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Sensory Assessment of Odour Emissions in Wastewater Treatment: Implications for Biosolids Management

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The beneficial reuse and recovery of biosolids is an attractive option instead of disposal. However, odour emissions present significant challenges to land application of biosolids, increasing operational costs and reducing community acceptance. This study aimed to assess the influence of conveying and storage conditions in wastewater treatment plants on the sensory impact from biosolids. For sensory assessment, samples of anaerobically digested biosolids were collected after centrifuge and during storage out-loading. The emissions were extracted over 15 days using a dynamic flux chamber and sensory analysis conducted using an ODP coupled to a TD-GC-MS. Odour descriptors and intensities (from 1 – weak to 4 – strong) were evaluated by expert panellists, providing insights into the sensory aspects of odour emissions. The ODP results showed variations in the number of occurrences, intensity and modified frequency of odour events across the stages of wastewater solids processing and laboratory storage. Conveying could potentially impact the release of volatile compounds due to the mechanical agitation that can aerate and disturb the structure and surface of the biosolids. On the other hand, storage can accelerate biological and chemical processes as a result of the development of anaerobic conditions leading to subsequent odour generation. The interplay between wastewater treatment processes and odour emissions is complex and requires targeted strategies. The application of sensorial analysis contributes to valuable insights into understanding and managing odour emissions in wastewater treatment plants, offering potential avenues for optimizing operational parameters to benefit biosolids reuse initiatives.
Keywords: Wastewater sludge; Anaerobic digestion; Biosolids; Beneficial reuse; Land application; Gaseous emissions; Sensory emissions; Sensory analysis; Odour detection port.

1. Introduction

Anaerobic digestion is a process largely used to manage wastewater sludge and generate biosolids (Fisher et al., 2019). Land application of biosolids is a better alternative than disposal in landfill or incineration, because of its agricultural, environmental, economic, and social benefits, promoting the cycling of water and nutrients and reducing the demand for raw materials. However, biosolids produce odour emissions that can impact the surrounding community. As the human nose detects these odorants at very low concentrations, communities are often unwilling to tolerate the odours associated with biosolids. Even when considered more of a nuisance than a health risk (Fisher et al., 2018). Odour impact thus poses a challenge to beneficial reuse of biosolids, increasing operational costs and reducing community acceptance. Shearing of biosolids, which can occur during conveyance, loading/unloading, spreading, and incorporation, can affect the generation of odorants (Chen et al., 2019). Nonetheless, there are still many unknowns regarding the effects of these processes on odour emissions from biosolids, including sensorial implications. This research proposes to assess the impact of wastewater treatment processes, including conveying and storage conditions, on odour emissions from biosolids using a sensorial method.

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2. Methods

2.1 Sampling protocol

Samples of biosolids were collected from a wastewater treatment plant (WWTP) in New South Wales, Australia. The WWTP produces biosolids through anaerobic digestion of primary sludge followed by dewatering via rotational centrifuge. Conveying is used to transport the biosolids from the centrifuge to the storage sealed silo, and during out-loading from the silo to beneficial reuse trucks. Biosolids were sampled from two collection points, after centrifuge and during out-loading, to study the effect of conveying and storage conditions on sensory emissions from biosolids. In this paper, samples called *"centrifuge"* refer to the samples after centrifuge (before conveying/storage), and samples called *"out-loading"* refer to the samples from the out-loading (after conveying/storage). The biosolids samples were transported to UNSW Sydney for emission assessment and placed and stored in duplicate shallow storage containers for 15 days (Figure 1(a)). The biosolids emissions were extracted during six sampling rounds – on days 0, 2, 5, 8, 12 and 15 – of 15 days of laboratory storage, using a US EPA dynamic flux hood, following AS/NZS 4323.4:2009, and collected in Nalophan bags in duplicate (Figure 1(b)).

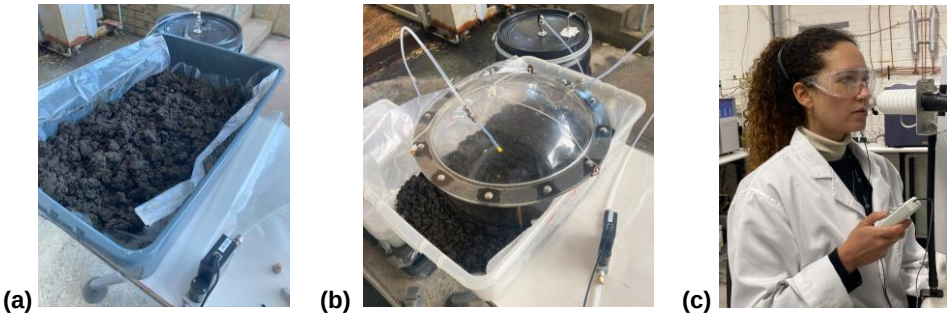

Figure 1: Experimental set-up (a) biosolids, (b) biosolids emission sampling, and (c) sensory emission analysis.

2.2 Sensory emission analysis

Sensory assessment was conducted using an olfactory detection port (ODP) from Gerstel GmbH & Co., Germany, connected to a TD-GC-MS (GC-MS – Agilent 6890 N GC, 5973NS MS, Agilent Technologies) (Figure 1(c)). Two trained panellists, here identified as ODP P1 and ODP P2, described the odours and rated the intensity on a scale from 1 (weak) to 4 (strong). Odour sensitivity tests were performed on the panellists to ensure their sensitivity to odours was acceptable. In total 48 samples were analysed, 24 each per biosolids type – centrifuge and out-loading. Odour descriptors between panellists were matched based on similar characteristics and retention time. The Modified Frequency (MF%), as a method that integrates both detection frequency and mean intensity (Brattoli et al., 2013), was used to determine the main odour events, as showed by Equations (1) to (3).

$$MF\ (\%) = \sqrt{F(\%) \times I(\%)} \quad (1)$$

$$F(\%) = \frac{Number\ of\ samples\ with\ occurences}{Total\ number\ of\ samples} \quad (2)$$

$$I(\%) = \frac{Average\ intensity}{Maximum\ intensity} \quad (3)$$

Where *'F (%)'* is the detection frequency expressed as percentage and *'I (%)'* is the average intensity expressed as a percentage of the maximum intensity. *'Total number of samples'* was 24, while *'Maximum intensity'* was 4.

3. Results and discussion

3.1 Sensory impact of wastewater treatment processes

In total, 44 different odour events were detected during the 15 days of laboratory storage for the two types of biosolids (Figure 2). Odour events frequently detected are likely to cause nuisance (Brattoli et al., 2011). For centrifuge biosolids, the two panellists detected 'putrid-like sulfur', 'musty earthy', and 'musty chemical' in more than half of the overall samples. While for out-loading biosolids, 'fishy', 'putrid garlic' and 'putrid-like sulfur' were frequent. ODP P1, however, was overall more sensitive than ODP P2 (Figure 2). Odour sensitivity tests based on hexanal and geosmin conducted with the two panellists agreed to this difference in sensitivity. However, ODP P2 detected geosmin at 5 ng/L, slightly outperforming ODP P1, who detected it at 10 ng/L. Although both panellists detected hexanal at same concentration of 100 ng/L and were considered sensitive panellists.

Sensory methods can not only identify significant odour events that might cause nuisance to a larger group, but also recognize individual sensitivities. This is particularly important in addressing odour complaints.

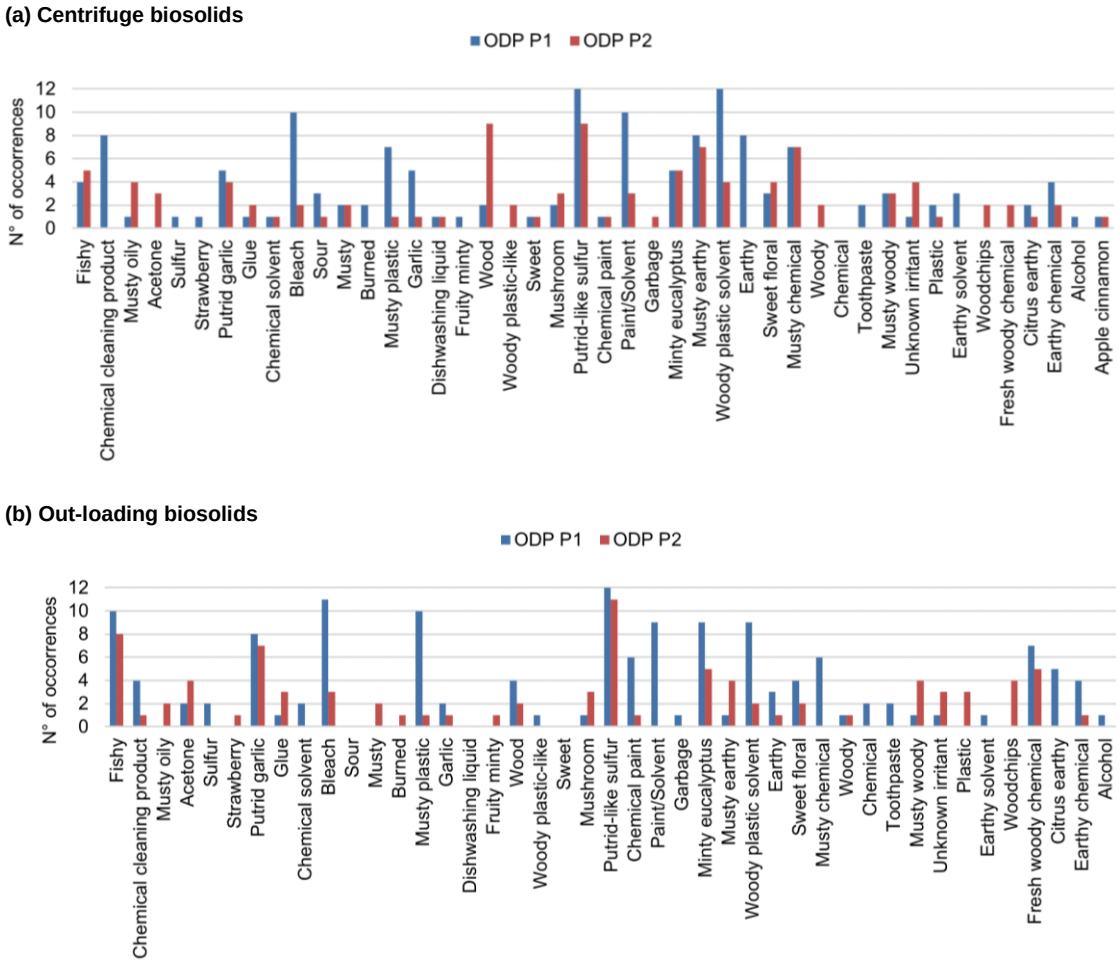

Figure 2: Number of occurrences of odour descriptors as identified by sensory panellists (ODP P1, ODP P2) using the olfactory detection port (ODP) over a period of 15 days for centrifuge and out-loading biosolids.

Seven odour events were prioritised based on their frequency and intensity (Figure 3). Their frequencies of occurrence fluctuated differently over the period of laboratory storage. 'Fishy' was only detected in the early stages for the centrifuge biosolids storage, while detected in almost all samples for out-loading. The two panellists presented similar overall sensitivity to 'fishy'. 'Putrid garlic' was also detected more frequently in out-loading samples than centrifuge, with ODP P1 detecting it more halfway through the sampling campaign and ODP P2 in the beginning for out-loading. For centrifuge samples, this odour event seemed to appear towards the end. 'Musty chemical' followed a similar pattern over time to 'putrid garlic', although being detected more frequently in the centrifuge than in the out-loading biosolids. 'Putrid-like sulfur' was detected for both biosolids in all six sampling days by ODP P1, while ODP P2 detected it in all but four samples. This odour event, thus, is likely to be of concern for the odour management of these biosolids. 'Putrid-like sulfur' is likely associated with emissions of volatile sulfur compounds (VSCs) (Fisher et al., 2018), which are microbial degradation byproducts of sulfur-containing amino acids (Higgins et al., 2006).

Furthermore, 'wood' and 'minty eucalyptus' varied throughout the sampling campaign for both panellists and biosolids, being detected in scattered days. 'Musty earthy' was only detected towards the end of sampling period – after day 5 – and more frequently in the centrifuge than in the out-loading biosolids. These odour events could be associated with volatile organic compounds (VOCs), which can be produced after VSCs dissipate and are difficult to degrade, persisting for a longer period of time (Chen et al., 2011). As VOCs can also have low threshold concentrations to human olfactory, it is likely that humans can still experience nuisance from these compounds. This odour impact, however, might be of concern for communities that live further away from the treatment plant or during land application, depending on transportation and spreading time.

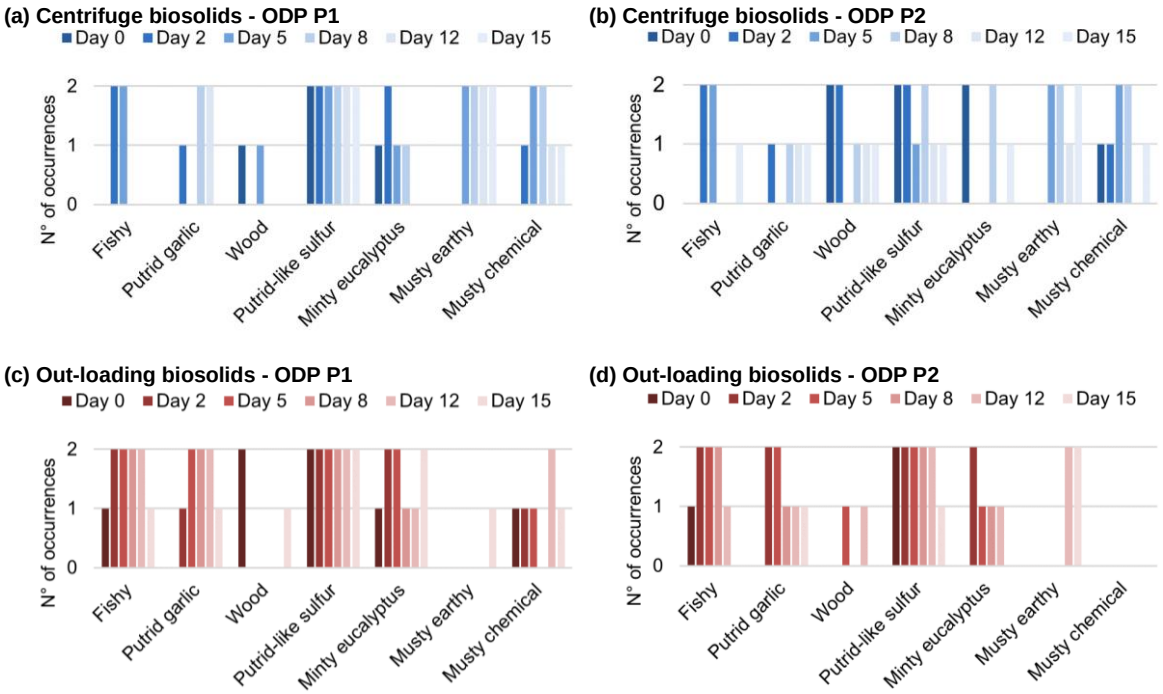

Figure 3: Number of occurrences of main odour descriptors for each of the six sampling days identified by sensory panellists ODP P1 and ODP P2 for centrifuge and out-loading biosolids.

Sensorial methods are also efficient in identifying intensity of odour events (Brattoli et al., 2011). Even though the intensity for the majority of the prioritised odour events were 1, mean intensities were > 1 in some days for 'fishy', 'putrid garlic', 'putrid-like sulfur', 'musty earthy' and 'musty chemical' (Figure 4). In the case of centrifuge biosolids, 'fishy', 'putrid garlic' and 'musty earthy' had these higher intensities closer to the last day of sampling. On the contrary, for out-loading biosolids, 'fishy' and 'putrid garlic' had higher intensities towards the beginning of the sampling period. Similarly, out-loading 'musty chemical' had mean intensity > 1 at day 0. 'Musty earthy' was only detected in the last few days of sampling and had higher mean intensities on day 12 for both types of biosolids. In turn, 'putrid-like sulfur' had intensities fluctuating during the sampling period, but with mean intensities > 1 for all six sampling days, except day 8 for centrifuge samples. Shearing of biosolids results in greater odour (Chen et al., 2011) due to disruptions in the methanogenic population (Higgins et al., 2006). This could explain the higher odour intensity at the beginning for out-loading samples, as shearing releases sulfur-containing proteins and other organics that act as substrates for microbial growth and odour production.

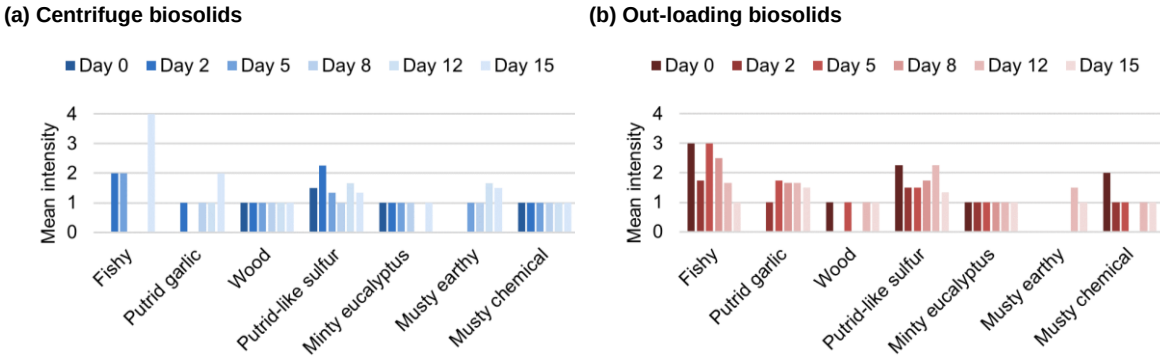

Figure 4: Mean intensity of main odour descriptors for each of the six sampling days over a period of 15 days identified by sensory panellists using ODP for centrifuge, and out-loading biosolids.

The MF (%) is a valuable tool to combine frequency of detection and intensity, effectively identifying the most important odours, which have MF (%) higher than 50% (Brattoli et al., 2011). MF (%) of 'fishy' were higher than

or equal to 50% for all detected days, apart from day 15 for panellist ODP P1 (Figure 5). 'Fishy" MF (%) ranged from 61% to 79% for centrifuge biosolids, and from 35% up to 93% for out-loading. Similarly, MF (%) of 'putrid garlic' and 'putrid-like sulfur' were higher for the out-loading biosolids compared to the centrifuge. MF (%) for 'putrid garlic' ranged from 35% to 50% for centrifuge, and from 35% up to 71% for out-loading; while 'putrid-like sulfur' had MF (%) ranging from 35% up to 79% and from 50% up to 87% for centrifuge and out-loading biosolids, respectively. Likely due to shearing of the biosolids (Chen et al., 2011), conveying and storage are increasing the emissions of these odour events. Anecdotally, the overall odour was observed to be stronger for out-loading biosolids than centrifuge during the emission sampling.

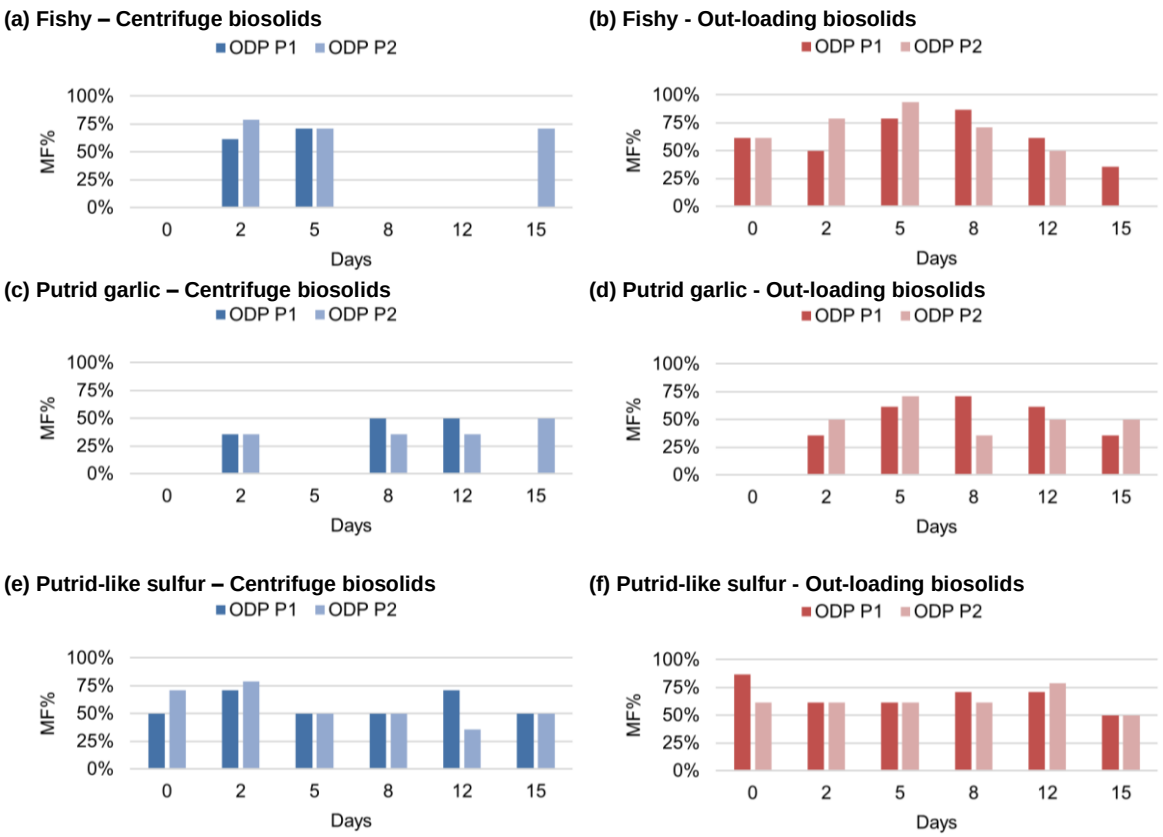

Figure 5: Modified frequency (MF%) of fishy, putrid garlic, and putrid-like sulfur odour events identified by sensory panellists ODP P1 and ODP P2 in centrifuge and out-loading biosolids for the six sampling days.

Odour events with MF (%) ≥ 25% – overall detected in more than 19 out of the 48 samples – are likely to be sensory important (Figure 6). Other than the previously discussed, odour events such as 'bleach', 'musty plastic', 'paint/solvent', 'minty eucalyptus', 'woody plastic solvent' and 'musty chemical' could also be odour of concern for both biosolids samples. Individually, 'chemical cleaning product', 'wood', 'musty earthy', 'earthy' and 'sweet floral' for centrifuge biosolids; and 'fresh woody chemical' for out-loading. Overall MF (%) of these odour events ranged from 14% up to 58%, and from 18% up to 65%, for centrifuge and out-loading, respectively. Comparing these odour descriptors with Fisher et al. (2018) odour wheel, it seems that emissions from centrifuge biosolids are potentially associated with the presence of VOCs, while out-loading biosolids with VSCs. Enhanced VSCs generation from the out-loading biosolids is likely caused by shearing of biosolids during conveyance, which disrupts methanogens (Adams et al., 2007), and the storage conditions that can develop anaerobic environments. VOCs can persist for a longer period of time after VSCs dissipate and are difficult to degrade (Chen et al., 2011), thus, the increase in the emissions of the overall odour events for centrifuge compared to out-loading (Figure 6). Sensory assessment proved useful in identifying the impact of storage and shear-inducing processes on odour emissions. Further research can link sensory assessment with its correspondent volatile compound improving odour management and address the knowledge gap in the impact of VOCs on the overall odour.

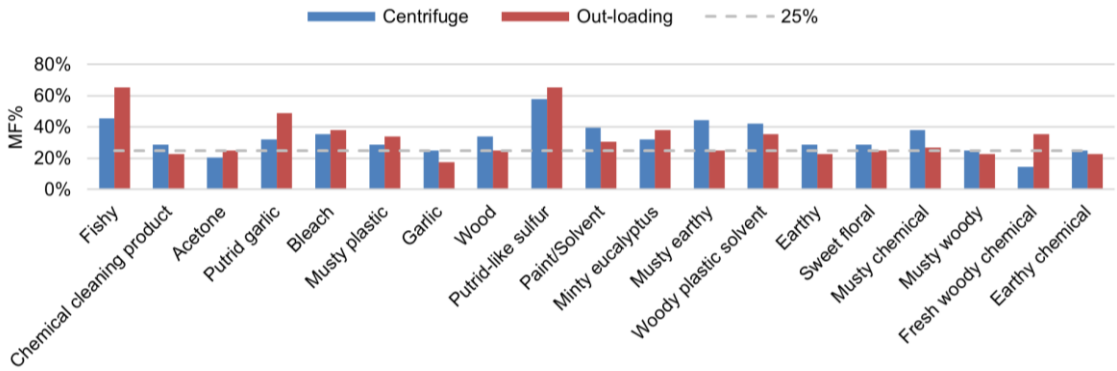

Figure 6: Modified frequency (MF%) of main odour events identified by sensory panellists combined for centrifuge and out-loading biosolids emissions.

4. Conclusions

The relationship between shear-inducing processes and odour emissions requires targeted strategies for biosolids odour management. ODP results showed variations in occurrences, intensity, and frequency of odour events during wastewater solids processing and storage. Odour events of concern include 'fishy,' 'putrid garlic,' 'putrid-like sulfur,' 'musty earthy,' and 'musty chemical.' Emissions from centrifuge biosolids are potentially linked to VOCs, while out-loading biosolids are associated with VSCs. VOCs persist longer and are harder to degrade, increasing overall odour events from centrifuge compared to out-loading. Enhanced emissions from out-loading biosolids are likely due to shearing during conveyance, which disturb the surface of the biosolids, and storage conditions, which can develop anaerobic environments. Odour emissions challenge the beneficial reuse of biosolids, increasing costs and decreasing community acceptance. Thus, the use of sensory analyses provides crucial insights into understanding and controlling odour emissions in wastewater treatment plants, presenting opportunities to optimize operational parameters and enhance biosolids reuse efforts.

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References

Adams, G.M., Witherspoon, J.R., Card, T., Erdal, Z., Forbes, R., Geselbracht, J., Glindemann, D., Hargreaves, R., Hentz, L., Higgins, M.J., McEwen, D., Murthy, S.N., 2004, 'Identifying and Controlling the Municipal Wastewater Odor Environment Phase 2: Impacts of In-plant Operational Parameters on Biosolids Odor Quality Water Environment Research Foundation Report No. 00-HHE-5T, Alexandria, VA, USA.

Brattoli M., Cisternino E., Dambruoso P.R., de Gennaro G., Giungato P., Mazzone A., Palmisani J., Tutino M., 2013, 'Gas chromatography analysis with olfactometric detection (GC-O) as a useful methodology for chemical characterization of odorous compounds', Sensors (Basel) 13:16759-16800.

Chen Y-C., Higgins M.J., Beightol S.M., Murthy S.N., Toffey W.E., 2011, 'Anaerobically digested biosolids odor generation and pathogen indicator regrowth after dewatering', Water Research; 45: 2616-2626.

Fisher R.M., Alvarez-Gaitan J.P. and Stuetz R.M., 2019, 'Review of the effects of wastewater biosolids stabilization processes on odour emissions', Critical Reviews in Environmental Science and Technology 49:17 1515-1586.

Fisher R.M., Barczak R.J., Suffet I.H."M.", Hayes J.E., Stuetz R.M., 2018, 'Framework for the use of odour wheels to manage odours throughout wastewater biosolids processing', Science of the Total Environment 634:214-223.

Higgins, M. J., Chen, Y. C., Yarosz, D. P., Murthy, S. N., Maas, N. A., Glindemann, D., Novak, J. T., 2006, 'Cycling of Volatile Organic Sulfur Compounds in Anaerobically Digested Biosolids and its Implications for Odors. Water Environment Research', 78(3), 243-252.