Processing strategies for organic wastes

Stratégies de traitement des déchets organiques.

Invited Paper

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Abstract

Treatment of organic wastes is often an essential part of the best management package to avoid pollution in many situations. Very dilute wastewaters may be released to water courses following rigorous treatments as typified by sewage purification processes. Otherwise, the disposal of most organic wastes continues to be land application. Where sufficient suitable land is not available, some form of processing is needed to reduce the strength of the waste in terms of its organic content (eg, BOD) and/or key nutrients (eg, nitrogen and phosphorus) and/or disease hazards.

Processes comprise one or more biological and physical stages; chemical additives may also be used. Biological degradation of organic matter has the general effect of breaking down the reactive organic chemicals which make up the BOD value and lead to offensive odours. Anaerobic treatment enables biogas collection but processing can be slow. Aerobic treatment of solid or liquid wastes is faster and exothermic enough to allow natural heating up to 60°C, but it is more expensive. The combination of such temperatures and oxygen destroys many pathogens especially strict anaerobes. Ammoniacal nitrogen can be removed as N_2 gas by nitrification followed by de-nitrification.

Physical processes include screening, centrifugation, sedimentation and filtration. They involve the separation of a solid phase and/or the production of a clarified wastewater. This often compliments the biological step as a great deal of the insoluble organic matter is not readily broken down. Furthermore, it enables the removal of a range of insoluble materials such as phosphates and heavy metals. This separation may be enhanced by the addition of lime or flocculants.

New processes for effluent treatment include membrane filtration, chemical electro floatation, incineration, heat treatment (sterilization) evaporation/drying, and ammonia stripping/recovery. Although effective, the high cost of some of these emerging technologies makes them less suitable for agriculture than for dealing with industrial effluent.

Résumé

Le traitement des déchets organiques constitue souvent une étape essentielle pour une gestion optimisée de ces produits sans risque pour l'environnement. Des effluents liquides très dilués peuvent être rejetés dans le milieu naturel après différents procédés de purification. Néanmoins la gestion des déchets organiques passe le plus souvent par l'épandage agricole. Lorsque les surfaces pour l'épandage sont limitées il est alors nécessaire de réduire la charge polluante de ces produits en termes de leur matière organique (DBO), et de leur teneur en éléments nutritifs (azote et phosphore) et/ou germes.

Les procédés comprennent souvent au moins une étape biologique et physique. Les additifs chimiques étant également parfois utilisés, le traitement anaérobie permet de produit du biogaz, mais la dégradation est lente. Le traitement aérobie des déchets liquides ou solides est plus rapide et exothermique, permettant une élévation naturelle de température jusqu'à 60°C. L'apport d'oxygène et le maintien de ces températures élevées permet également la destruction des germes pathogènes notamment les germes anaérobies stricts. L'azote ammoniacal peut être éliminé sous forme de N_2O par nitrification suivie d'une dénitrification.

Les procédés physiques comprennent le tamisage, la centrifugation, la sédimentation et la filtration. Ils impliquent la séparation d'une phase solide et/ou la production d'un effluent liquide clarifié. Ces étapes complètent les procédés biologiques et permettent notamment de séparer les composés insolubles tels que les phosphates et métaux lourds. Cette séparation peut être améliorée par l'ajout de chaux ou de floculants.

Les nouveaux procédés pour le traitement des effluents comprennent la filtration sur membranes, la flottation électro-chimique, l'incinération et le traitement thermique (stérilisation), l'évaporation / séchage et le « stripping » de l'ammoniac.

Bien qu'efficaces, le coût élevé de ces technologies émergentes ne les rend pas nécessairement disponibles en agriculture, comparativement à leur utilisation développée en secteur industriel.

1. Introduction

The role of treatment in the management of organic wastes (eg, agricultural manures, sewage sludge and food processing effluent) is increasing. Such wastes can pose serious water and air pollution risks (*eg*, as reported by the NRA, 1995) as well causing offensive odours (*eg*, as reported by the IEHO, 1988); in some cases, they are also a hazard to public health. However, these same wastes can be a useful resource in the supply of plant nutrients or a feedstock to a composting system or a biogas plant.

Good management practice has been advocated for farm wastes for many years such as presented in MAFF codes (1991 and 1992). This includes adequate storage facilities and controlled applications to fields taking into consideration loading and seasonal constraints; a similar approach is common in many parts of Europe (Parfait et al, 1996). These same methods have been used with other organic wastes that are also disposed of by landspreading (eg, sewage sludge). However, applications in *excess* of the capacity of the local environment can only end up as pollution of one sort or another. Furthermore. even if there is enough local land with a theoretical capacity to receive the applied manure, the related pollution problems may still not be eliminated due to a range of other factors such as a hilly terrain or the close proximity of streams or boreholes. In these cases, and where there is insufficient land or where the waste poses special hazards such as disease risks, some form of treatment will be required as part of the solution.

2. Processing strategies

A large number of treatment processes now exist for tackling these problems some of which have already been reviewed especially with respect to agriculture (Burton, 1992 and 1996). However, evaluating their effectiveness can easily be muddled by the interpretation of the very word *treatment*. Colloquially, this word can become very imprecise and it can be relegated to implying that no more than *something* has been done to the waste by the process; but what this amounts to is often not clear. The remedy for this situation must be the focusing on the *purpose* of the treatment rather than how it is done. For example, it is not the practice of bubbling air through pig slurry that brings about any benefit, but the subsequent measured odour abatement or reduction in organic matter. There is a need to identify and set unambiguous targets for the treatment process. In this way (a), any given process can be scored as inadequate, successful or, in some cases, excessive and (b), objective comparisons between different processes become possible - the most cost effective package can thus be identified.

Thus the starting point in dealing with an organic waste stream should be the clear definition of what the problem is (*eg,* odour nuisance, excess nitrogen, water pollution). This will depend on the intended disposal route (*eg*, to farm land, to a water course, for re-use). The second step is setting the treatment target required to resolve this problem (*eg*, a 50% reduction in the BOD_5, removal of 90% of ammoniacal nitrogen). Such targets can be set even for the subjective area of odour abatement (Williams, 1984; Pain et al, 1990). Only when the purpose of treatment is clear should the various methods and equipment be considered. Figure 1 summarizes many of the current scenarios starting with the intended disposal route, identifying the likely requirements and lastly considering possible processes.

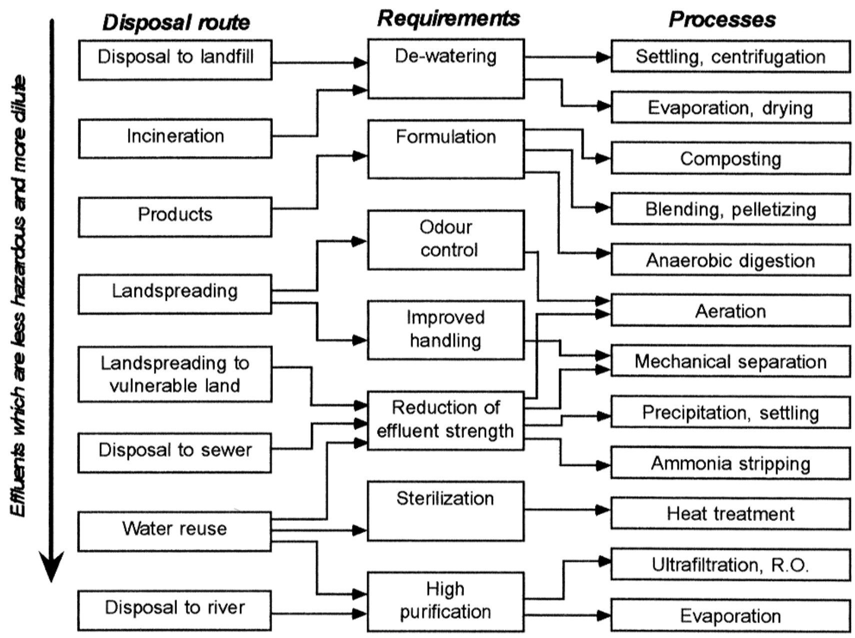

Figure 1.
Treatment strategies: process options depend greatly on the type of effluent and proposed use or disposal route.

A system that works (ie, that fulfils the requirements) may turn out not be a realistic option owing to cost or some other factor. A cheaper and less effective option may still be considered but only if this is an acceptable compromise. The danger in the use of inadequate treatments though is that they can present the operator with a cost without fully resolving the underlying problem.

3. Physical processes

3.1. Mixing

Mixing of tank contents is a key part of any process although it doesn't in itself impart any change to the average effluent composition. In provides a homogeneous feed to subsequent stages enabling a steady operation of what is often a continuous process producing a consistent treatment. Variations in the effluent can result from the natural separation of the suspended matter either into a floating layer or a settled sludge. The composition of effluents entering a treatment plant can be normally expected to vary as a result of many factors such as the periodic washing routines. Maintaining a steady feed to the treatment plant requires large feed tanks to provide buffering and again mixing is necessary.
A great deal of research has gone into mixing theory and equipment and many

reviews have been produced (eg Cumby, 1990). Common weaknesses include inadequate power input (a minimum of $10W/m^3$ is recommended - Cumby, 1987a) and poor selection and location of equipment especially in large stores.

3.2. Mechanical screening

Screening is a simple way of removing the coarse matter from effluents and thus greatly improving its ease of handling. If large quantities are present such as in livestock manures then the separated fibre can be useful in subsequent composting processes. In this case, it is important to ensure a high solids concentration in the separated fibre (ie 25%+) which leads to the selection of the more elaborate equipment such as screw and belt presses. However, if the main purpose of the operation is the removal of relatively small quantities of coarse matter (eg to protect equipment) then simpler screens will suffice. These have the advantage of higher throughput but a wetter fibre product is produced.

	Screen (drum)	Screw press	Decanter centrifuge	Laboratory centrifuge
	Burton et al, (1997)			Martinez et al, (1995)
% removal of :-				
TS (total solids)	41	42	61	76
N-Kj (Kjeldahl N)	17	17	30	-
P (phosphorus)	18	20	65	-
K (potassium)	17	12	12	16
Cu (copper)	-	-	-	82
Volume of concentrate (%)	17	15	21	13

Table 1
Performance of three types of separating systems in terms of the removal of specific components from pig slurries into a concentrated stream. Values from a laboratory centrifuge test (10,000g for 30 minutes) are given for comparison.

3.3 Separation and clarification

A more rigorous clarification of wastewater effluents is based on settlement. This can be by natural gravitation or enhanced by the use of flocculants and/or centrifugation. Gravity settling works best with dilute effluents (TS below 25 kg/m^3) due to the production of large volumes of sludge with increased dry matter (Martinez et al, 1995). Centrifugation can produce concentrated sludges and a high degree of clarification but equipment is expensive and throughput modest. In either case, separation is more complete than simple screening as finer particles are included in the removed sludge layer. This extends to a more effective removal of some of the specific components of the effluent as shown in table 1. Whereas the screen and screw press only make a significant difference (ie, removal in excess of the concentrate volume) to the TS, the decanter centrifuge also removes Kjeldahl nitrogen and phosphorus. The laboratory test indicates the maximum extent of physical separation which can also include certain metals but not the highly soluble potassium.

4. Biological processes

4.1 The oxidation process

Adequate aeration involves dissolving enough oxygen into liquid manure in order to replace an anaerobic system (chemically reducing) with an aerobic environment for microbial activity. As a result, organic matter, characterized by BOD_5 (biological oxygen demand), is rapidly oxidized to relatively harmless products such as carbon dioxide and water. The removal of the same material also takes away the main cause of the offensive odours associated with organic effluents and many pathogens that are strict anaerobes are destroyed. Under certain conditions (eg, treatment times of 3+ days and a dissolved oxygen concentration above 1ppm) nitrification of ammonia to nitrites and nitrates can occur with nitrogen release (as N_2) in the subsequent de-nitrification, although the pollutant gas, nitrous oxide (N_2O) can also be produced as an unwanted bi-product (Burton et al, 1993).

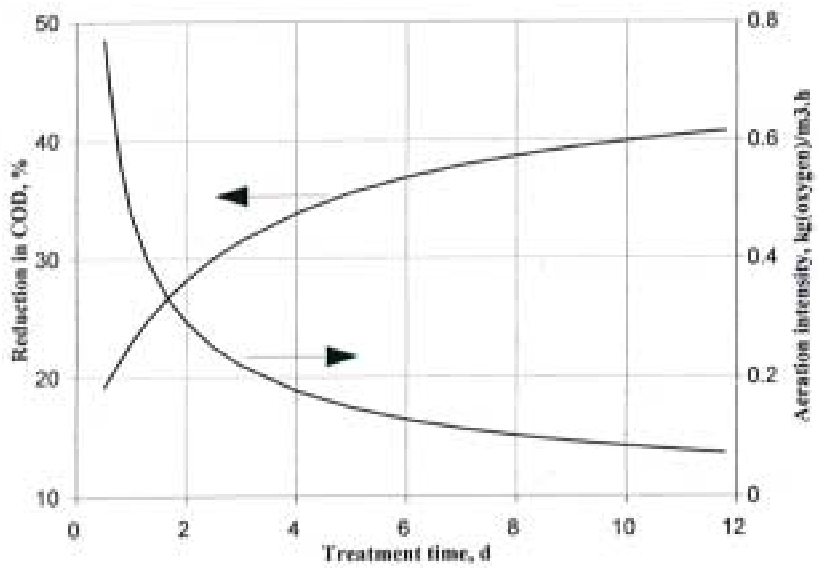

Figure 2.
Required aeration intensity compared to COD breakdown achieved.
Longer treatments enable more gentle and efficient aerobic treatment.
(Evans et al, 1983; Burton & Farrent, 1998).

4.2 Aerobic treatment

Continuous aerobic treatment is nutrient-limited and is thus independent of both temperature and aeration level within limits. In the case of temperature, activity should be kept within the mesophilic range (ie 15 to 45^oC); at higher temperatures thermophilic activity takes over leading to poorer performance (Burton et al, 1995).

Unless nitrification is desired, the aeration level is not critical so long as enough oxygen is supplied to meet the demand. For all but the most dilute effluents this still implies large volumes of air based on anticipated reduction of the organic load expressed as COD or chemical oxygen demand (Figure 2). Short treatments have the additional problem of requiring a high *intensity* of aeration ie the hourly oxygen requirement per unit volume; this tends to rule out the more efficient but gentle bubble type diffuser type aerators.

Aeration systems are commonplace at sewage treatment works and some experimental units are also being used for treating stronger effluents such as farm slurries (figure 3). Trials with this system using pig slurry revealed degradation of 93% of the ammoniacal nitrogen, 67% of the Kjeldahl nitrogen, 43% of the COD content but only 8% of the total dry matter (Burton et al, 1998). The implication is that aeration only removes the reactive part of the organic matter leaving much of the inert material (including the suspended matter) unaffected.

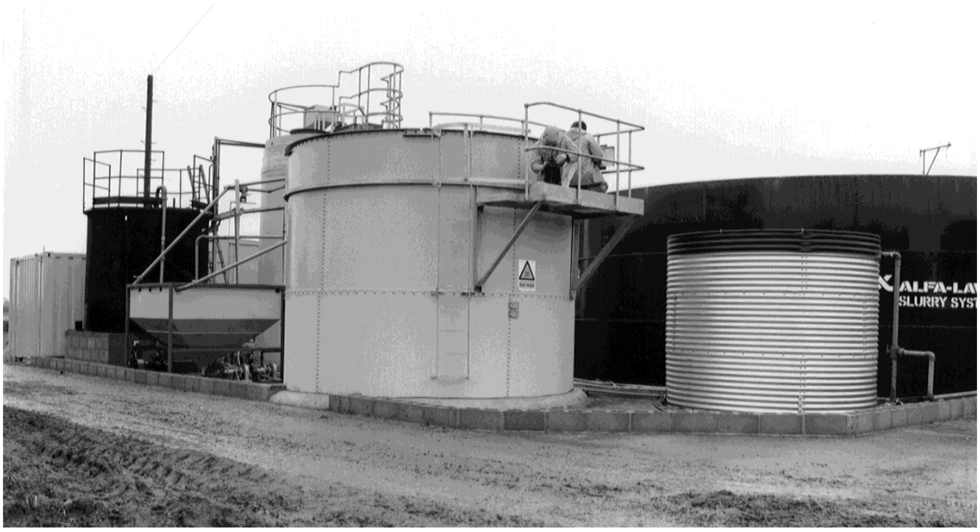

Figure 3.
Farm scale treatment plant for aerating piggery slurry and typical performance values (Burton & Farrent, 1998).

Although effective for certain duties including odour abatement and nitrogen removal, aeration is not a universal solution to all effluent problems.
Batch aeration is straightforward and sometimes preferred for dealing with small effluent volumes; it is also relatively cheap to install in existing storage tanks or lagoons. However, it can result in control problems due the variable load and the treatment tends to be inconsistent. A compromise might be sequential batch processing (Lo et al, 1990) which can also incorporate a settling stage.

4.3 Composting

The principles of composting solid organic wastes follow closely those of the aerobic treatment of wastewaters. It is essentially an aerobic process in which the more reactive organic components are broken down leaving a stabilized mass. Adequate oxygen must again be supplied either by regular agitation or forced aeration if anaerobic conditions are not to develop. In addition, the structure of the solid needs to be open and dry matter content should be around 250 kg/m^3. An important feature of a successful process is the rise in temperature of the solids as the result of the exothermic activity. Ideally this should exceed 60^{o}C thus both destroying pathogens and any weed seeds. The fate of the ammoniacal nitrogen depends on the C:N ratio in the solid mass; the higher the level of carbon, the more retention can be expected. Losses fall to zero for very high levels of carbon (C:N ratios over 60:1) but the fertilizer value is then much lower (Cshei et al, 1996).

4.4 Anaerobic digestion

In the absence of oxygen, microbial activity continues anaerobically. The process is slower but reactive organic matter is again broken down thus leading to a reduction in the BOD_5 value and biogas can be produced as a bonus. In the simplest form of an anaerobic lagoon system, such gas is not collected and the main benefit of the approach is a reduction of organic load plus the removal of some phosphate along with other insoluble matter if settlement is encouraged. However, even if unwanted, the free emission of methane is generally unacceptable and some form of gas collection is needed. The gas is in fact an important bi-product in most cases and the design of digesters to maximize yield is important. This involves agitation and the maintenance of temperatures in the range 30 to 40^{o}C. The performance of digesters varies widely reflecting the feed material as much as the design but the example described by Montuelle et al (1992) summarizes the main features: reductions in BOD_5 and COD were reported as 84 and 58% respectively. There was no significant effect reported on the nitrogen (including ammonia) and phosphorus components as might be expected as there is no obvious removal route. Anaerobic digestion can have the benefit of odour abatement in that many of the organic chemicals implied are broken down and some pathogens can be destroyed in the digester environment but the reduction is less than for aerobic systems.

5. Chemical treatment

A range of specific chemicals already feature in currently available treatment technologies including acids, flocculants and precipitants (Burton et al, 1997). The addition of strong acids to livestock manures has been explored as a method to cut ammonia losses by reducing the pH. Although an effective abatement measure, the hazards and cost of the method make it unattractive. The use of various flocculants in conjunction with a clarification step is common in many areas of effluent treatment although the performance can be variable. Many of the agents work on the basis of introducing strong ions (eg ferric or Fe^{3+}) into the effluent to break down the colloidal system; their contribution is less pronounced in concentrated effluents or where good settlement naturally occurs such as after aerobic treatment (Martinez et al, 1995).

The addition of a precipitant such as lime can also enhance clarification but the main purpose is to increase insolubility of the phosphorus and some of the metals. The method is effective but the quantities required can be large (30kg+ per tonne of effluent) and ammonia emissions can be increased. Ammonia is incorporated in the precipitate along with magnesium and phosphate in the MAP process used with livestock slurries. However, the MAP complex (magnesium-ammonium-phosphate) follows a precise stoichiometry requiring additional magnesium and phosphate to be added.

There is also a wide range of additives on the market offered for many purposes including breaking down of organic material, reduction in ammonia emission and odour abatement. The way that such additives [allegedly] work is not always clear but mechanisms include providing enzymes, bacteria cultures or entrapment. Many of these products remain unproven and due to a lack of information, it can be difficult to decide which, if any, should be used.

6. New processes

6.1 Thermal treatments

The use of heat as a part of a treatment process is already well established such as in the case of some aerobic and anaerobic systems. The primary aim though has been to sustain the process and, in some cases, to extract heat as well (Evans et al, 1982; Hemmersbach et al, 1985); temperatures above 50^{o}C have rarely been needed. Heat is also effective for destroying pathogens which is a requirement in some specialised effluent treatments (Turner et al, 1997) but consistently high temperatures are needed to ensure a sufficient degree of pathogen inactivation. Where such sterilization is essential (*eg*, to combat a high disease risk) the related higher energy costs may be tolerated but otherwise they can be prohibitive for the more general treatment of wastewaters. Nonetheless, interest in this approach continues to grow with the emergence of well developed systems such as the Sirven process (Veil, 1994). Energy efficiency (*eg*, heat recovery) will be the key to the uptake of such technology.

For the more hazardous wastes incineration may well be stipulated. However, the approach may also be used more generally for solid wastes with the motivation of energy generation. The commercial burning of chicken manure has already been established in the UK and other wastes are being considered (Burton et al, 1997). However, a high dry matter content (25%+) is essential if there is to be a net generation of energy. For the purpose of disposal alone, small quantities of wastes with a higher moisture can be incinerated if blended with solids, otherwise the process must be supported with conventional fuels such as oil or gas.

6.2 Filtration

Filtration processes are subject to similar limitations to physical separation processes in that they affect mostly the insoluble components. However the specific options emerging each offer additional treatment potential. In the case of soil filters for example, there is also a biological factor leading to a breakdown of the dissolved organic material as well. This principle is used in the Solepur process for the total treatment of pig slurries (Martinez, 1997). Recognizing the limitation of soil filters in that they can generate a nitrate rich leachate, this process includes the collection and separate de-nitrification of such water before it is finally irrigated to land.

The use of membranes allows the physical removal of some of the dissolved materials from the wastewater. The extent of the filtration is a function of the membrane: the more open ultrafiltration type (UF) will only retain the larger molecules whereas the highest quality reverse osmosis type (RO) can lead to a virtually pure water stream. The application to wastewater treatment is limited though due to the high cost of the equipment and the relatively low throughputs. There may be a role for the treatment of very dilute effluent prior to disposal to the water course or to enable its reuse.

Treatment by electro floatation is linked with the use of flocculants in clarification and thickening steps in a process to produce a treated effluent and sludge. The electro flotation unit itself enhances flocculation and probably removes some of the dissolved matter also by precipitation. Its general suitability for wastewater treatment remains unproven at present.

6.3 Ammonia stripping

The natural tendency of ammonia to volatilize from alkaline solutions is used as the basis of ammonia stripping as a treatment process. Lime can be added to raise the pH and ammonia is stripped by air/steam; it is subsequently recovered by scrubbing the effluent gases with sulphuric acid to produce a solution of ammonium sulphate. The approach is effective as a treatment but its viability will require there to be some value to the fertilizer solution produced.

6.4 Evaporation and drying

Evaporation can offer a means of producing a useful concentrate from the effluent as well as leading to a heat-treated condensate for disposal. It has limitations though, including the need for an energy efficient operation which itself can result in very elaborate plant. Some de-watering of dilute effluents may be required and further treatment of the condensate may be necessary as it will invariably include a high proportion of the volatiles. The economics and technical demands of this treatment approach will limit its application although it will be an important first step if drying is intended.

The production of a dry stable product from waste concentrates has many attractions. Storage and transport is greatly improved and there is the opportunity for marketing a serious organic product as an alternative to inorganic fertilizers. Revenue from sales may or may not pay for the process but it will at least defray the overall treatment cost to an approach that has considerable environmental credibility in terms of nutrient re-use. Schemes have been piloted for sewage sludge processing (Boniface, 1990) and for animal manures. Blending is important with the addition of deficient components to provide a balanced fertilizer. Processing is very elaborate though and requires a dedicated operator who will probably manage a variety of effluents from different sources. Location and transport costs could become key factors.

For certain hazardous wastes (*eg*, sewage sludges containing high concentrations of heavy metals), drying prior to landfill may be required as the only acceptable disposal route. The drying process itself then is for the purpose of ensuring product stability in terms of mobility.

Process	Effect of treatment on the reduction of:							
	TSS	BOD_5	Odour	Kj-N	Am-N	P	K	Pathogens
Mechanical screening	+	?	?	?	?	?	?	?
Sedimentation	++	?	?	+	?	+	?	?
Precipitation (lime)	+	?	?	?	!!	++	?	?
Composting	?	++	++	+	?	+	?	+
Aeration*	?	++	++	+	++	?	?	+
Thermophilic aeration	?	+	++	?	!!	?	?	++
Anaerobic lagoon	+	+	!!	?	?	+	?	+
Anaerobic digestion	?	++	+	?	?	?	?	+
Acidification	?	?	?	?	++	?	?	?
Ammonia stripping	?	?	?	+	++	?	?	+
Additives	?	?	+	?	?	?	?	?
Evaporation & drying	++	+	+	+	?	++	?	++
Reverse osmosis	+	+	?	?	+	++	+	+

Table 2.
The relative contributions of the main treatments in the abatement of specific effluent components.

Key: **++** large effect; **+** some benefit; **?** little or no benefit; **!!** Possible negative effect. * Including nitrification and denitrification

7. Conclusions

Poor management of organic effluent from the livestock, sewage and food industries can lead to a range of pollution problems including water contamination (by nitrates, phosphates and organic matter) air emissions (including ammonia, nitrous oxide and methane) and soil residues (including phosphates and heavy metals). There are also disease risks. Although not strictly an environmental pollution, the issue of odour nuisance is sometimes a major factor owing to the pressure of public complaints.

It is important to set unambiguous targets for treatment processes to enable both the verification of satisfactory performance and objective comparisons with alternatives.

A range of treatments for organic effluents which can tackle many of the problems identified are already available. These include aeration (e.g., odour, water and air pollution abatement), anaerobic digestion and lagooning (e.g., biogas production, odour abatement, reduction in BOD), separation (e.g., easier handling, reduction in TS) and composting (e.g., formation of a fertilizer product). Some treatment systems remain unproven as effective and/or cheap enough for the intended application.

There are also a range of new processes that may contribute towards effective treatment in the future. These include thermal treatments, purification by soil, use of chemical additives and membrane processes.
The suitability of these processes will depend both on the effluent composition and the criteria of treatment. The latter will be influenced by the intended disposal route. Table 2 summarizes the effectiveness of the main treatment options.

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