Evaluating pathogen risks in production of biosolids in Victoria

Duncan A. Rouch[1*], Vennessa Fleming[1], Margaret Deighton[1], Judy Blackbeard[2] and Stephen R. Smith[3]

[1] Department of Biotechnology and Environmental Biology, RMIT University, Bundoora Vic 3083
[2] CRC for Water Quality and Treatment, CSIRO Land & Water, P O Box 56, Graham Road, Highett Vic 3190
[3] Department of Civil and Environmental Engineering, Imperial College, London

* **Corresponding Author**: e-mail, duncan.rouch@rmit.edu.au; Tel, +61 3 9925 7111.

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Abstract

Current Guidelines in the state of Victoria require that digested and dewatered (>10% w/w) biosolids be stored for three years before they can be applied as treatment grade T1 for agricultural and horticultural purposes. The storage period is stipulated to ensure that residual pathogenic micro-organisms are reduced to levels unlikely to be a health risk. In Victoria liquid biosolids from sludge digestion processes are usually placed in drying pans to facilitate air drying, followed by stockpiles for the storage period, to reduce pathogen numbers. The efficacy of these individual phases in the overall treatment process for pathogen removal, however, is uncertain. The question also arises as to whether storage for this extended period of time is actually necessary to protect human health when treated sludge is recycled to agricultural land. Furthermore, extended storage may reduce the agronomic value of the product as a fertiliser and soil conditioner, due to the loss of nitrogen and organic carbon from the biosolids, which discourages its recycling as a soil improver. We have investigated the inactivation of pathogenic microbial indicators for bacteria, viruses and protozoa parasites (*Escherichia coli*, F-specific bacteriophage, *Salmonella* and *Clostridium perfringens*, respectively) in biosolids during the air-drying phase and storage of anaerobically digested biosolids at two wastewater treatment plants in Victoria.

The results indicate a $>10^4$ cfu g^{-1} removal of *E .coli* during the air drying phase due to destruction related to retention time and drying of the sludge. This would exceed the conventional treatment requirements for agricultural use of biosolids prescribed in the UK Safe Sludge Matrix. Moreover, in the stockpiles the prevalence of *E. coli* was reduced by $>10^6$ cfu g^{-1} dry solids (DS) compared to primary sludge entering the plants. Completion of air-drying in pans reduced the survival of *E. coli* to below detectable limits ($< 2 \times 10^1$ cfu g^{-1}), which is compliant with enhanced treatment status for agricultural use of biosolids in Victoria, and also the UK and USA. The Victorian Guidelines for Environmental Management: Biosolids Land Application (2004) require $<10^2$ *E. coli* MPN g^{-1} DS for Treatment Grade T1, while the UK requires ($\leq 10^3$ cfu g^{-1} DS and $\geq 10^6$ cfu g^{-1} reduction of *E. coli*) as does the USA EPA pathogen reduction criteria for Class A biosolids for the highest flexibility or unrestricted end-uses. F-specific bacteriophage numbers also decreased substantially during the air-drying phase, indicating that enteric viruses are also likely to be destroyed during this phase. The preliminary results suggest air-drying sludge by the drying pan process significantly reduces the pathogen content of biosolids, to a level that may be acceptable for recycling to farmland, without the need for an extended storage period. The completion of air-drying in pans produced a treated product of a high microbiological safety suitable for application with minimal land use restrictions.

1. Introduction

Biosolids are highly beneficial, renewable, and natural resources for land application. As natural soil conditioners and fertilisers, these have commercial markets in four key areas; agriculture, horticulture, forestry rehabilitation, and land rehabilitation. In Australia during 2005 the value of demand for all fertilizer products was worth more than 300 billion dollars (IBISWorld, 2007). Of this market, the group of organic fertilizers, which includes biosolids, are a small but growing sector. Organic fertilizers may attract a premium for their natural and renewable properties.

Nevertheless, in Victoria less than 5 % of annual sludge production (66,700 t DS) is used beneficially (EPA, 2004), equivalent to little more than 3000 t DS per year. In the meantime approximately 2 million t dry solids (DS) of sludge are either stored in lagoons or stockpiled.

One reason for this low use is the requirement for producing non-restricted treatment grade T1 products by the normal industrial process: digestion, air-drying, and storage for 3 years specified in the Guidelines (EPA 2004). Air-drying and storage of digested sludge (aerobic or anaerobic) is the principal method of sludge management in the State of Victoria. During storage, the nutrient value of biosolids diminishes owing to the loss of mineral nitrogen (N) by volatilisation of the ammoniacal content and stabilisation of the organic N fraction, reduced solubility of phosphorus (P) and degradation of the organic matter content. Over time, this compromises the quality and value of the 'treated' material as a soil improver and fertiliser.

In addition, although a normal industrial treatment process is listed for producing T1 Grade biosolids, there are no recommendations in the Guidelines (EPA, 2004) for normal industrial processes to make restricted T2 treatment grade products. Moreover, shorter treatment times than 3 years, by standard industrial processes, can only allow recommendation for the T3 grade. Biosolids with T3 treatment grade have restricted use. This follows the multi-barrier approach to minimising risks to pathogens from sludge, by significantly reducing the numbers of enteric organisms by sludge treatment followed by land use restrictions to allow natural attenuation of the residual numbers of pathogens to take place in the soil. The multi-barrier approach is widely adopted and recognised as a safe and acceptable practice for biosolids management and is the principal outlet for treated biosolids in countries such as the US and UK.

Shortening the storage period has the benefit of increasing the agronomic value of the biosolids, but due account must be taken of the implications for the microbiological quality of the sludge. Storage after mechanical or solar/air drying for periods of between 3 to 6 months to meet appropriate microbiological criteria for agricultural application is commonly practised in other countries with climates ranging from temperate (e.g., UK) to arid (e.g., Egypt).

We have investigated the inactivation of pathogenic microbial indicators for bacteria, viruses and protozoa parasites (*Escherichia coli*, F-specific bacteriophage and *Clostridium perfringens*, respectively) in biosolids during the air-drying phase and storage of anaerobically digested biosolids at two wastewater treatment plants in Victoria.

2. Materials and Methods

2.1 Sites

Biosolids samples were taken from two wastewater treatment plants (WWTP) in the Melbourne area, Victoria: Eastern Treatment Plant (ETP, Melbourne Water Company) and Mt Martha WWTP (South East Water Limited). These two plants have similar process sequences, including anaerobic digesters and air-drying pans, though differ in scale: the ETP services 42% of Melbourne city, while Mt Martha WWTP services a smaller regional area, Mornington Peninsula.

2.2 Biosolids sampling and analysis

At both sites samples were taken from the anaerobic digesters, air-drying pans and stockpiles, with different ages of biosolids in pans and stockpiles. On a day of sampling, single samples were taken from the pump output of anaerobic digesters and three composite samples were taken from air-drying pans. Stockpiles were sampled three times at three depths, 0-0.2 m (surface), 0.4-0.6 m, and 0.9-1.1 m. Samples were stored at 4 ^{o}C and analysed within 72 h for the presence of *Escherichia coli*, *Clostridium perfringens*, and F-RNA bacteriophages. A subset of samples were also analysed for the presence of *Salmonella*.

Enumeration by membrane filtration of *E. coli* and confirmation were by methods modified from those detailed by the Environment Agency (2002a, 2003). The presence by membrane filtration and confirmation of *Clostridium perfringens* was determined based on methods described by the Environment Agency (2002b). F-RNA bacteriophages were enumerated using the *E. coli* HS(pFamp)R host by standard methods (ISO, 1995). Detection of *Salmonella* was based on the membrane filtration method of the Environment Agency (2002c).

Due to the focus on pan air-drying, brief details of the air-drying processes at the two plants are given. The drying pans sampled at each plant had clay bases, however, between the two plants there were differences in the treatment of bisolids in the pans. At ETP pans were filled over 5 weeks, decanted and air-dried over 11 months. In contrast, At Mt Martha pans were filled over 6 months, with serial filling, settling and decanting, then a water cap was left over for 6 months for secondary digestion, followed by decanting and 4 months of air-drying. In addition, pans were regularly stirred vertically during the drying phase at ETP, but not at Mt Martha.

3. Results and Discussion

With the dates of phases in air-drying pans (SDP 33 at ETP, and pan 3 at Mt Martha), and the sampling data, trend lines were calculated for the reduction of *E. coli* (Fig. 1). Time 0 represents completion of anaerobic digestion and completion of filling. At ETP the T2 grade limit was reached by about 6 months digestion, while the T1 grade limit was reached before 9 months digestion. A similar trend was observed at Mt Martha; here the T2 grade limit was reached by 7 months digestion, while the T1 grade limit was reached before 10 months digestion. Destruction of bacteriophage was similar to that of *E.coli* in both cases, with the reduction of prevalence by $>10^4$ pfu g^{-1} DS in stockpiles compared to primary sludge: no bacteriophages were detected in harvested sludge or stockpiles. Given the differences in the treatment of biosolids in pans between the two plants (section 2.2), the similarity in removal of *E. coli* and phage between the two plants indicated that air-drying was a robust process for removal of enteric bacteria and viruses.

Fig. 1a ***E. coli* removal at Pan SDP 33, MWC ETP**

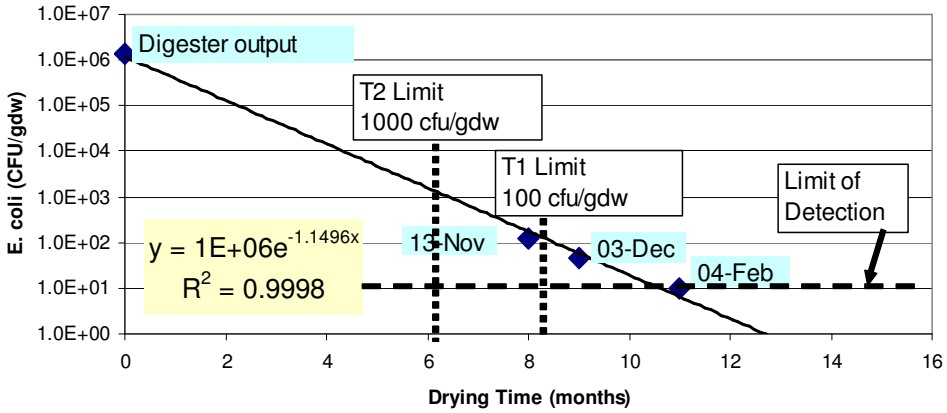

Fig. 1b ***E. coli* removal at Pan 3, SEWL Mt Martha**

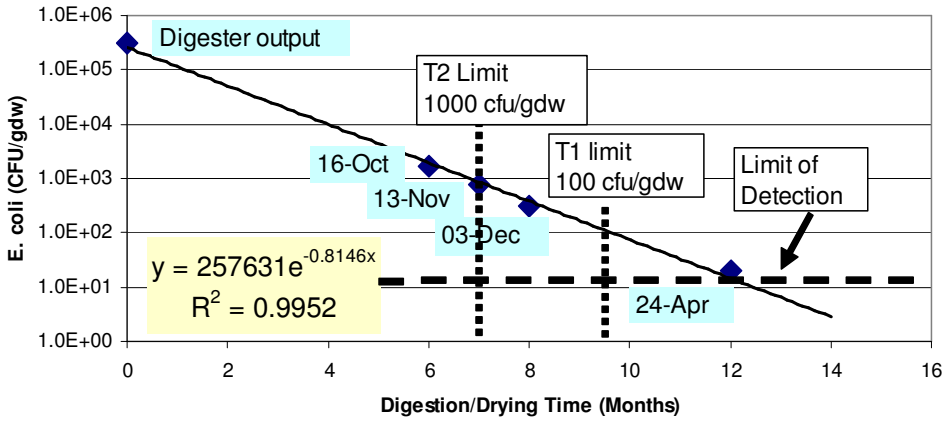

Fig. 1. Effect of air-drying processes on removal of *E. coli*, (a) Pan SDP 33 at MWC, (b) Pan 3 at SEWL Mt Martha.

In stockpiles from 6 months to 3 years age no *E. coli* or *E. coli* bacteriophages were detected (limit 20 cfu/gdw or pfu/gdw). During February 2008 a small number of *E. coli* were detected in the surface level of a stockpile set up in February 2007 at Mt Martha, which previously had not shown any detectable presence of this indicator. As no *E. coli* were detected at a lower level (0.5 m), the results suggested that contamination of the stockpile had occurred recently, presumably due to faecal contamination by birds or land animals.

In contrast to the presence of *E. coli* and F-RNA bacteriophage, *Clostridium perfringens* was detected at similar levels in all samples, at 10^6 to 10^7 g^{-1} DS. In contrast, *Salmonella* was not detected in a range of samples from the two plants (data not shown).

The results indicate $>10^4$ cfu g^{-1} removal of *E .coli* during the air drying phase due to destruction related to retention time and drying of the sludge. Moreover, in the stockpiles the prevalence of *E. coli* was reduced by $>10^6$ cfu g^{-1} dry solids (DS) compared to primary sludge entering the plants. This would comply with the conventional treatment requirements for agricultural use of biosolids prescribed in the UK Safe Sludge Matrix.

Completion of air-drying in pans reduced the survival of *E. coli* to below detectable limits (2×10^1 cfu g^{-1}), which is compliant with the T1 treatment grade in Victoria and Class A biosolids in the USA for unrestricted use, and enhanced treatment status for agricultural use of biosolids in the UK. The Victorian Guidelines for Environmental Management: Biosolids Land Application (2004) require $<10^2$ *E. coli* MPN g^{-1} DS for Treatment Grade T1, as does the USA EPA pathogen reduction criteria for Class A biosolids for unrestricted use. The UK requires $\leq 10^3$ cfu g^{-1} DS and $\geq 10^6$ cfu g^{-1} reduction of *E coli* to achieve enhanced treatment status allowing the most flexible end-uses for treated biosolids. F-specific bacteriophage numbers also decreased substantially during the air-drying phase, indicating that enteric viruses are also likely to be destroyed during this phase.

In contrast to the presence of *E. coli* and F-RNA bacteriophage, *Clostridium perfringens* was detected at similar levels in all samples, at 10^6 to 10^7 cfu g^{-1} DS. *E. coli* and F-RNA bacteriophage are accepted indicators for microbial safety of wastewater. In addition, *C. perfringens* has been suggested as an indicator in water treatment for removal of parasites such as *Cryptosporidium* and *Giardia*, but is it also useful in biosolids treatment? King et al. (2005) examined the loss of infectivity of *Cryptosporidium* oocysts stored in water at a variety of temperatures likely to be found in water storage, treatment and distribution systems. For oocysts stored at 30 °C, a 4 log decline in infectivity took place after 360 hours (~15 days). At 40 °C, the same 4 log decline in infectivity occurred after only 98 hours (~4 days). In mesophilic anaerobic digestion reduction of *Cryptosporidium* is reported to be 2-3 log (Stadterman et al., 1995). The loss of infectivity occurs due to the depletion of energy resources.

Our data showed that the prevalence of *C. perfringens* was increased by ~0.5 log in the anaerobic digester at Mt Martha. At ETP this species showed only a half log reduction between the anaerobic digester and the drying pan after 3 weeks (results not shown). This suggested that *C. perfringens* is highly conservative as an indicator of enteric organisms in biosolids and is likely to provide a poor relation to their inactivation.

In future we also plan to analyse samples for phyto-available nitrogen, total phosphorus, and organic matter content, to determine their plant nutritional values of air-dried and stored biosolids.

Conclusion

The results suggest alternative processing options are possible to produce biosolids suitable for use on land, compared to producing and storing stockpiles for 3 years. In the reported cases at two plants microbial safety of treatment T1 grade was reached before the end of the air-drying phase. This would save over three years storage for producing T1 grade biosolids in Victoria, compared to current guidelines. It is additionally suggested that air-dried biosolids with treatment T2 and T3 grades be suitable for direct use on agricultural land, following a standard regime of land-use restrictions, without the need for an extended storage period. Furthermore, across Victoria the metropolitan and regional wastewater plants have a range of different process sequences, for example some do not have anaerobic digesters, which may lead to some variation in removal of pathogens. Therefore, it is considered important to assess the removal of pathogens by each type of plant.

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