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A Review of Solid Waste Composting Process – The UK Perspective

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ABSTRACT

Due to increasing political and environmental pressures, a sustainable solid waste management scheme is required. The urgency of scheme is more in countries heavily relied on landfilling such as the UK. Imposition of the European Union Landfill Directive (1999/EC/31) placed tremendous pressures on local authorities and waste management industries in the UK. In this paper, we review the composting process, one of the principle treatment options for biodegradable waste. This process not only produces useful end-product in the form of compost but also contributes in meeting landfill diversion and recycling targets. Informations regarding the parameters controlling the process, suitable feedstocks for composting and types of processes are also provided. In addition, previous studies were used to compile the information on the product quality and its impacts on plant growth. It has been suggested that immature compost and high heavy metal content are most likely to inhibit plant growth. In addition, the most significant air emissions from the compost sites are identified and data available in the open literature related to the release of these pollutants is being presented. Preventive measures to reduce the release of air pollutants to the atmosphere are also suggested. Apart from this, current regulatory climate in the UK is also reviewed to assess the feasibility of the process. Recommendations for future work include the need for the improvement in risk assessment methods and sampling strategies for air pollutants.

Keywords: composting, environmental emissions, plant growth, policy analysis

CONTENTS

INTRODUCTION

Solid waste management is a major problem all around the world due to continuously increasing quantities and implementation of more stringent policies and regulations. In order to divert waste from landfills, a well known hierarchy is suggested (IEA Bioenergy 2003). This includes prevention, reuse, recycle, recover and landfilling as major elements. Recovery in the form of energy and waste disposal by landfilling are not preferred options due to the loss of recyclable materials, toxic air emissions, shortage of land and public opposition. Therefore, biological processes (such as composting and anaerobic digestion) and a combination of mechanical and biological treatment (MBT) methods are suggested as prospective options for waste stabilization and recycling of the waste derived products. One of the biological processes, anaerobic digestion, forms solid digestate and bio gas during the operation. The digestate is not considered good enough to be used for land applications and also the process releases objectionable odour due to prevailing anaerobic conditions. Consequently, an unobjectionable and hygienic method is to be adopted for safe waste disposal. Composting is another alternative biological treatment method wherein biodegradable organic materials decompose into a stabilized material by microbes in the presence of oxygen. This treatment process can be used singly

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or in combination with other unit processes (involving mechanical methods to sort out the non-compostable material). As a result, the volume and weight of solid waste (*ca.* 50%) is reduced significantly and a stabilized material is produced (Pace *et al.* 1995). The compost produced after the treatment has potential of being used in a number of land applications.

After implementation of European Union Landfill Directive (1999/EC/31), all county councils in the UK have to comply with the guidelines stating the targets for waste diversion and recycling. Due to heavy reliance on landfilling in the past, the UK has been given relaxation of 4 years to meet the set targets. The significance of composting process becomes more as it also contributes to the waste management industries in meeting their recycling targets. In the current paper information on the fundamentals of the composting process, important factors affecting the process and end product quality, commercial processes in operation, impact on plant growth and environmental releases from the waste site to the atmosphere is being provided. In addition, regulatory framework in the UK is also reviewed to assess the impact of existing policies and legislation on the composting process.

FUNDAMENTALS OF COMPOSTING PROCESS

Composting is a controlled aerobic process to decompose organic materials that utilizes microbes in preferably thermophilic temperature conditions (40-65°C) (EA 2002; Beatty and Zygmunt 2007). During the process, microbes consume oxygen and release heat, CO_2 and water vapour. Consequently, significant reduction in weight and volume of the waste is obtained. A simple aerobic decomposition of organic materials can be represented as:

$$\text{Organic compounds} + O_2 \xrightarrow[\text{microbes}]{\text{Temperature} = 40\text{-}65°\text{C}} CO_2 + H_2O + \text{Heat}$$

Generally, the composting process starts with the decomposition of easily degradable materials into stabilized material in the presence of oxygen. This leads to the release of heat and subsequent rise in temperature of the compostable material. This situation sustains for several weeks until faster decomposition of organic matter takes place. Once all easily biodegradable organic compounds are consumed, temperature of the feedstock is dropped to the ambient temperature. This period is followed by curing period that is characterized by slow decomposition of the material. Almost no further reduction in weight indicates the end of the curing period. The whole process takes around 20-30 days to complete (Tchobanoglous *et al.* 1993). The schematic diagram of the composting process (different stages) is shown in **Fig. 1**.

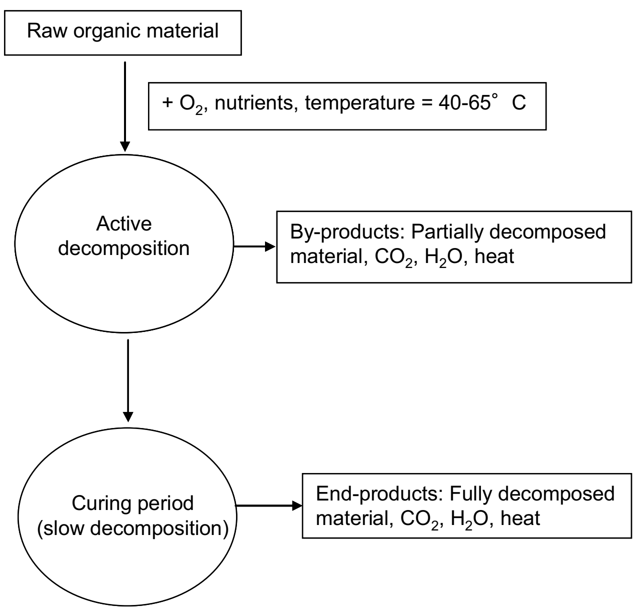

Fig. 1 Simplified schematic diagram of composting process.

SUITABLE FEEDSTOCK FOR COMPOSTING PROCESS

In order to run composting process efficiently, the raw material should contain biodegradable organic compounds and sufficient nutrients to support microbial growth. Apart from this, according to The Publicly Available Specification 100 (PAS 100) (BSI 2005), the properties of the input material should be measured. Ideally, the suitable feedstock should be separately collected solid, carbon based biodegradable material and this has not been mixed or polluted with other wastes, products or materials. Hence untreated waste should be processed mechanically and/ or biologically to separate the undesirable pollutants from the waste stream. Essentially the quality of the end product highly depends upon the characteristics of input material and operating conditions.

Solid wastes that can be recycled through composting process include food and drink waste, garden waste, paper, discarded wood (e.g. from construction and demolition waste), packaging waste, textiles, sewage and agriculture (e.g. crop residues and manure) (http://www.ecochem.com/t_compost_faq2.html; DTI 2001).

FACTORS AFFECTING THE COMPOSTING PROCESS

In this section, the major factors influencing the composting process are discussed. Upper and lower limits of various parameters and ways of controlling them within the limiting values are also given.

Temperature

Rate of organic matter decomposition depends on the temperature of the raw material. The decomposition of organic compounds starts in a temperature range (40-65°C). Temperatures higher than 50°C should be maintained for at least 3-4 days to destruct the harmful organisms such as plant pathogens, weed seeds and fly larvae. It is reported that temperature as high as 85°C doubles the decomposition rate than at 55°C. However, this high temperature is fatal for a certain microbial populations. Hence, most of the modern composting plants are operating in thermophilic temperature range (55-65°C).

Carbon to Nitrogen (C: N) ratio

To perform effective composting process, C: N ratio must be in the range of 20: 1-40: 1 (on dry weight basis). Carbon and nitrogen are the source of energy and protein production, respectively. A C: N ratio lower than 20: 1 leads to the formation of NH_3 due to the fully utilization of available carbon that will cause odour nuisance. If C: N ratio exceeds 40: 1, decomposition of organic compounds retarded due to insufficient nitrogen. The most preferred range of C: N ratio is 25: 1 to 30: 1 (Pace *et al.* 1995; Beatty and Zygmunt 2007). The C: N ratio for different raw materials and supplements are listed in **Table 1**. In case, raw material has insufficient or excessive ratio, supplement material is added to fulfill the requirement. For instance, saw dust can be added to enhance the C: N ratio of the feed stock having vegetable waste as raw material. Similarly, poultry manure can be added to wood or paper waste to bring the ratio within prescribed limits (McMahon *et al.* 2008, 2009). In some systems, the physical structure of the composting mix can be improved by adding wood chips or shredded green waste. Any pieces of wood left in the stabilized material can be separated out by screening during the post-composting stage (DTI 2001).

Table 1 General values of C: N ratio of different materials.

Material	C: N ratio
Vegetable waste	12-20: 1
Fruit waste	35: 1
Grass clippings	12-25: 1
Leaves	40-80: 1
Paper	150-200: 1
Saw dust	100-500: 1
Poultry manure	10: 1

Source: http://www.ecochem.com/t_compost_faq2.html

Moisture content

The raw material should contain sufficient moisture for adequate microbes functioning. The prescribed limit of moisture content is 40-65% (preferred range = 50-60%). Moisture content below 40% hinders microbial activity and thus makes the aerobic decomposition of solid waste difficult. On the other hand, moisture content in excess of 65% will reduce the air concentration in the pores and pose danger of establishing the anaerobic conditions. Another term that can be used in place of moisture content is the 'water activity' (McMahon *et al.* 2009). Water activity is a measure of 'tightness' by which water is bound to the compost mixes. Total moisture content does not differentiate between the 'states' of the water in the substrate – some will be freely available but some will be 'held', either matrically or osmotically, and not available to be utilized by micro-organisms. However, water activity can be related to moisture content by producing moisture sorption isotherms (McMahon *et al.* 2009).

Particle size

Nevertheless aerobic decomposition of fine or dense particles occurs at faster rate, it may cause obstruction in oxygen movement through the raw material. Hence, a bulking agent like straw, paper and cardboard is added to the raw material to facilitate free aeration. In general, preferred particle size range depends on the particular feedstock, pile, size and weather conditions. However, it is suggested that the average particle diameter should be in the range of 0.3-5.0 cm (Pace *et al.* 1995).

Aeration

Sufficient oxygen supply must be ensured for aerobic decomposition of raw material. Anaerobic conditions can be developed in oxygen deficit environment that will cause bad odour and production of CH_4 gas. Oxygen can be replenished in the waste material either by turning or through perforated pipes.

Time

Total organic matter decomposition period depends on a number of factors such as nature of the contaminants, temperature, oxygen availability, particle size, moisture content etc. For example, generally period of active composting for dairy cattle waste is around 10-14 weeks. This stage is followed by 3-4 weeks curing period.

FEASIBILITY OF COMPOSTING PROCESS IN VIEW OF CURRENT REGULATORY CLIMATE IN THE UK

In the section, we review existing UK policies and legislation framework and assess how these policies are facilitating or constraining the composting of municipal solid waste (MSW). The major pertinent policies and legislation include European Union (EU) Landfill Directive (1999/31/EC), UK Government Waste strategy (DETR, 2000), Animal – By Product Regulations (2002/1774/EC), the Waste Management Licensing Regulations (2005), Kyoto protocol targets (UNFCC Secretariat, 2007), UK targets for generating electricity from renewable sources (2001/77/EC) and The Environmental Damage (Prevention and Remediation) Regulations 2009.

The Landfill Directive sets the targets for the diversion of biodegradable waste from landfills. According to the Directive, UK has to reduce the amount of biodegradable waste to 25, 50 and 65% of the 1995 quantities by 2010, 2013 and 2020 respectively. It is estimated that mixed waste composting may contribute up to 90-95% diversion of total biodegradable material (EA 2002). Hence, composting can be a potential treatment option in overall waste management strategy.

UK Government Waste strategy states that 33 and 67% of the total waste must be recycled and recovered, respectively by 2015. Again, the composting process may play an important part in achieving the stated targets. For mixed waste composting, a part or whole product is sent to the landfills due to inferior quality. Thus, this does not count towards recycling targets and loss of material during the process is considered as recovery rather than recycling. On the other hand, generally compost produced after the treatment of source segregated waste contributes towards recycling and recovery targets. Therefore, this can be suggested that for source separated waste, composting is a potential way of achieving the set targets by UK Government Waste strategy. However, it is doubtful to meet the goals with mixed waste composting.

Animal – By Product Regulations classifies animal by-products in three categories from high risk materials (category 1) to low risk materials (category 3). The low risk category can only be treated using composting process. In addition, the treatment must comply with the guidelines laid in the regulation. The materials qualify for category 3 include rabbit and chicken carcasses, part of slaughtered animals with no danger of communicable diseases to humans, raw milk, features, etc. A research study showed that composting of these wastes results in stabilized materials, the quality of which comply with European hygienization standards (Barrena *et al.* 2009). On the basis of above discussion, this can be said that Animal – By product regulations restrict the composting process to low risk materials that form the largest fraction of animal by-products.

After implementation of the changed version of the Waste Management Licensing Regulations (2005) it has become mandatory for the land owners to get a waste management licence exemption before applying the compost on agricultural land, unless the Quality Protocol applies.

In order to meet the targets for reduction in greenhouse gas (GHG) emissions mentioned in Kyoto Protocol, the UK promulgated a policy stating the reduction in 20% CO_2 emissions of 1990 levels by 2010. As a result of composting, CO_2 is generated along with other GHG gases like N_2O and CH_4. Since CO_2 is produced from biogenic fraction of waste, it does not contribute to the GHG emissions (Garg *et al.* 2007). The other two gases are normally produced in very small quantities and their production may further be reduced in controlled process conditions. Hence, treatment of waste using composting process will not enhance GHG emissions to the atmosphere.

The UK government has also set targets for the electricity generation from renewable energy sources (10% by 2010). Composting process does not produce any renewable energy. In the UK, MSW contains *ca.* 70% biomass fraction in the form of food waste, paper, wood and textile (Lee *et al.* 2005). It is understood that segregation of inert material, a part of plastics and metals from MSW may increase the biogenic fraction in the resulting mass to 90% or more (Klein 2005). This material will have substantial heating value (15-18 MJ/kg) and can be eligible for renewable energy sources (Garg *et al.* 2007). In this way, composting process suppresses the chances of the renewable energy contribution from MSW.

The Environmental Damage (Prevention and Remedia-

Table 2 Influence of existing legislation and policies on MSW composting.

Legislation	Direct	Indirect	Facilitating	Constraining	Comments
EC Landfill Directive (LD) (1999/31/EC)	√		√		Encourage treatment of MSW
UK Government Waste strategy (DETR, 2000)		√	√	√	Facilitating for sorted waste and constraining for mixed waste
Animal - By Product Regulations (2002/1774/EC)	√		√	√	Only low risk waste (category 3) can be composted.
Waste Management Licensing Regulations (2005)	√			√	Waste Management licence exemption is required.
Kyoto Protocol targets		√	√		Due to the majority of biogenic fraction, GHG emissions are not increased.
The Renewable Energy Directive (2001/77/EC)		√		√	Biogenic fraction of MSW may qualify for renewable energy source.
The Environmental Damage (Prevention and Remediation) Regulations 2009	√		√	√	Encourage diversion from landfills, but there is also need to maintain the controlled conditions at composting site.

tion) Regulations 2009 implement the European Directive on Environmental Liability (2004/35/EC) that was enforced on March 1, 2009 (Defra 2009). In the legislation, 'Environmental damage' refers to the adverse impacts on habitats and species protected by EU legislation, water resources and land area. Existing liability legislation are still in place and the new regulation will only cover the most serious cases. Enforcing authorities of the new legislation will identify the operators or business where there are chances of damage or actual damage has already taken place and will decide the immediate actions that must be taken to restore the condition of environment. Enforcement of the legislation triggers the diversion of the solid waste from landfills to protect the land area and water resources (may get contaminated due to the seepage and overflow of leachate). In addition, poor landfill practices may have adverse impact on the biodiversity in the surrounding area due to the release of toxic air pollutants. However, composting process should also be carried out in controlled environment so that contamination due to air pollutants, leachate and application of product on the land could be minimized. Therefore, it can be said that the implementation of the new legislation in the UK have direct impact on the waste management practices and has facilitating as well as constraining effect on the composting process.

From the above discussion, it can be observed that at present some policies favour the process and some do not. However, waste managers can successfully implement the process provided the input and output materials meet the desired standards. **Table 2** provides the information on the influence of various legislation and policies on the MSW composting.

COMPOSTING SYSTEMS

In general, all the composting systems are designed to perform controlled stabilization of the raw material (Defra 2007). In the UK, windrow composting systems are used in majority for the treatment of MSW. The statistics shows that 87 out of 89 composting systems were based on windrow process in 1998 (EA 2002). Open composting systems are most widely adopted systems. In these systems, air is introduced either through pumping into the waste or by turning the windrows using mechanical means. The former approach is known as static aerated pile and the latter one is called turned windrow. In the UK, turned windrow approach is very popular and is used in the majority of composting sites.

In-vessel composting process is gaining more attention over the conventional windrow composting systems due to following major advantages:

- Much controlled process
- Fast organic biodegradation process
- Lesser pollutant emissions to the adjacent surroundings and little odour

These systems can further be classified on the basis of their shapes, material flow and aeration methods. In-vessel systems can be in the form of tunnels, vertical towers, rotating drums and housed bays, piles or extended beds (Defra 2007). The material flow in tunnels and housed bays may either be in batch mode or continuous mode whereas in vertical towers and rotating drums raw material is fed on continuous basis. A summary of the two major composting systems are depicted in **Fig. 2**.

Another in-vessel system is known as EcoPOD® system. In this enclosed system the waste is turned into stabilized material. This is mobile flexible and forced aeration system.

Vermicomposting is a process that utilizes earthworms to decompose organic wastes (Neuhauser *et al.* 1980). The 'tiger' or 'brandling' worm *Eisenia foetida* has received the most attention and has been found to be very effective in transforming a wide range of wastes including horse manure and potato waste into good quality product (Edwards *et al.* 1985). It has been reported that addition of cow dung to the sewage sludge improves the ability of *Eisenia foetida* significantly (Gupta and Garg 2006).

IMPACT OF COMPOST QUALITY ON PLANT GROWTH

As a result of composting of MSW or any other waste comprising biodegradable organic compounds, a stabilized and sanitized product is generated. The quality of the product depends upon input material (such as mixed or source segregated MSW) and other parameters discussed earlier in Section 4. Mixed MSW derived compost is generally found to be more contaminated than source separated waste (EA 2002). The produced compost can be used for land restoration, soft landscaping and domestic use in gardens depending on its characteristics. Besides, it can be used as fertilizer in agriculture and horticulture sectors (Defra 2007). For qualifying as 'quality compost', the residue must comply with the PAS 100 (BSI 2005). Immature compost may cause continuous evolution of phytotoxic gas such as NH_3 in case of low C: N ratio. By applying immature compost on arable land metabolic rate of plants is inhibited and plant growth is severely damaged (Zucconi *et al.* 1981; Saviozzi *et al.* 1988). Hygienic quality of the compost must be checked before using this for various land applications so that spreading of infectious disease epidemics could be prevented (Hamer 2003).

As mentioned above, MSW compost is often used as fertilizers in agricultural land and soil conditioner as this can fulfill the requirement of nitrogen and organic matter (Courtney and Mullen 2008; Hargreaves *et al.* 2008). However, the major concerns include the entrainment of excess metal in plant and danger of the groundwater contamination with metals and unused nutrients (Hargreaves *et al.* 2008). In a research study, field experiments for two composts (spent mushroom compost and forced aeration compost) were conducted to observe their effect on soil properties and barely yield (Courtney and Mullen 2008). The quantity of the two composts was varied from 0-100 t/ha (also called application rate). The results were also compared with con-

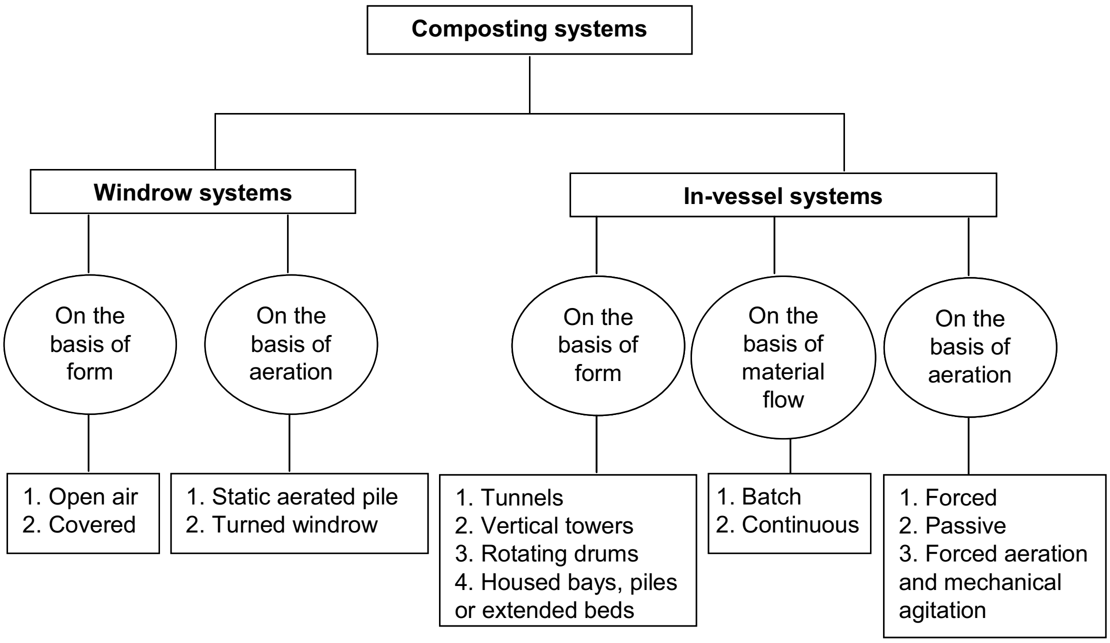

Fig. 2 Classification of composting systems.

Fig. 3 Lentil growing trial using the compost produced from wood waste (obtained from construction and demolition waste). Source: **Hobbs G, McMahon V, Harrex RM, Swainson M** (2005) Composting in the construction industry. BRE Information paper IP 3/05, ISBN 1 86081 741 6, ©2005, BRE, with kind permission from BRE and the authors.

ventional inorganic fertilizer. Application of compost mix on land did not cause in increase Cu and Zn concentrations beyond the permissible limits. In addition, high application rate reduced iron content in the soil. Spent mushroom compost exhibited the better correlation in soil nutrient quantity, organic status and grain yield. However, it was suggested that high phosphorous content and electrical conductivity can limit the use of both composts in larger applications.

McMahon *et al.* (2008) have reported that compost mix obtained after the composting of wood waste was not phytotoxic and resulted in very good growth for lentil and radish plants. A picture of growth of lentil plant after the application of waste derived wood compost is depicted in **Fig. 3**.

A review of compost use in urban green areas was carried out by Sæbø and Ferrini (2006). It was suggested that compost can potentially be used for mulching and soil amendment to enhance the quality of plant during establishment and management phases. For mulching, the thickness of the compost layer should be less than 100 mm. In order to efficient nutrient supply to the trees and shrubs, the lower part of the layer (20-50 mm) should contain small nutrient rich particles, whereas upper layer should be nutrient-deficit having larger particle sizes to inhibit the growth of weeds. Another study demonstrated that addition of wood ash to organic waste caused an improvement in the compost quality and performance of the resulting product (Kuba *et al.* 2008). Wood ash obtained from the incineration plant was found to be rich in micronutrients and nutrients. The study concluded that wood ash addition (16% w/w) did not show any adverse influence on the composting process but seemed to improve the quality of the product. The performance of ash amended, mineral and organic composts were tested on re-vegetated sky slopes. Ash amended composts showed the best performance in terms of plant cover and soil microbiological properties. An experimental study conducted by Wong *et al.* (1999) demonstrated that manure compost can be used as replacement for fertilizer since it increased the soil fertility and crop yield in organic farming. Nair *et al.* (2006) examined the effect of thermo-composting as pretreatment step before vermicomposting of the kitchen waste. The optimum period required to achieve the better product quality were determined. The optimum period was found to be 9 days for pre-composting and 2.5 months for vermicomposting. The advantages of short period pre-composting include reduction in mass and substrate, moisture and pH stabilization. This was found that a period of 3 weeks was sufficient to bring acceptable values of C: N ratio and homogeneous product. However pathogens (*E. coli*, *E. faecalis*) were found in high numbers (> 110 MPN/g) and this quantity was sustained for 2 months. By the end of three months, numbers of these pathogens were found within the prescribed limits. This was concluded that addition of vermicomposting period reduced *E. coli* concentration significantly.

EMISSIONS FROM COMPOSTING SITES

Air emissions

The major air emissions that are expected from a composting plant include volatile organic compounds (VOCs), bioaerosols, odours and dust (Kissel *et al.* 1992; Eitzer 1995; EA 2002; Sánchez-Monedero *et al.* 2003; Taha *et al.* 2005; Taha *et al.* 2007; Albrecht *et al.* 2008; Fischer *et al.* 2008). Kissel *et al.* (1992) suggested that proper measures for odour and VOCs control must be taken for successful operation of a composting plant. Generally, main sources of odour in composting sites are organic compounds of nitrogen and sulfur, aliphatic acids, terpenes and alcohols. The reason of odour release from the composting facility may be either the presence of odorous waste material in the feedstock or inadequate environment for composting such as deficiency of oxygen or high moisture content. Odour can be controlled by proper design of waste treatment facility, installment of air handling systems and good management of the site. It was proposed that VOCs emissions may be of great concern on-site rather than off-site and these can be controlled by separation of VOC-rich waste fraction and use of properly designed biofilters (Kissel *et al.* 1992). Eitzer (1995) conducted a study to observe VOC emissions from solid waste composting site. It was reported that most VOCs were produced in the early stages of the composting process and the concentrations remained within the permissible values. An Austrian study reported emissions of VOCs from MBT plants in the form of carcinogenic organic compounds including benzene, toluene, xylene etc in significant concentrations. VOCs also contained alkanes, alcohols and aldehydes that were captured in biofilters (EA 2002).

Sánchez-Monedero *et al.* (2003) studied the efficacy of the biofiltration process for the removal of bioaerosols at composting sites. Generally, bioaerosols are originated during the delivery of fresh waste, mechanical sorting processes, turning of compost pile and compost screening (Sánchez-Monedero *et al.* 2003; Taha *et al.* 2007). The concentrations of two kinds of airborne micro-organisms *Aspergillus fumigatus* and mesophilic were determined and average reduction from biofiltration was found greater than 90 and 39%, respectively. The major reason anticipated for different removal efficiency of micro-organisms was particle size distribution. Fungus can be removed more efficiently than bacteria due to coarser particle size distribution (For fungus = 2.1-3.3 µm; Bacteria = 1.1-2.1 µm) (Sánchez-Monedero *et al.* 2003). Taha *et al.* (2007) presented the results obtained from the modeling of bioaerosol emissions from passive (e.g. compost windrows) and active (agitation of windrows, shredding operations etc) compost sources. The effect of compost age on the emissions was also studied. Two models, namely, SCREEN3 and ADMS 3.3 were used in the study for comparing the emissions. The former exhibited more precautionary results than the latter. The results suggested that for passive composting, compost age did hardly have any considerable effect on bioaerosol emissions whereas for active composting (turning of pile) emissions might be higher during the early phase. Suggestions for the modification in current risk analysis practices were also being made.

Several researchers have conducted studies for measurements of nitrous oxide (N_2O) from composting of organic wastes (Czepiel *et al.* 1996; Hellebrand 1998; He *et al.* 2000, 2001). Emission of N_2O to the atmosphere leads to the increase in GHG emissions. Nitrogen oxides are also act as catalyst in ozone destruction (Czepiel *et al.* 1996). During composting process, N_2O concentration starts increasing with O_2 concentration, reaches to the maximum and finally decreases with additional O_2 supply. A study was carried out to measure the N_2O emissions during the composting of wastewater sludge and livestock wastes (Czepiel *et al.* 1996). The results showed the potential of livestock waste for N_2O emissions (1.2×10^{12} g yr^{-1}). In another study, emission of N_2O and other trace gases from composting of grass and green waste (from land maintenance) was investigated (Hellebrand 1998). It was found that release of N_2O is related to the initial nitrogen concentration in the feedstock. Out of total elemental nitrogen present in the waste, around 0.5% (by weight) of the total nitrogen content in the mixture was escaped as N_2O. Apart from this, CH_4 release from the compost pile was observed from the regions having shortage of oxygen. Around 1.5-2% of the total carbon converted into CH_4.

To reduce the gaseous emissions, proper emission control arrangements should be made on-site and the quality of input material should be maintained.

Water emissions

Leachate and/ or run off are considered the major contaminants from composting plants that can be deteriorate the quality of surface or ground water (EA 2002; Defra 2007). In order to prevent the contamination of natural water resources, control measures like impermeable surfaces and proper drainage system must be built and hygiene procedures given in Animal – By Product Regulations must be implemented (Defra 2007).

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

Composting of organic waste is a very effective method for stabilizing and weight reduction of the solid waste. Besides, the end-product has the potential of being used in a number of applications e.g. as fertilizer on agricultural land and soil restoration. The importance of the process further increases due to the public opposition for the combustion of waste. In the context of the UK, it can be said that majority of legislation having direct impact on the implementation of composting process are of facilitating nature. There are several composting systems available that includes open systems (windrows), in-vessel composting and vermicomposting. The product quality is the major concern for farmers and other users. Entrainment of metals, immature compost and excessive phosphorous may inhibit the plant growth and thus careful supervision is required to obtain good quality product. The major emissions observed from the composting sites are VOCs, bioaerosol, odour and N_2O releases to the atmosphere. Suitable arrangements like biofilters can be used to reduce the bioaerosols and odour. Initial elemental nitrogen is converted into N_2O during nitrification and denitrification processes. In composting, sufficient oxygen supply should always be available to reduce the N_2O quantities in the trace gases. In order to reduce VOCs from released gas streams, on-site and off-site measures should be taken. Proper ventilated buildings can mitigate the effect of these toxic wastes. The advantage with in-vessel composting systems is the reduction in odour and trace gas emissions.

Future studies can be aimed towards the improvement in current risk analysis methodologies. Besides, sampling strategies adopted for airborne microorganisms, microbial volatile compounds and odour should be plant specific. Local meteorological conditions (such as wind speed and direction, humidity, etc.) and topography of the area should also be considered. Sampling should be performed in most common working conditions ('normal case'). Also, further studies can be made to make improvement in aeration process to maintain hygienic conditions.

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