / beverage industry areas. Another supplier also indicated that many plants involving high oils / BOD would typically use MBBR processes.

However, the general indication was that with appropriate pre-treatment, TFs could work, but a possible pilot plant to determine loading rates would be required. In addition, suppliers indicated that TF systems have operated at tanneries, dairies, chicken processing plants, and food industry (potato) plants.

6. Other Industry Trickling Filter Applications – Literature Review

6.1 Municipal wastewater

As noted above, trickling filters have not been considered for municipal upgrades for many years. The activated sludge process has generally overshadowed the older technology TF on the basis of effluent quality and operational control aspects. Replacement of stone by plastic has occasionally been considered, but costs have largely ruled against this.

There are still many old stone TFs in operation (generally in small / rural areas) as illustrated in Figure 9. Typically effluent is used for irrigation so only limited nutrient removal is required.

Figure 9: Stone media TF in NSW

However, there are a number of large plastic TF installations in Australia including:

- Burwood beach (Newcastle) WWTP (as part of trickling filter solids contact process) – 40 ML/d flow
- Rosny (Tasmania) WWTP – also as part of trickling Filer solids contact process – 1.5 ML/d flow
- Macquarie Point (Hobart) WWTP -15 ML/day trickling filter plant
- Drouin WWTP (Victoria). Used for nitrifying of effluent from a lagoon plant prior to discharge to waterway- 1 ML.

All operators note the easy operation of the TF process, and preference to activated sludge. They have not reported any issues with odours or flies. However, Burwood Beach has been covered and air treated via biofilter for odour control. Initially there were also some issues with blockages at Rosny with fibrous material collecting at the top of the filter so screening was upgraded, and this has been corrected.

Large plants are also located in England, Europe and North America (Laginestra 1992), including:

- Manukau (Auckland), New Zealand (280 ML/day TF plant

- Connecticut municipal wastewater treatment plant (with extreme industrial load, contributing about 70% of the organic load to the treatment plant) uses a trickling roughing filter (HDPE strip filter media) to remove BOD prior to activated sludge
- Annacis Island wastewater plant in Vancouver, Canada (500 ML/d), which is based on TF/solids contact technology. The trickling filters are covered and the odour scrubbed
- Some 50 combined TF-AS plants (flows over 10 ML/d)

6.2 Industrial wastewater

Nearly all known TF applications constructed within the last 25 years involve plastic media TFs (although in developing countries stone trickling filters are still built).

Australian / New Zealand applications include (most of which are 10 – 15 years old) include:

- Nestle Tongala dairy processing plant (now Fonterra); used it as a roughing filter prior to BNR plant, Joe White Malting in Perth [although now believed to have been replaced by MBR]
- In New Zealand, a TF was installed at chicken processing plant (Figure 10)
- Pepsi 7-Up (Sydney) – as preliminary high rate system prior to activated sludge (Figure 11)
- Huntingwood – roughing filter for activated sludge for soft drink manufacturer – a number of issues – mainly related to design and operation, but still achieved reasonable BOD reduction
- Pesticide manufacturing plant (north of Sydney) – uses AC trickling filter downstream of activated carbon system to cater for high COD, prior to SBR system.

It is interesting to note that all the above applications are a combined / hybrid system with activated sludge (AS). The AS was introduced to cater for nutrients and enhance effluent quality in a number of systems, while the TF technology was adopted to either cater for peak organic loads or minimise aeration costs.

There are numerous applications for high BOD wastes being treated by trickling filter technology overseas including:

- Canning operations – TFs preferred due to ease of maintenance, possibility of shock loads and weekend shut downs (Oleszkiewicz 1981)
- Bakery wastewater (Wang et al 2006) - rock media TF demonstrated significant reduction on oil / grease from 1500 mg/L to 30 mg/L
- Tomato wastewater (Tawfick 2013), polyurethane media (high specific surface area 256 m^2/m^3) TF pilot plant downstream of anaerobic treatment, loading of TF = 1 - 3 kg COD/m^3.d. It was shown that nitrification ability of TF was dependent on Volatile Suspended Solids (VSS) / TN ratio - achieved 82 % nitrification at loadings of < 1.4 kg COD/m^3.d (but only 20 % at 3 kg COD/m^3.d).

Key issues in the past for some of the Australian TF applications have included:

- Odours (some filters have been decommissioned)
- Flies
- Overloading leading to problems of above
- Poor air recirculation (broken underdrains and lack of vents at base)
- Break down of distributor.

Figure 10: Chicken processing plant – TF downstream of DAF

Figure 11: TF – Activated sludge process at soft drink manufacturer

7. Other Fixed Film and Combined Systems

7.1 Aerated Biofilters

A fixed biofilm reactor combines aeration and clarification in one unit by using a granular media for biomass attachment and a degree of suspended solids removal. Compressed air and untreated effluent are injected at the base of the media. Stensel & Reiber (1983) undertook a review of a biological aerated filter (BAF) system (carrier media system with mechanical aeration) as being new innovative fixed film system for industrial wastewater. Reportedly best suited for moderate inflow concentrations, upstream treatment for COD > 1,000 mg/L (anaerobic) is required. Capital costs and land area savings are achieved compared to plastic media TFs and activated sludge systems. However BAF energy requirements are only some 10 % lower than activated sludge, with TF being some 40% lower again.

The moving bed TF is a biological filter which treats air and wastewater simultaneously and comprises a cylindrical tank filled with plastic support spherical media, specially designed to prevent bridge forming, and act as carriers for micro-organisms. Wastewater is fed in to the top. Air flows counter-currently from the base. RCL (2006) (refer Figure 12) cite some example installations of treating wastewater of 40 m^3/h with a moving bed TF 17 m high and 4 to 5 m diameter (chicken and fish processing wastewater).

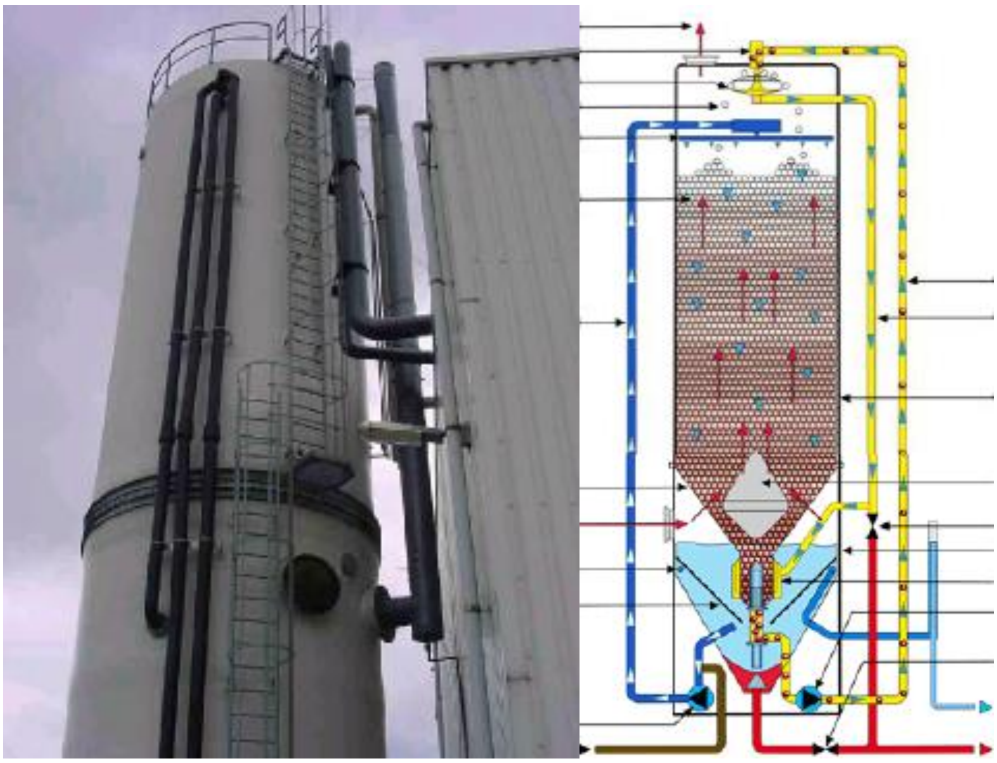


Figure 12: MBTF system (RCL, 2006)

7.2 Hybrid Systems

There are a number of hybrid TF / activated systems that have been developed for municipal and industrial applications, which will also be discussed as part of this review. The TF minimises the operating costs, and acts as the main organic treatment unit, while the activated sludge system (with vastly reduced aeration requirements) acts to reduce nitrogen and polish the effluent for environmental discharge. Pre-treatment TFs have been designed for numerous industrial wastewaters including brewery, fish factory and vegetable processing plant – all subject to seasonal flow and wastewater variations. The high rate plastic media TF acts as buffer after anaerobic digestion to obtain stable COD concentration for the AS system (Cervantes et al, 2006).

WEF (2007) notes that greater treatment could be achieved through combination of highly loaded TFs followed by activated sludge, taking advantages of strengths and overcoming weakness of both process. This has led to coupled simplicity, shock resistance and low maintenance of TF with improved effluent quality or increased nitrification of the activated sludge process. Moodie (1979) consider that plastic media filers are best suited for roughing or partial treatment (nominally 40 – 75% of the BOD load), before further treatment. This lends to a combined / hybrid process. Figure 13 indicates typical hybrid systems.

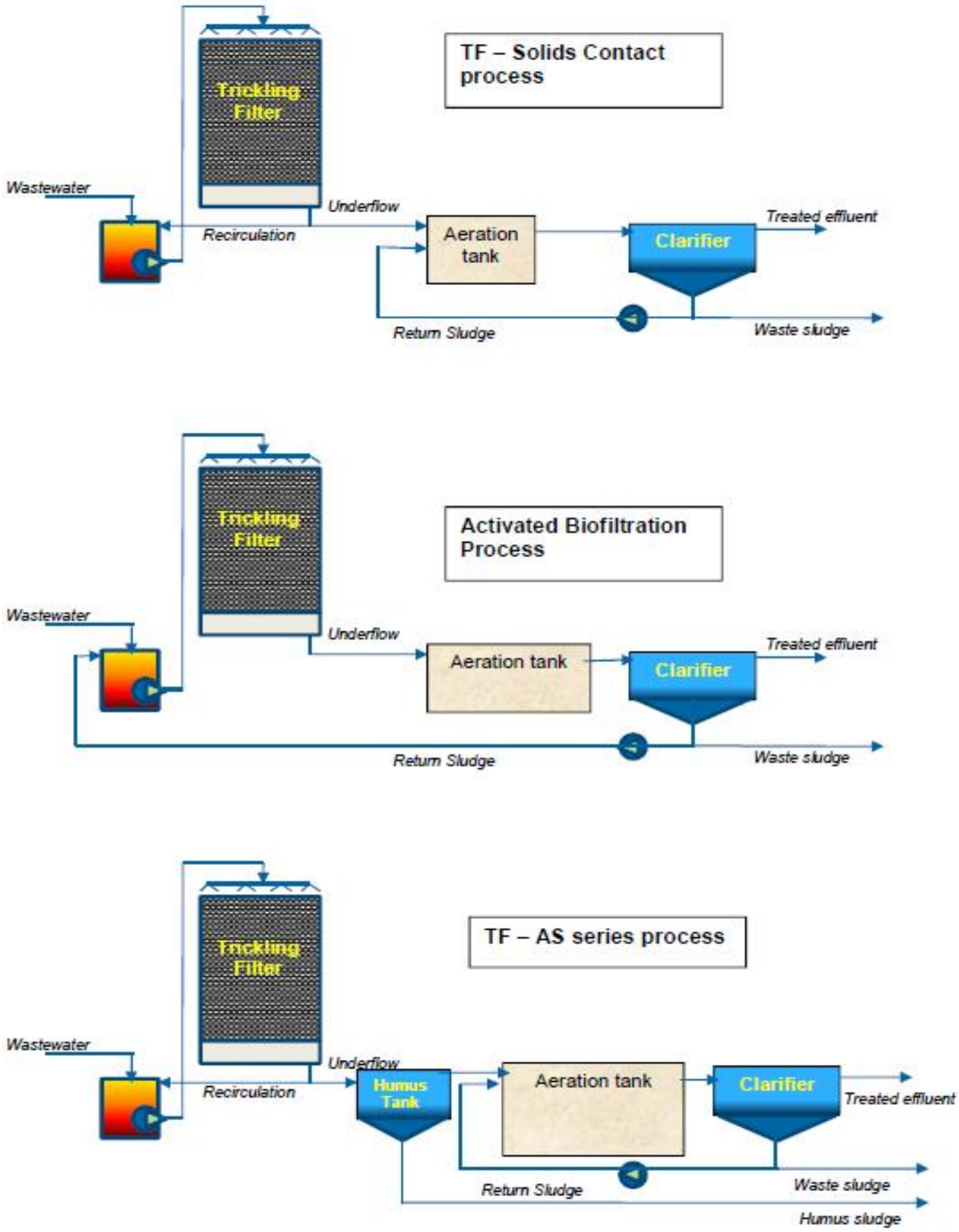


Figure 13: Hybrid systems – TF / AS

Table 6: Combined Activated Sludge and Trickling Filter Processes

System	Description	Design Criteria
Activated biofilter	Lightly load TF, with AS recycled form secondary clarifier to the TF. Reportedly high DO and F:M ratio contribute to better settling.	Plastic media 0.5 kg BOD/m^3.d 5.7 m^3/m^2.d TF MLSS 2,000 mg/L
Trickling Filter Solids Contact	Moderate to high loaded TF, followed by small aerated chamber (15 % of size of conventional AS).	Plastic or rock media 0.65 kg BOD/m^3.d 2.85 m^3/m^2.d AS MLSS 2,000 mg/L AS HRT 1 h AS SRT 1 day RAS SS 8,000 mg/L
Roughing Filter/AS, TF/AS, BF/ AS	Common method of upgrading AS plants. Typically used where high sol. BOD. Smaller TF, but aeration requirements higher. Also sued as 2 stage approach where nitrification is required.	Plastic or rock media 2.4 kg BOD/m^3.d 5.7 m^3/m^2.d AS MLSS 2,500 mg/L AS HRT 2 h AS SRT 3 day

Albertson & Okey (2001) note that the addition of a suspended growth reactor can greatly enhance the quality of TF effluent.

As a general rule with combined processes, the first stage (fixed film process) supplies 30 – 50 % of the oxygen requirements of the total biological treatment with RF / AS, BF / AS and TF / AS. With TF-SC and ABF, almost all oxygen is provided by the TF. Like with normal TF processes, biological solids are sloughed off, with varying frequencies dependent on type of system adopted (WEF, 2007).

7.3 Other Systems

Rotating biological disc contactors (RBCs) involve a tank in which filter media disc is rotated (periods of aeration versus submerged wastewater contact). Although performance of RBCs has been good, equipment operation has been plagued by failures (WEF, 2007) and it is not typically used in meat processing applications (there is a chicken processing plant in NSW – but was subject to mechanical failure with excessive growth).

Dai et al (2013) looked at a stone trickling filter, consistently achieving low ammonia in effluent and BOD reduction > 95 %. A number of successful pilot and full scale trials of activated sludge denitrification coupled with TF nitrification was reported. Recirculation of nitrified liquor to the TF will not work as this increases wetting rate (increasing oxygen transfer) but potentially could work, although loading needs to be reviewed.

Shipin et al (2000) report on the PETRO system (combined lagoon / TF technology) which is a cost-effective technology (but mainly focused on municipal applications.

8. Development and Implementation of Technology

8.1 Research & Development Process Overview

Research and development might involve initial identification of effective treatment (which is sustainable and could be in lieu or as an adjunct to existing treatment) with the key aim to reduce operational costs and / or improve efficiency. The emphasis of the project is to give direction on suitability of the process and so enable the selection of the most effective solutions that will achieve the greatest efficiencies for treatment of abattoir wastewater. A key aspect would be to identify the benefits of the technology (and applications) and undertake review of issues / constraints.

8.2 Trickling Filtration

Based on the literature review, broad areas for TF design (and applicability to the red meat industry) that might be considered as part of a developmental research program could include the following:

- **Irrigation rate** – dependent on media type
- **Recirculation** – likely to be site specific and concentration of BOD
- **Odour generation** - particular where downstream of anaerobic ponds
- **Organic loading** – dependent on requirements for nitrification
- **Greases / pre-treatment requirements** – no floatables
- **Effluent Quality** –resulting in appropriate quality of treated water
- **Cost – Benefit** – energy efficiency, cost of media, savings for energy, operations etc.

8.3 Extension and presentation to Industry

Presentation of applications or initiation of a pilot scale trial to demonstrate efficiency and application is deemed appropriate for the industry. In a survey undertaken of meat industry members (attached as Appendix B), results indicated that general knowledge of the process was lacking and there was only one known installation of TF in the industry. The introduction of the activated sludge process has become entrenched and is often regarded as the only option (downstream of anaerobic treatment).

The issue of nitrogen removal is regarded as significant, and ability to nitrify / denitrify is regarded as a potential issue with trickling filters, as are filter flies and odours.

Consequently, a trial to establish TF application and design criteria is regarded as an important step prior to implementation (which, without complete knowledge addressing of issues, could result in a technological set back).

An ideal configuration might involve a portable system nominally 3 – 4 m high plastic media filter, delivery pump, with humus tank, and recirculation pump. Both pumps should be variable speed to provide adjustable feed rate (to adjust organic loading and recirculation rate). The system would ideally be portable, and should be operated downstream of the DAF and / or anaerobic lagoon.

Examples of trickling filter pilot plants set up at Glenelg WWTP, SA and North Head, NSW

(Laginestra, 1992) are shown in Figure 14.

Figure 14: Example pilot plant trickling filters

9. Summary and Conclusions

Aerobic treatment is required for red meat wastewater treatment to recover organic material after DAF or anaerobic treatment. The activated sludge process (or aerated lagoon system) has generally overshadowed the older trickling filter (TF) technology on the basis of effluent quality and operational control aspects. TFs have not been considered for any municipal upgrades for many years (and activated sludge is certainly more poplar on basis of nutrient removal requirements). Not to the same extent, but certainly noticeable is the general adoption of activated sludge systems for industrial applications, although hybrid systems have been employed to some extent. It should be noted that TF technology has a very low energy usage, marginally above lagoons. However, pre-treatment is generally regarded as critical for TF systems (more so than activated sludge).

Improperly designed TFs can have a number of issues, including:

- Failure to achieve required organic / nitrogen reduction
- Odour generation
- Filter flies
- Clogging
- Media collapse.

While TFs are simple to operate, and highly energy efficient, the process does have limitations and these need to be acknowledged. The TF process is potentially suited to the red meat industry for treatment of wastewater. However, there will be a need for good pre-treatment - to remove the bulk of grease (nominally < 150 mg/L) and all floatables. In addition, downstream conditions / disposal points will dictate the requirements for further treatment.

Pre-treatment might include DAF (well operated) or an anaerobic system. However care will be required to avoid odour stripping from the latter.

The key advantage of the TF process is a significant reduction in energy requirements compared to activated sludge systems. If high BOD or nitrogen reductions are required, a combined TF / activated sludge system could be adopted. Appropriate design criteria will involve controls to mitigate against flies and odours, with ability for high recirculation, etc.

Overall it is considered that TFs have application in the red meat industry and foreseeably could be used downstream of DAF and / or anaerobic lagoons and upstream of activated sludge to reduce BOD, and provide stable performance.

Appendix A –Treatment History and Examples of Trickling Filter Applications

History of TFs

Trickling Filters have been used extensively for at least 100 years for the treatment of both sewage and industrial effluents. They were the municipal "work-horse", prior to the emergence of the activated sludge process which is now more commonly employed for treatment of sewage.

Trickling filters mimic the natural purification process that occurs when polluted water enters a receiving stream, and trickles over rocky river base. The bacteria in the base remove soluble pollutants and purify the water. For more than 100 years (since 1880's) TFs were regarded as the principal method of wastewater treatment. Rock bed for purification was applied the beds ranging from 0.9 – 2.4 m depth. After declining in the 1970's, TFs gained some renewed popularity in the 1980's, with advent of plastic media, which offered greater surface area and eliminated plugging and pooling issues.

WEF (2007) report that continuous flow to the trickling filter media is required to provide food for biomass and prevent drying out of the attached growth. This is especially important for higher rated systems, using plastic media. Minimum recommended irrigation rate is 30 – 60 m3/m2.d. Dosing siphons (regulate flow to trickling filters) typically used on old style rock media TFs, but are rarely used in new designs. Flow to the TF is typically applied by fixed nozzles or rotating distributor arms (smaller and larger units respectively). The distributor arm is most currently frequently used due to reliability and ease of maintenance – typically consisting of 2 0 4 arms, with the reaction force of the spray from the orifices along the arm (recoil) providing the momentum for rotational force. Dosing siphon is only used minimum flow is insufficient to meet the hydraulic design of the distributor (Corbitt, 1999).

Broad Design Criteria

Biomass in zoogleal slime in TFs typically consists (where TF is used for BOD reduction) of various species of heterotrophic bacteria with small populations of protozoa and fungi. If reactors are used for nitrification, autotrophic nitrifying microbes dominate with smaller numbers of heterotrophic bacteria (WEF, 2007).

Sloughed solids from low rate filter are well digested so yield less sludge (0.5 kg TSS / kg inflow BOD) for rock media.

To mitigate cold, and conserve heat in TFs there are a number of examples to achieve this:

- cover the unit, reduce recirculation
- remove unit form service or operate TFs in parallel
- adjusting orifice / splash plates to reduce wind effects
- use forced draught rather than natural ventilation
- covering open sumps, transfer structures

Comparison to AS systems and alternative systems

In general an activated sludge plant can achieve better effluent quality than trickling filter plants, but the trickling filter has much lower associated operating costs, because of lower energy requirements to aerate and ensure sufficient oxygen supply to the attached growth media. Trickling filter plants are relatively simple to operate, reasonably resistant to toxic shock loads and are considered to be reasonably reliable.

The odour emissions from a trickling filter can be considerably higher than that from activated sludge processes and can require further consideration.

AS – most commonly used aerobic system in US (conventional, EA, Ox D, SBR). HRT – 18 - 36 h, SRT 5 – 15 days. Issues – typically include low aeration (leading to sub-optimal biomass, and proliferation of filamentous organisms, which impairs settleability).

Aerobic stabilisation Lagoons also widely used (typically 1.5 m) – typically 3 – 10 d HRT, 10 – 300 kg BOD/ha.d. Mechanically aerated lagoons – 2.4 – 4.5 m deep.

Johns 1995 reports that AS systems treating slaughterhouse wastewater have been reported to produce light, poor settling floc (and due to high fat in inflow and low DO in the AS reactor), leading to filamentous organism growth. Appropriate design criteria – 0.03 – 0.06 kg BOD/kg MLVSS.d, secondary clarifier < 10 m^3/m^2.d.

Examples of TF Applications and Issues

Site	Application	No. / type of filters	Design criteria	Comments on operation
Drouin WWTP (VIC	Municipal, downstream of ponds for nitrification	2 no. 4 m high Plastic cross flow media	DAF downstream, nitrification, steel frame , iron clad, cement lined	Good job achieving nitrification. Continuous recirculation. No flies or odours
Huntingwood (Sydney)	Industrial - Soft Drink	1 no., plastic media, upstream of AS system	Used as preliminary roughing filter, after pH adjustment and flow equalisation, Continuous flow	Poor performance, but found that underdrains had collapsed and operator adding caustic to “mitigate odours”, little air inflow, arm not rotating (poor distribution)
Te Aroha (New Zealand)	Chicken processing	1 no., plastic media, upstream of AS system and downstream of DAF	Used as roughing filter to take partial load off aerobic system to reduce power costs. Continuous recirculation.	Loaded quite high, and after odours found, taken off-line.

Appendix B – Survey Questions for Meat Industry Group Members

Questions:

1. Are any members currently using trickling filters? (Contact name and number?) Alternatively is there an installation which they have seen and been impressed? (Type of installation and location).
2. Have any members ever operated a trickling filter pilot plant (or had work experience students or University run trials on their behalf)? (Contact name and number?)
3. Can any members nominate current annual costs for running their current treatment system (nominating what it comprises – delineating between aeration versus other costs)? (Contact name and number?)
4. Are any members in contact with parent company or colleagues here or overseas that currently (or have previously) run / operate trickling filter systems (meat or other industry)?(Contact name and number ?)

Results

General response was negative to each of the above, although there was a reference to an installed wastewater system at the Manildra Group Nowra (although our research indicated this was not trickling filtration).

Appendix C – Glossary of Terms

Activated Sludge	Consists of living micro-organisms (bacteria, protozoa, algae, fungi), which are used to decompose wastes in water. The micro-organisms are maintained in an aerobic environment by supplying them with air/oxygen via mechanical means.
AS	Activated Sludge
Anaerobic Conditions	Conditions where no dissolved oxygen or molecular oxygen is available. Micro-organisms break down the organic waste producing methane and carbon dioxide.
Biological Treatment	This refers to the process of biological oxidation, whereby organic pollutants are converted to carbon dioxide and water. Examples of biological treatment are the trickling filter and activated sludge processes.
BOD	Biochemical Oxygen Demand, which refers to the decrease in oxygen content brought about by bacterial breakdown of organic matter. Analysis typically involves incubation of the waste samples for 5 days.
Clarifier	The settling (sedimentation) tank after biological treatment to provide separation of sludge and effluent
COD	Chemical Oxygen Demand
Denitrification	Conversion (by microbes) of nitrate nitrogen to nitrogen gas
Dissolved Air Flotation	Process involving air injection into wastewater, entrainment of solids and collection of solids at surface. Typically enhanced by chemical conditioning (ferric chloride or alum).
Effluent	Outflow stream from process (treated effluent typically refers to effluent from treatment plant, septic tank effluent is outflow from septic tanks)

Extended Aeration (EA) Process	Extended (long detention time) activated sludge proves – which achieves biological BOD degradation and nitrogen reduction. Example includes Intermittently Decanted Extended Aeration (IDEA) process where reaction (aeration) and settling phases may be carried out in single reactor through alternating operational phases (aeration, settling, decanting over total cycle of say 4 hours). The aerobic/anoxic cycling will achieve nitrification / denitrification.
Humus Tank	Settling tank downstream of the trickling filter process
IDEA	Intermittently Decanted Extended Aeration process
Irrigation rate	Wetting rates for TFs, cubic metres per m^2 surface area
kg BOD/ha.d	Organic loading of stabilisation ponds – refers to BOD load per hectare of pond surface area
kg BOD/m^3.d	Organic loading of trickling filters – refers to BOD load per cubic metre of trickling filter packing
Mechanical Aeration	Surface aerators or jet aspirators, which are installed in lagoons or reactors to provide biological oxygen requirements.
ML	Megalitres (one million litres)
N	Nitrogen
NH_3-N	Nitrogen as ammonia
Net Present Value (NPV)	This represents the cost or worth in present day $, of operating costs / profits over the expected life of a project
NFR	Non filterable residue (same as suspended solids)
Nitrification	Conversion of ammonia to nitrites and nitrates by micro-organisms
NPC	Net Present Cost
Organic Loading	This refers to the amount of BOD applied to a unit process per volume.
Oxidised Nitrogen	Nitrate and nitrite nitrogen (formed as a result of oxidation of ammonia nitrogen during wastewater process)

RAS	Return Activated Sludge
SBR	Sequencing Batch reactor – an intermittent process, which differs slightly from IDEA by batch feeding inflow to reactors which are only aerating
Sludge	Solids by-product of wastewater treatment
S	Sulphur, as dissolved sulphide
SO_3	Sulphites
SS	Suspended Solids
TDS	Total Dissolved Solids (salts)
TF	Trickling Filter
TKN	Total Kjeldahl Nitrogen (ammonia + organic nitrogen)
TN	Total nitrogen (TKN + Oxidised Nitrogen)
Trickling filtration	Biological treatment system / bioreactor which involves fixed film biomass, growing over a support media. Wastewater is distributed over the top of the media. Microbes degrade organic contaminants in the presence of oxygen (which is present within the void spaces of the media).
TSS	Total Suspended Solids (same as SS)
UV	Ultra Violet (referring to disinfection method)
VSS	Volatile suspended solids
WAS	Waste Activated Sludge
Wastewater	Used water from industry or domestic facilities
WWTP	Wastewater Treatment Plant

Appendix D – References

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