Solid waste treatment and disposal: effects on public health and environmental safety

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Abstract

The safety and acceptability of many widely used solid waste management practices are of serious concern from the public health point of view. Such concern stems from both distrust of policies and solutions proposed by all tiers of government for the management of solid waste and a perception that many solid waste management facilities use poor operating procedures. Waste management practice that currently encompasses disposal, treatment, reduction, recycling, segregation and modification has developed over the past 150 years. Before that and in numerous more recent situations, all wastes produced were handled by their producers using simple disposal methods, including terrestrial dumping, dumping into both fresh and marine waters and uncontrolled burning. In spite of ever-increasing industrialisation and urbanisation, the dumping of solid waste, particularly in landfills, remains a prominent means of disposal and implied treatment.

Major developments have occurred with respect to landfill technology and in the legislative control of the categories of wastes that can be subject to disposal by landfilling. Even so, many landfills remain primitive in their operation. Alternative treatment technologies for solid waste management include incineration with heat recovery and waste gas cleaning and accelerated composting, but both of these technologies are subject to criticism either by environmentalists on the grounds of possible hazardous emissions, failure to eliminate pathogenic agents or failure to immobilise heavy metals, or by landfill operators and contractors on the basis of waste management economics, while key questions concerning the effects of the various practices on public health and environmental safety remain unanswered.

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The probable and relative effects on both public health and environmental safety of tradition and modern landfill technologies will be evaluated with respect to proposed alternative treatment technologies.

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### 1. Introduction

Waste disposal and pollution are inextricably linked. The term pollution describes both the act of polluting and the consequences of that act. Waste describes unwanted residues that are usually perceived to be of negative value. Pollution can be defined as the introduction into the natural environment by humans of substances, materials or energy that cause hazards to human health, harm to living resources and ecological systems, damage to structures and amenities or that interfere with the legitimate uses of the environment. It is implicit in the definition that pollution only describes situations where unwanted effects occur (Royal Commission on Environmental Pollution, 1984). The majority of waste disposal situations involve pollution of one kind or another.

Waste results from consumption. Depending on the product or resource in question, it is its mode of consumption that dictates the fraction that is wasted during use and the fraction that only becomes waste upon system redundancy. Until some 150 years ago, waste production was the direct responsibility of individual consumers, but in the interim an industry, described as waste management, has been established with the resultant effect that individual consumers have transferred their responsibilities for the waste they generate to waste management practitioners, so that the majority of consumers ignore the ultimate fate of the waste that they generate and frequently resent the financial penalties and legislative restrictions that are increasingly placed on waste discharge. At the same time these same consumers abhor pollution, but rarely identify with the fact that they themselves are significant contributors to pollution.

The traditional basis for waste stream classification is physical state, i.e., gaseous waste streams, liquid waste streams and solid waste streams, including concentrated slurries. In spite of the fact that all three streams contain and can be transformed into gases, vapours, liquids and solids, each class has been considered to be unique as far as its management is concerned. The present discussion focuses on public health and environmental safety aspects of solid waste management practice.

### 2. Solid waste management

Solid waste management comprises a diverse range of activities encompassing reduction, recycling, segregation (separation), modification, treatment and disposal at varying levels of sophistication. The industry finds its origins in waste disposal using simple methods such as local terrestrial dumping (landfill), dumping into both fresh and marine waters and
uncontrolled burning, none of which offer health-safe and hazard-free waste management solutions. Historically, disposal was presented as a form of treatment on the grounds that after disposal the characteristics of deposited wastes frequently changed as a result of degradation, a phenomenon that greatly increases the polluting potential of many wastes. The major objective of waste treatment is stabilisation, preferably by accelerated degradation, so that the final residues produced are either nonnoxious and incapable of further change, i.e., they are completely mineralised, or able to find ready entry into the various natural biogeochemical (elemental) cycles that govern materials cycling in the environment, without causing distortion in any cycle relative to another.

In general terms the constituents of solid wastes can be categorised as:

- Nonbiodegradable inorganic matter;
- Recalcitrant synthetic organic matter;
- Biodegradable natural organic matter;
- Off-specification and fire- and water-damaged chemicals of unknown composition and characteristics;
- Toxic organic compounds;
- Metals, metalloids and their derivatives;
- Partially biodegradable natural organic matter.

Biodegradability is a property that is governed by the environmental conditions that pertain as well as the nature of the material in question and the availability of appropriate consortia of microbes.

Some of the main categories of solid waste are:

- Municipal solid waste (domestic, market and trade wastes);
- Construction industry and demolition waste;
- Fuel production and energy-generation waste;
- Food, beverage and agro-industry waste;
- Catering industry waste;
- Forestry and forest product industry waste;
- Amenity area and garden waste;
- Slurries from intensive animal husbandry (animal manures);
- Slaughterhouse solid waste (including specified materials) and diseased carcasses;
- Waste sewage sludge (treated or untreated) and night soil;
- Septic hospital waste.

The fundamental problem that faces the management of virtually all solid wastes is that they comprise complex mixtures and are usually subjected to indifferent storage conditions resulting in deterioration before collection and subsequent treatment.

The various strategies available for solid waste management must be considered as a hierarchy of opportunities with waste reduction at source as the best option. Intuitively, recycling would seem to be the second best option, but effective recycling and, for that
matter, effective modification (reprocessing) can only occur after complex wastes have been separated (segregated) into their various fractions. Amongst the components of municipal solid waste that are particularly suited to recycle are glass bottles and jars, aluminum beverage cans, paper and cardboard, while hard plastics can frequently be reprocessed into lower-grade material. Only then should the question of treatment be considered and, as a last resort, disposal. Although zero waste (total elimination) initiatives are frequently discussed, they have yet to become technological realities as far as the majority of products are concerned.

The major feature of any solid waste that makes it suitable for treatment is that it is either biodegradable or combustible, thereby dictating that such waste fractions must be organic in nature.

3. Traditional practice

Traditional solid waste management practice has been characterised by the frequently irresponsible dumping of complex mixed and toxic solid wastes in landfill sites. Additionally, toxic liquids and slurries contained in corrosion-prone metal drums have frequently been buried in landfills or have been subject to marine dumping. Until recent times, solid waste segregation at source and refusal to accept hazardous materials for landfill and landfill site licensing have been largely unknown. Historically, landfill site selection was based on both close proximity to waste production and the availability of large pits, which were usually the result of either quarrying or gravel, sand or brick–clay extraction, rather than on geological criteria of site suitability. The primary operational criterion for traditional landfills was disposal at minimum immediate cost, a depository type of approach that sought to ignore future problems, particularly containment failures, the discovery of toxic hot spots and the resultant effects of partial degradation, which in recent times have been responsible, in many cases, for substantial remediation requirements. Traditional landfills were always associated with operational difficulties such as noxious gas and vapour, dust and leachate production, as well as rodent infestation and, even today, modern engineered landfills are perceived to have similar problems as a result of their acceptance of readily biodegradable solid waste that constitute either an available food source, in the case of rodents, or feedstocks for anaerobic biodegradation, the primary source of noxious gaseous emissions that migrate within and are released from landfills.

Biogas production from waste is a subject that is emotionally, but not necessarily, economically attractive. Methane is the end product of anaerobic digestion of biodegradable organic matter. Most modern engineered landfills have been designed for biogas production by undersealing and capping and installing both appropriately designed wellheads for gas collection and appropriate leachate collection and treatment facilities. Landfill biogas typically contains between 48% and 56% methane and has, therefore, in its produced form a calorific value of approximately half that of natural gas, as supplied from distribution networks. The project life for economic landfill biogas production is typically 10 years, but residual production can be expected to last for more than 40 years. For economic operation, landfill biogas must, from all but the very largest installations, have a captive market that does not require gas cleaning and purification. Examples of such
markets are cement and brick kilns. For very large installations, where diverse uses for the
gas produced are envisaged, both calorific value upgrading and purification procedures for
moisture, carbon dioxide, hydrogen sulphide and halogenated hydrocarbon removal
(Dernbach and Henning, 1987) are essential ancillary facilities for the methane to realise
its market price.

A well-known feature of traditional landfills containing potentially biodegradable
matter has been major spatial variations in biodegradative activity as a result of a lack
of system design, but in more recent times, with the advent of engineered landfills, the
requirement for optimisation to maintain anaerobic biodegradation and possibly enhance
biogas production rates was recognised. Some of the operating conditions that were
identified as impacting on process rates were the need for elevated moisture contents and
elevated moisture throughputs by leachate recirculation, pH control/buffer addition,
nutrient addition, anaerobic sewage sludge inoculation and elevation of the operating
temperature (Kinman et al., 1987). However, the practicability of some of these proposals
is questionable and, clearly, others could introduce deleterious side effects with respect to
overall system operation. Both the potential environmental impact of massive engineered
landfills for the degradation of biodegradable organic wastes and their extended, but
decreasing rate of residual biogas production, seems to suggest that landfills provide only an
interim solution for biodegradable solid waste management. In the future, landfills would
seem to be only appropriate for essentially stable wastes such as that derived from
construction and demolition or from incineration, but even here, avoidance of dust,
particularly in situations where asbestos or sorbed carcinogens are present, is paramount. If
landfill is not to be used for biodegradable solid waste and slurry disposal, the critical
question that arises is: What economically viable and safe alternative large scale processes
exist that will satisfy legislation and will be acceptable to the general public? The two most
widely discussed options are biotreatment and incineration, but it must be noted that both
require waste segregation either at source or immediately before processing.

4. Solid waste biotreatment

Biotreatment has, for many decades, been the preferred method for effectively treating
biodegradable waste materials. As far as bulk pollutant load elimination from waste
streams is concerned, biotreatment technology has dominated wastewater and waste
sludge treatment for almost a century and, more recently, is finding rapidly expanding
application in waste gas stream pollutant elimination. The fundamental problem of
effective and economic biotreatment involves the attainment of high process rates at high
process intensities. Traditional biotreatment processes for solid wastes are generally low
rate, often because of either low or negligible rates of mixing and relatively large particle
sizes resulting in low surface area to volume ratios. The former problem can be overcome
by enhanced mixing, while the latter can be alleviated by greater feedstock diminution.
Both measures involve both increased capital investment and increased operating costs in
the form of energy requirements.

Biotreatment processes for solid wastes can be operated either aerobically or anaero-
bically. In the case of readily biodegradable solid waste treatment, the best known aerobic
process is composting, while the most extensively applied anaerobic process is, as has already been mentioned, digestion with attendant biogas production. However, when operated on a high rate basis, composting remains a solid-state process, but digestion requires the solid waste to be processed as a slurry, thereby adding an additional cost in the form of spent residual feedstock treatment. In addition, when digestion processes are optimised for feedstock treatment, biogas production becomes suboptimal or vice versa.

Compost, the marketable end product of composting, results from the aerobic thermophilic degradation of complex organic matter under moist conditions. Its added value results from its ability to enhance soil fertility, thereby increasing crop productivity. Many of the wastes that are subjected to composting contain faecal matter, with its associated pathogens, while animal product wastes frequently contain both aerobic and anaerobic bacterial spores that are not inactivated during composting. Therefore, the hygienic quality of compost must be considered as far as its potential application is concerned. A fundamental requirement for effective (safe) waste treatment is prevention of the transmission of infectious disease epidemics of the type so commonly encountered before the introduction of effective wastewater and drinking water treatment. Even so, the mechanisms responsible for the inactivation of pathogenic organisms and agents have been identified in remarkably few waste treatment technologies, and the fate of pathogens both in treatment processes and in treated discharges to nature remain a subject for continuing debate.

The bacterially mediated aerobic thermophilic stage in composting is generally followed by a maturation stage involving the action of various earthworms. Modern reactor-based technology for composting has reduced residence times for the composting stage from weeks to ca. 72 h, and the maturation stage from months to weeks, while new developments in vermiculture have also allowed single-stage vermiculture to be conducted on a large scale. For industrialised compost production, effective mechanical removal of nonbiodegradable matter from solid waste feedstocks has greatly enhanced the attractiveness of such processes and will, no doubt, also impact favourably on vermiculture. Even so, the tendency to incorporate animal slurries and sewage sludge into many solid waste feedstocks for both composting and vermiculture must be questioned until the hygienisation potentials of such processes have been fully elucidated.

5. Pathogens and hygienisation

Remarkably few waste treatment technologies can be guaranteed to eliminate all pathogenic organisms and agents even though solid waste, particularly sanitary solid wastes and specified materials from animal slaughter and destruction, have been identified as significant sources of various pathogens. Historically, most screening tests used indicate the possible presence of pathogenic organisms and involve faecal indicator bacteria, in spite of the fact that human pathogens include bacteria, yeasts, protozoa, intestinal and other worms, flukes, viruses and prions and that individual elimination and survival characteristics vary dramatically. Hygienisation processes involve two major facets: the destruction or irreversible inactivation of all pathogens present and the prevention of subsequent regrowth (recovery) of or reinfection with pathogens. As far as biological hygienisation processes are concerned, the three major mechanisms
contributing to process efficacy are elevated temperatures, effective hydrolytic enzyme production and high residual substrate affinities. Enhanced temperature clearly implies the need to use thermophiles exhibiting high metabolic rates that permit autothermal operation for process mediation. In heat inactivation, process temperature and time are inversely linked as far as inactivation is concerned, so that guaranteed minimum process residence times, with no possibilities of either material bypassing or cool spot (frequently head space) segregation, are absolute requirements that depend on both process equipment and operating system design.

Thermophilic bioprocessing has a range of definitions, particularly when applied to waste treatment (Hamer and Zwiefelhofer, 1986). Virtually any temperature above 45 °C has, on occasions, been described as thermophilic, but for pathogen inactivation, only the temperature range between 60 and 72 °C can be considered to be potentially effective. At temperatures only slightly more than 72 °C, process-mediating thermophilic bacteria are themselves inactivated, placing an operational limit with respect to temperature. While a temperature of 72 °C will, at appropriate residence times, inactivate many pathogens, others are able to survive, particularly in the absence of significant hydrolytic activity, or where dormant forms such as spores are formed.

The autothermal nature of high intensity and rate thermophilic biotreatment processes is the key to economic process performance, but even the maximum process temperatures that can be attained do not achieve sterilisation, the absolute requirement for pathogen elimination. Hence, in any such process, a degree of risk with respect to possible pathogen survival is always involved, and the acceptability of such risk must ultimately govern validation of particular treatment technologies and systems. Any realistic evaluation of the effectiveness of biotreatment for pathogen elimination must ultimately conclude that seriously pathogen infected solid waste streams are unsuitable for treatment by any currently available biotreatment technology, leaving incineration as the obvious alternative technology for the treatment of such pathogen-infected wastes.

6. Incineration

In many respects the incineration of combustible solid waste can be regarded as an absolute treatment method for eliminating infectious components present in such wastes, although claims to this effect are not without question. However, incineration is also associated with the production and release of carcinogenic and toxic compounds, and particularly in those countries where the performance of waste management and treatment facilities has failed to gain public confidence, the widespread assumption of potential hazards stemming from incineration is overemphasised relative to any hazards that are perceived to occur from nonthermal treatment and disposal methods. In certain respects, incineration has fallen foul of ever-diminishing detection limits in analytical chemistry, but denial of hazardous releases has rarely been effective because of failure to establish the no-effect concentration thresholds for either individual or mixtures of gaseous phase combustion products, thereby allowing detection limits to dictate release legislation.

Incineration, as with all other solid waste treatment options, involves effective waste stream sorting and sorted fraction recycling. The incineration of the combustible fractions
of solid waste streams, irrespective of source, results in product streams requiring further treatment for safe disposal. The major categories of such products are solid residues from the furnace hearth, i.e., ash and clinker, fly ash and gaseous products of partial combustion. The ash and clinker frequently contain up to 0.5% unburnt biodegradable matter, but by far the greatest emphasis has been placed on potentially noxious gaseous phase emissions, particularly the highly toxic organic chemicals described collectively as “dioxins,” which include a wide range of compounds based on both dioxin and furan structures and, more recently, on halogen-substituted biphenyl structures. However, the presence of such compounds in emissions from incinerators can be reduced by the optimisation of incinerator operating variables and by emission treatment. Even so, zero emission levels are unlikely to be achieved because of the equilibrium nature of the treatment methods used, but any contribution of dioxins to the environment from incineration must be compared with emissions from other sources, particularly coal-fired electricity generation, while the mode by which dioxins enter the human food chain also requires detailed investigation.

A major consideration with respect to solid waste incineration project economics is heat recovery by linked district heating schemes, but such schemes are only realistic when incinerators are in close proximity to solid waste generation, i.e., in urban environments, and where heating is required for most of the year. Alternative approaches to solid waste incineration are offered by using solid waste as fuel in cement kilns, although the cement industry might not wish to add to its existing environmental problems, and, in the future, by gasification.

Finally, in the context of thermal solid waste treatment, mention should be made of the rendering industry, which has traditionally provided thermal treatment for slaughterhouse waste. Rendering is an industry that has been tolerated rather than accepted. The industry’s product is meat and bone meal, which has traditionally been used as an animal feed ingredient. To enhance the protein quality of meat and bone meal, rendering temperatures have been reduced, with the unfortunate effect that prions present in specified material from infected bovine carcasses have not, in all cases, been completely eliminated from the meat and bone meal product, causing subsequent infections in cattle that were fed contaminated meal, but even more alarmingly, through possible cross-species transfer, fatal infections in humans who might have consumed meat products contaminated with specific material from such cattle.

The failure of high-temperature processes to provide absolute safety with respect to infectious agent survival is a cause for significant concern and points to a pressing need for studies that elucidate the fate of pathogenic agents both in treatment processes and in the natural environment that provides the ultimate sink for residues of waste treatment processes and to potential dangers that pathogen-contaminated residues might pose.

7. Concluding remarks

Without doubt, untreated solid waste streams frequently contain components that have the potential to cause infectious diseases. The level of this potential remains largely unassessed, but no current treatment process can either totally or consistently eliminate
such risks. Both wastewater and waste sewage sludge treatment processes are effective in
the prevention of epidemics of waterborne diseases, but the mechanisms responsible for
pathogen inactivation in such processes are ill defined and the fate of pathogens in such
processes and in nature after treated product discharge from such processes needs
considerable further study. However, what is clear is that treatment processes alter the
phase distribution of pathogens during treatment.

The policy of mixing essentially pathogen-free waste streams with sanitary and other
pathogen-contaminated waste streams to enhance treatment process rates and intensities is
inappropriate from the safety point of view, and segregation of seriously pathogen
contaminated streams and their separate specific treatment is recommended.

Essentially pathogen-free biodegradable solid waste streams offer excellent feedstocks
for aerobic biotreatment technology based on either composting or vermiculture where the
end product finds a ready market as a soil conditioner for horticulture and agriculture.
Solid-state anaerobic digestion, although emotionally attractive, is a technology that
creates additional difficulties, particularly gas migration and extended suboptimal residual
gas production. Incineration of biodegradable solid waste results in emission problems and
should be reserved for the treatment of seriously pathogen contaminated wastes, but even
here, absolute pathogen elimination cannot be guaranteed.

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