Bioresource Technology 100 (2009) 4301–4310

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Review

Critical evaluation of municipal solid waste composting and potential compost markets

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ARTICLE INFO

Article history:
Received 30 January 2009
Received in revised form 9 April 2009
Accepted 13 April 2009
Available online 13 May 2009

Keywords:
Agriculture
Contaminated land
Landfill reclamation
Recycling
Waste management

ABSTRACT

Mechanical biological treatment (MBT) of mixed waste streams is becoming increasingly popular as a method for treating municipal solid waste (MSW). Whilst this process can separate many recyclates from mixed waste, the resultant organic residue can contain high levels of heavy metals and physical and biological contaminants. This review assesses the potential end uses and sustainable markets for this organic residue. Critical evaluation reveals that the best option for using this organic resource is in land remediation and restoration schemes. For example, application of MSW-derived composts at acidic heavy metal contaminated sites has ameliorated soil pollution with minimal risk. We conclude that although MSW-derived composts are of low value, they still represent a valuable resource particularly for use in post-industrial environments. A holistic view should be taken when regulating the use of such composts, taking into account the specific situation of application and the environmental pitfalls of alternative disposal routes.

1. Introduction – the waste problem

The term municipal solid waste (MSW) describes the stream of solid waste generated by households, commercial establishments, industries and institutions. MSW consists of everyday items such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint and batteries. It does not include medical, commercial and industrial hazardous or radioactive wastes, which must be treated separately. The USA alone produces approximately 254 million tons of MSW each year, with production rates in Europe and North America typically varying between 0.6 and 2.0 kg^{-1} person d^{-1} (EPA, 2008). The production of MSW is an inevitable consequence of today's consumer society. Finding safe, sustainable and cost-effective alternatives to the disposal of MSW in landfills represents a major challenge to the waste management industry. Recycling and composting are seen as attractive waste management options, providing that there are few negative effects on the environment, however, we are still a long way from diverting MSW into these processes. For example, in the USA only 33% of the MSW generated is composted and recycled with the rest either being landfilled (54% of total) or combusted for energy recovery (13% of total; EPA, 2008).

In many nations there are now strict mandatory targets to reduce the amount of biodegradable municipal waste (BMW) entering landfill due to the lack of available landfill space and increasing concerns about climate change (EC, 1999). Further some countries also advocate that any waste that does enter landfill must first be treated to reduce its environmental impact. Treatment options include incineration (with landfill of the ash produced), separation of recyclable and compostable materials at source by householders, or the raw waste undergoing some form of mechanical biological treatment (MBT), with the residuals being landfilled. Treatment is defined as physical, thermal, chemical or biological processes (including sorting) that change the characteristics of waste in order to reduce its volume or hazardous nature, facilitate its handling or enhance recovery (DEFRA, 2005). Where legislation requires that MSW must be pre-treated before landfill, it is expected that there will be a large increase in the amount of low grade compost produced. The use of lower quality composts such as MBT residuals has been questioned due to quality concerns. The purpose of this review is to critically evaluate MSW- and MBT-derived composts, covering their production, potential pollution issues and end uses.

2. Composting of MSW

Composting is defined as the biological decomposition of organic matter under controlled aerobic conditions to form a stable, humus-like end product. The process is facilitated by a diverse population of microbes, whose population dynamics vary greatly both temporally and spatially, and generally involves the development of thermophilic temperatures as a result of biologically produced heat (Swan et al., 2002). Inoculation of MSW with specific organisms can also enhance the speed of composting (Wei et al.,

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doi:10.1016/j.biortech.2009.04.029

2007). The organic matter contained in MSW feedstocks can range from garden and food waste to mixed household wastes, the biodegradable proportion varying from 50% to 90% depending upon country (Déportes et al., 1995). Within the UK, it is currently estimated to be 68% but is predicted to fall to 54% by 2020 due to increased collection of source-segregated waste (SU, 2002).

Thermophilic aerobic composting of MSW on a commercial scale uses systems of varying complexity, of which there are essentially two main types: turned or forced aeration systems. Turned systems are commonly based upon the windrow system, which entails the feedstocks being piled in elongated heaps up to 2 m high and 50 m in length (Swan et al., 2002). These piles are turned with decreasing frequency throughout the period of active composting to maintain O_2 and moisture levels, and to release spent air. Due to environmental legislation, MSW windrowing is often done indoors within large commercial premises to minimize leachate production, improve odour control and reduce visual impact.

In contrast to turned systems, actively aerated systems are often more complex with computer controlled aeration regimes, and generally offer greater control over the process conditions. Having greater process control is often desirable with highly heterogeneous wastes such as MSW as this aids the operator in adapting the process to suit the chemical and physical makeup of the feedstock. In an optimized forced-aeration MSW composting system, there are three main stages of composting (Stentiford, 1996). The first stage is the 'sanitization' stage, where vigorous aeration regimes are used to encourage rapid microbial breakdown of readily biodegradable substrate within the feedstock. The energy released during this rapid microbial respiration produces heat which typically raises the temperature of a compost vessel to >70 °C (Abu Qdais and Hamoda, 2004). This thermophilic stage is a requirement of most compost standards to ensure destruction of both plant and animal pathogens (Déportes et al., 1998). Whilst high temperatures are required for pathogen eradication and legislative compliance (WRAP, 2002; DEFRA, 2004; Stentiford, 1996) this is not optimal for MSW breakdown (MacLeod et al., 2008). Consequently, a secondary biodegradation phase of 45–55 °C is desirable to facilitate rapid substrate degradation (Abu Qdais and Hamoda, 2004). The tertiary phase for MSW compost maturation is similar for both aerated and turned composts and requires little active management. Typically, this stage facilitates the conversion of potentially toxic NH_4^+ to NO_3^-, allows loss of phytotoxic volatile compounds and stabilization of the microbial community. At this stage mesophilic fungi and actinomycetes colonize the compost which are thought to be responsible for the breakdown and transformation of humic substances and lignin (Swan et al., 2002). This crucial final stage is frequently given insufficient time, or is even missed out altogether, in order to save space and increase the throughput of composting plants. However, it is a vital stage if the composts are to be applied to plants, and to improve the overall physical and chemical quality of the finished compost (Ozores-Hampton et al., 1999).

Within many countries, enclosed, in-vessel systems are a legal requirement for composting wastes containing food and animal by-products (e.g., MSW-derived waste). Further, some countries (e.g., UK) require that sanitization temperatures are met twice in a two-stage batch process to ensure complete pathogen kill (DEFRA, 2004). Enclosed systems can be either static or agitated, and can have their air circulation tailored for optimization of the different stages of composting. Forced aeration can be operated in three modes, either positive, negative or a mixture of the two (Stentiford, 1996). Using a mixture of the two aeration regimes gives flexibility of operation, allowing a wider range of moisture contents and carbon-to-nitrogen ratio wastes to be accepted. Under the correct conditions, MSW and MBT residues have been shown to compost effectively, behaving in a similar to green waste-derived composts. Further information detailing the process of composting and the numerous variables that affect the process can be found in de Bertoldi et al. (1983), Swan et al. (2002) and Sharma et al. (1997).

3. Municipal solid waste compost

3.1. Mechanical biological treatment (MBT)

The role of MBT in waste management is predicted to grow for the foreseeable future, with the primary aim of MBT plants is to recover a large percentage of recyclables from mixed waste streams (e.g., MSW and curbside collection schemes). Once this has been achieved, the main objective of the subsequent biological section of the treatment is to produce a material with low environmental impact fit for disposal or land application (Pahl et al., 2008). Using a range of technologies, MBT plants are designed to separate all recoverable recyclables/energy rich waste with a typical screen cut off of >40 mm (e.g., glass, plastics, paper, and metals; Clemens and Cuhls, 2003). The fraction smaller than this is known as mechanically sorted organic residuals (MSOR), and is usually composted (Robinson et al., 2004). The production of mixed-waste derived compost will increase as nations move towards meeting statutory targets.

Although mass reduction during composting can be between 20% and 40%, the expected increase in the volume of MSW composts poses a problem for disposal as most countries are suffering from ever diminishing landfill space (Omran et al., 2007). Its placement in landfill or use as landfill cover is not deemed sustainable, environmentally desirable or politically acceptable. Consequently, other disposal options are rapidly required. Indeed, the literature on MBT gives an incomplete picture of whether or not the biological treatment of wastes before landfilling is actually an environmentally sustainable option. Mature MBT residue compost has been shown to produce a "low impact" waste which yields 82% less greenhouse emissions than untreated landfilled waste (Adani et al., 2004). Long maturing times (>6 months) may, however, prove inconvenient for plant operators due to storage costs and lack of space. In contrast to these results, Binner and Zach (1999) conclude that poor aeration at the start of the biostabilization process can result in poor reductions in emissions. Their study only covered a period of 22 weeks, and postulated that even this length of composting would be prohibitive, given that the waste is only to be landfilled once processed and is therefore of no monetary value. If the MBT composts are landfilled they still produce gaseous and leachate emissions, albeit at a lower rate than for untreated waste (Zach et al., 2000). Laboratory scale reactors have indicated that although leachates from MBT residues have a reduced BOD_5, COD and NH_4^+ levels, they still posed an environmental risk (Zach et al., 2000), and Robinson et al. (2004) found that levels of non-degradable COD are often higher in MBT-compost derived leachates than in standard methanogenic leachates. Despite the hope that MBT wastes will be suitable for 'final storage' style landfill sites, it is apparent that landfills containing MBT residues will require an aftercare period similar to conventional MSW landfill (i.e. 50–100 years after site closure). However, further research is required in this area to assess the timescales in which management activities may be curtailed after the initial aftercare period.

In conclusion, optimized aerobic treatment of MBT-derived organic residues can effectively reduce the mass of material whilst also mitigating its potential to produce greenhouse gases and reducing leachate volume and toxicity if subsequently landfilled. However, given that landfill void space is a finite resource, alternative sustainable uses for the composts produced from mixed MSW must be sought.